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Dakoterra Vol. 6

Eocene-Oligocene rocks in Badlands National Park, South Dakoata.

Table of Contents

Dedication 8

Introduction 9

Presentation Abstracts

*PRESERVING THE PYGMY MAMMOTH: TWENTY YEARS OF COLLABORATION BETWEEN CHANNEL ISLANDS NATIONAL PARK AND THE MAMMOTH SITE OF HOT SPRINGS, S. D., INC.

LARRY D. AGENBROAD, MONICA M. BUGBEE, DON P. MORRIS and W. JUSTIN WILKINS 10

PERMITS AND PALEONTOLOGY ON BLM COLORADO: RESULTS FROM 2009 TO 2013

HARLEY J. ARMSTRONG 10

DEVIL'S COULEE DINOSAUR EGG SITE AND THE WILLOW CREEK HOODOOS: HOW SITE VARIABLES INFLUENCE DECISIONS MADE REGARDING PUBLIC ACCESS AND USE AT TWO DESIGNATED PROVINCIAL HISTORIC SITES IN ALBERTA, CANADA

JENNIFER M. BANCESCU 12

USDA FOREST SERVICE PALEONTOLOGY PASSPORT IN TIME PROGRAM: COST EFFECTIVE WAY TO GET FEDERAL PALEONTOLOGY PROJECTS COMPLETED

BARBARA A. BEASLEY and SALLY SHELTON 17

PALEONTOLOGICAL INVENTORY AT GREAT BASIN NATIONAL PARK, NEVADA

GORDEN L. BELL JR. 18

*DESCRIPTION OF THE FIRST ORELLAN FAUNA DEFINED IN BADLANDS NATIONAL PARK, INTERIOR, SOUTH DAKOTA AND IMPLICATIONS FOR THE STRATIGRAPHIC POSITION OF THE BLOOM BASIN LIMESTONE BED

CLINT A. BOYD and ED WELSH 19

A NEW METHOD FOR THE IDENTIFICATION OF FOSSIL FROGS (ANURA) WITH APPLICATION TO LATE CENOZOIC SITES FROM THE WESTERN UNITED STATES

KEILA E. BREDEHOEFT and JOSHUA X. SAMUELS 20

FOSSIL TRACKS AND FUTURE SCIENCE: MANAGING ICHNOLOGICAL RESOURCES ON BLM'S PUBLIC LAND

BRENT H. BREITHAUPT and NEFFRA A. MATTHEWS 20

PODCASTS AND THE PUBLIC: PALEONTOLOGICAL EDUCATION AT THE RED GULCH DINOSAUR TRACKSITE, WYOMING

BRENT H. BREITHAUPT and NEFFRA A. MATTHEWS 23

+EFFICIENT PALEONTOLOGICAL RECORD-KEEPING: WHAT'S THE BEST APPROACH?

CRAIG BROMLEY and KARINA BRYAN 25

*+VERTEBRATE PALEONTOLOGY AND STRATIGRAPHY OF THE LATE CRETACEOUS HOLMDEL PARK SITE, MONMOUTH COUNTY, NEW JERSEY

WAYNE R. CALLAHAN, CARL M. MEHLING, ROBERT K. DENTON, JR. and DAVID C. PARRIS 26

* also a manuscript; + poster presentation

UTILIZING NATIONAL PARKS AND BUREAU OF LAND MANAGEMENT LANDS FOR A TWO WEEK COMMUNITY COLLEGE FIELD GEOLOGY COURSE-IT'S LIKE HERDING CATS!

CARL E. CAMPBELL *26*

+GEOCHEMICAL ANALYSIS OF FOSSIL BONE FROM BADLANDS NATIONAL PARK: A TEST OF THE RARE EARTH ELEMENT FINGERPRINTING METHOD TO COMBAT FOSSIL POACHING

ANTHONY D. CERRUTI, DENNIS O. TERRY JR. and DAVID E. GRANDSTAFF *28*

+PROYECTO DINOSAURIOS – ENGAGING UNDER-REPRESENTED STUDENTS IN PALEONTOLOGICAL RESEARCH

LUIS M. CHIAPPE, ALYSSA BELL, and JAMES KISIEL *31*

UNIVERSITY OF CALIFORNIA MUSEUM OF PALEONTOLOGY LOCALITY DATABASE—A NEW PORTAL FOR ACCESSING NATIONAL PARK SERVICE INFORMATION

ERICA C. CLITES; CHARLES R. MARSHALL, and VINCENT L. SANTUCCI *31*

FOSSIL CYCAD NATIONAL MONUMENT: A GEOLOGIC STORY

TIM CONNORS, VINCENT L. SANTUCCI; and STEPHANIE O'MEARA *32*

LOCATING HISTORICAL PHOTOGRAPH SITES AS AN AID TO NATURAL RESOURCE MANAGEMENT

EMMETT EVANOFF, KATHLEEN A. BRILL, and PAUL C. MURPHEY *33*

*ARROYO DEL VIZCAÍNO, URUGUAY

RICHARD A. FARIÑA and MARIANA DI GIACOMO *34*

MULTI-YEAR PALEONTOLOGICAL MITIGATION AT THE KETTLEMAN HILLS LANDFILL—CHALLENGES, OPPORTUNITIES AND PRELIMINARY RESULTS

LANNY H. FISK, DAVID F. MALONEY, HUGH M. WAGNER, and DAVID M. HAASL *34*

*THE FEDERAL MANDATE FOR MITIGATION PALEONTOLOGY

SCOTT FOSS *35*

FOSSIL CYCAD NATIONAL MONUMENT: PRESERVING THE HISTORYOF A FORGOTTEN TREASURE

JOHN M. GHIST, VINCENT L. SANTUCCI[2], BRENT H. BREITHAUPT, and GREGORY A. LIGGETT *36*

ADVENTURES IN PALEONTOLOGY: USING BLM LANDS AND FOSSILS TO CREATE UNIQUE LEARNING EXPERIENCES FOR THE PUBLIC

RON GIESLER *36*

*PRESERVING THE FALLS OF THE OHIO'S FOSSIL BEDS—A SUCCESSFUL INTER-GOVERNMENTAL EFFORT

ALAN GOLDSTEIN and LISA FREEMAN *37*

THE ROLE OF AN INTERACTIVE FOSSIL PREPARATION LAB IN CROWD SOURCING PALEONTOLOGICAL RESOURCE PRESERVATION

MINDY HOUSEHOLDER, E. N. STARCK, and RACHEL BENTON *37*

+TAPHOFACIES OF SELECTED FOSSIL SITES WITHIN THE EARLY CRETACEOUS CEDAR MOUNTAIN FORMATION IN EAST-CENTRAL UTAH

MATTHEW L. HOWARD, DAVID A. LEE, and DARRIN C. PAGNAC *38*

FOSSILS ON THE FRONTLINES: A FOCUSED APPROACH TO PALEONTOLOGICAL RESOURCES MAPPING, MITIGATION AND PROTECTION: BUREAU OF LAND MANAGEMENT CODY AND WORLAND FIELD OFFICES, WYOMING, USA

GRETCHEN L. HURLEY, LISA M. MARKS, MARIT BOVEE, and BRENT H. BREITHAUPT *39*

THE BURGESS SHALE IN YOHO AND KOOTENAY NATIONAL PARKS, BRITISH COLUMBIA, CANADA: AN INTEGRATED MANAGEMENT APPROACH FOR A GROWING PORTFOLIO OF FOSSIL RESOURCES

TODD KEITH and JIM MAMALIS 42

*THE DEMOGRAPHICS OF MITIGATION PALEONTOLOGY: RESULTS OF AN ONLINE SURVERY

GEORGIA E. KNAUSS, LANNY H. FISK, AND PAUL C. MURPHEY 42

A PRIMER ON CASUAL COLLECTING ON FEDERAL LANDS

LUCIA KUIZON 43

THE USE OF NONDESTRUCTIVE X-RAY FLUORESCENSE AS A FORENSIC TOOL FOR GEOCHEMICALLY FINGERPRINTING FOSSIL RESOURCES

EVE F. LALOR, DENNIS O. TERRY Jr., DAVID E. GRANDSTAFF, and ANTHONY D. CERRUTI 44

*THE CHESAPEAKE AND DELAWARE CANAL: TWO CENTURIES OF PALEONTOLOGY ON A PUBLIC TRACT

EDWARD M. LAUGINIGER, DAVID C. PARRIS, and RODRIGO A. PELLEGRINI 47

*WAS CHARLES H. STERNBERG THE PROFESSIONAL ANCESTOR OF THE MODERN COMMERCIAL FOSSIL COLLECTOR?

GREGORY A. LIGGETT 48

FOSSIL CYCAD NATIONAL MONUMENT: A HISTORY WITH A FUTURE

GREGORY A. LIGGETT, BRENT H. BREITHAUPT, and VINCENT L. SANTUCCI 48

THE FUTURE OF BLM PERMIT PROCESSING AND REPORTING—YOU'RE GONNA LOVE IT

GREGORY A. LIGGETT and NEFFRA MATTHEWS 49

*USING GEOGRAPHIC INFORMATION SYSTEM (GIS) TO UPDATE MONTANA GEOLOGY MAPS AND FACILITATE FOSSIL POTENTIAL DATA ANALYSES

GREGORY A. LIGGETT and LAURA B. SILSBEE 50

TAPHONOMY OF A MULTI-TAXA BONE-BED IN THE HELL CREEK FORMATION (LATE CRETACEOUS) OF SOUTH DAKOTA (USA)

PHILLIP L. MANNING and VICTORIA M. EGERTON 51

UP, UP, AND AWAY: THE USE OF UNMANNED AIRCRAFT SYSTEMS FOR PALEONTOLOGICAL DOCUMENTATION

NEFFRA A. MATTHEWS, TOMMY A. NOBLE, LANCE R. BRADY, and BRENT H. BREITHAUPT 53

FOCUSING AROUND WITH PHOTOGRAMMETRY: CAPTURING 3D DATA ON DIMENSIONALLY COMPLEX SUBJECTS

NEFFRA MATTHEWS, TOMMY NOBLE, and BRENT H. BREITHAUPT 53

LAND MANAGERS AND REPOSITORIES: A CRITICAL PARTNERSHIP FOR THE LONG-TERM MANAGEMENT OF FOSSIL RESOURCES FROM PUBLIC LANDS

H. GREGORY MCDONALD 56

PRESENTING SCIENTIFIC RESEARCH TO THE PUBLIC THROUGH NEW EXHIBITS AND INTERACTIVE MEDIA AT FLORISSANT FOSSIL BEDS NATIONAL MONUMENT, COLORADO

HERB MEYER, LINDSAY WALKER, and LINDSAY YANN 57

WEST OF THE MISSISSIPPI ANTHILLS REALLY HELP

PATRICIA E. MONACO, SUE BILBEY, EVAN J. HALL, PETER ROBINSON 57

*A FOUNDATION FOR BEST PRACTICES IN MITIGATION PALEONTOLOGY

PAUL C. MURPHEY, GEORGIA E. KNAUSS, LANNY H. FISK, THOMAS A. DEMÉRÉ, ROBERT E. REYNOLDS, KELLI C. TRUJILLO, and JUSTIN J. STRAUSS *58*

OPERATION EQUINOX – APPLICATION OF THE PALEONTOLOGICAL RESOURCE PRESERVATION ACT TO A CRIMINAL PROSECUTION

JOSEPH NARDINGER *58*

CURRENT AND FUTURE RESEARCH ON THE PALEOECOLOGY AND TAPHONOMY OF PLIOCENE MUSTELOIDS FROM HAGERMAN FOSSIL BEDS NATIONAL MONUMENT

KARI A. PRASSACK *59*

SMALL MAMMAL DIVERSITY THROUGH THE CENOZOIC OF NORTH AMERICA AND THE IMPACTS OF PAST CLIMATIC CHANGE

JOSHUA X. SAMUELS *59*

PALEOHERITAGE, PALEOCONSERVATION, AND PRESERVING FOSSILS IN NATIONAL PARKS

VINCENT L. SANTUCCI *60*

THEFT AND VANDALISM OF NATIONAL PARK SERVICE PALEONTOLOGICAL RESOURCES: ARE FOSSILS SAFE ANYWHERE?

VINCENT L. SANTUCCI *60*

FOSSIL CYCAD NATIONAL MONUMENT: A HISTORY FROM DISCOVERY THOUGH DEAUTHORIZATION

VINCENT L. SANTUCCI, JOHN M. GHIST, TIM CONNORS, and RODNEY HORROCKS *61*

GYPSUM CAVE, NEVADA: A TREASURE TROVE OF FOSSILS OF LATE PLEISTOCENE EQUUS FROM THE MOJAVE DESERT

ERIC SCOTT and CHRISTINA M. LUTZ *61*

FOSSIL REMAINS OF EQUUS FROM THE TULE SPRINGS LOCAL FAUNA, SOUTHERN NEVADA: IMPLICATIONS FOR THE DIVERSITY AND BIOGEOGRAPHY OF LATE PLEISTOCENE EQUIDS IN WESTERN NORTH AMERICA

ERIC SCOTT, KATHLEEN B. SPRINGER, and CRAIG R. MANKER *62*

COLLECTING AND DISPOSITION OF AMMONITE SHELL IN ALBERTA: A MODEL FOR PROVIDING PRIVATE OWNERSHIP OF GOVERNMENT-OWNED FOSSIL RESOURCES

DANIEL N. SPIVAK *63*

REGIONAL VARIABILITY OF GEOCHEMICAL SIGNATURES IN FOSSILS FROM THE PALEOGENE WHITE RIVER SEQUENCE OF SOUTH DAKOTA, NEBRASKA, AND WYOMING

DENNIS O. TERRY Jr., DAVID E. GRANDSTAFF, ANTHONY D. CERRUTI, EVE F. LALOR, and W. E. LUKENS *67*

GEOCHEMICAL FINGERPRINTING OF FOSSIL VERTEBRATES AS A POSSIBLE DETERRENT TO POACHING: SUGGESTED GUIDELINES FOR ESTABLISHMENT OF A GEOCHEMICAL REFERENCE DATABASE

DENNIS O. TERRY, JR. and DAVID E. GRANDSTAFF *69*

*SMASHED RODENTS, FALSE PREPRINTS, AND THE BBC: THE PALEONTOLOGY OF MISSISSIPPI NATIONAL RIVER AND RECREACTION AREA, MINNESOTA

JUSTIN S. TWEET *72*

+*DANCING THROUGH DANTE'S TRACKSITE FROM THE GROUND AND AIR: THE USE OF AERIAL DATA COLLECTION AND PHOTOGRAMMETRY TO RECORD A DINOSAUR TRACKSITE IN ELK BASIN, WYOMING

MARILYN D. WEGWEISER, BRENT H. BREITHAUPT, and NEFFRA A. MATTHEWS.....72

+CSI BIG HORN BASIN: FORENSIC MINERALOGY USING EOCENE MAMMAL BONE FRAGMENTS FROM THE WILLWOOD FORMATION, NORTHWESTERN WYOMING, A NEW TOOL FOR RESOURCE MANAGEMENT?

MARILYN D. WEGWEISER, BRENT BESTRAM, AARON KANIA, and BRENT H. BREITHAUPT.....73

Manuscripts

History of Paleontology

FOSSIL CYCAD NATIONAL MONUMENT: A HISTORY FROM DISCOVERY TO DEAUTHORIZATION

VINCENT L. SANTUCCI and JOHN M. GHIST.....74

WAS CHARLES H. STERNBERG THE PROFESSIONAL ANCESTOR OF THE MODERN COMMERCIAL FOSSIL COLLECTOR?

GREGORY A. LIGGETT.....86

FOSSIL POINT (LAKE CLARK NATIONAL PARK & PRESERVE): ALASKA'S "JURASSIC PARK" FOR MIDDLE JURASSIC INVERTEBRATE FOSSILS

ROBERT B. BLODGETT and VINCENT L. SANTUCCI.....90

SMASHED RODENTS, FALSE PREPRINTS, AND THE BBC: THE PALEONTOLOGY OF MISSISSIPPI NATIONAL RIVER AND RECREATION AREA, MINNESOTA

JUSTIN S. TWEET.....99

Paleontological Research

PRESERVING THE PYGMY MAMMOTH: TWENTY YEARS OF COLLABORATION BETWEEN CHANNEL ISLANDS NATIONAL PARK AND THE MAMMOTH SITE OF HOT SPRINGS, SD, INC.

LARRY D. AGENBROAD, MONICA M. BUGBEE, DON P. MORRIS, and W. JUSTIN WILKINS.....111

DESCRIPTION OF AN EARLIEST ORELLAN FAUNA FROM BADLANDS NATIONAL PARK, INTERIOR, SOUTH DAKOTA AND IMPLICATIONS FOR THE STRATIGRAPHIC POSITION OF THE BLOOM BASIN LIMESTONE BED

CLINT A. BOYD and ED WELSH.....116

IT'S NOT YOUR PARENTS' ERG DEPOSIT ANYMORE: FOSSIL MANAGEMENT IMPLICATIONS OF A PALEONTOLOGICAL STUDY OF THE NUGGET SANDSTONE IN NORTHEASTERN UTAH

DANIEL J. CHURE, GEORGE F. ENGELMANN, BROOKS B. BRITT, and THOMAS R. GOOD.....140

VERTEBRATE PALEONTOLOGY AND STRATIGRAPHY OF THE LATE CRETACEOUS HOLMDEL PARK SITE, MONMOUTH COUNTY, NEW JERSEY

WAYNE R. CALLAHAN, CARL M. MEHLING, ROBERT K. DENTON, Jr., and DAVID C. PARRIS.....155

THE CHESAPEAKE AND DELAWARE CANAL: TWO CENTURIES OF PALEONTOLOGY ON A PUBLIC TRACT

EDWARD M. LAUGINIGER, DAVID C. PARRIS, and RODRIGO A. PELLEGRINI.....162

FOSSIL PLANTS FROM THE NATIONAL PARK SERVICE AREAS OF THE NATIONAL CAPITAL REGION

VINCENT L. SANTUCCI, CASSI KNIGHT, and MICHAEL ANTONIONI.....173

Management of Paleontological Resources

ARROYO DEL VIZCAÍNO SITE, SAUCE, URUGUAY: FIELDWORK, RESEARCH, CONSERVATION, EXHIBITION, EDUCATION

RICHARD A. FARIÑA and MARIANA DI GIACOMO 183

PRESERVING THE FALLS OF THE OHIO'S FOSSIL BEDS: A SUCCESSFUL INTER-GOVERNMENTAL EFFORT

ALAN GOLDSTEIN and LISA FREEMAN 191

LATE PLEISTOCENE FOSSILS AND PUBLIC OUTREACH IN NORTHWEST ALASKA

JONATHAN G. HARDES 199

USING GEOGRAPHIC INFORMATION SYSTEM (GIS) TO UPDATE MONTANA GEOLOGY MAPS AND FACILITATE FOSSIL POTENTIAL DATA ANALYSES

GREGORY A. LIGGETT and LAURA B. SILSBEE 203

INVENTORY OF U.S. GEOLOGICAL SURVEY PALEONTOLOGY COLLECTIONS TO IDENTIFY FOSSIL LOCALITIES IN NATIONAL PARK SERVICE AREAS

VINCENT L. SANTUCCI, JOHN M. GHIST, and ROBERT B. BLODGETT 207

DANCING THROUGH DANTE'S TRACKSITE FROM THE GROUND AND AIR: THE USE OF AERIAL DATA COLLECTION AND PHOTOGRAMMETRY TO RECORD A DINOSAUR TRACKSITE IN ELK BASIN, WYOMING

MARILYN D. WEGWEISER, NEFFRA A. MATTHEWS, and BRENT H. BREITHAUPT 211

RAPID PROTOTYPING OF PALEONTOLOGICAL RESOURCES FACILITATES PRESERVATION AND REMOTE STUDY

JOHN R. "JACK" WOOD and VINCENT L. SANTUCCI 220

UP, UP, AND AWAY: THE USE OF UNMANNED AIRCRAFT SYSTEMS FOR PALEONTOLOGICAL DOCUMENTATION

NEFFRA A. MATTHEWS, TOMMY A. NOBLE, LANCE R. BRADY, and BRENT H.BREITHAUPT 223

Mitigation Paleontology

THE FEDERAL MANDATE FOR MITIGATION PALEONTOLOGY

SCOTT FOSS 232

A FOUNDATION FOR BEST PRACTICES IN MITIGATION PALEONTOLOGY

PAUL C. MURPHEY, GEORGIA E. KNAUSS, LANNY H. FISK, THOMAS A. DEMÉRÉ, ROBERT E. REYNOLDS, KELLI C. TRUJILLO, and JUSTIN J. STRAUSS 235

RECOMMENDED STANDARDS FOR FIELD ASSESSMENTS IN MITIGATION PALEONTOLOGY

RANDOLPH J. MOSES, JAMES E. MARTIN, CLINTON A. SCHAAF, BENTLEY E. SHOUP, and JASON S. ADAMS 278

THE DEMOGRAPHICS OF MITIGATION PALEONTOLOGY: RESULTS OF AN ONLINE SURVEY

GEORGIA E. KNAUSS, LANNY H. FISK, and PAUL C. MURPHEY 294

Index 300

Dedication

The 10th meeting of the Conference on Fossil Resources is dedicated to the memory of William R. “Bill” Schurmann GEOE’63, 1940-2014.

William R. “Bill” Schurmann was dedicated to the Museum of Geology and the South Dakota school of Mines and Technology. From his student days, which included service as the school mascot Grubby the Miner in homecoming parades, Bill was an outstanding SDSM&T alumnus.

The Museum of Geology will never be quite the same again. We believe it will be even bigger and better in years to come—but just never quite the same again. That’s because Bill is gone and there is no one quite the same to replace him.

Bill Schurmann proved you don’t have to be a professional paleontologist to be a great paleontologist. He always wanted to be a professional in paleontology—but his father told him he couldn’t make any money that way. So he became a petroleum geologist—putting his money to good use without giving up his dreams.

After retiring from the petroleum industry, Bill came back to Rapid City and started working for the Museum as a volunteer. He put in over 35,000 hours over 20 years, anchoring the laboratory, lending a hand in the field and tirelessly helping with our move to the great new facility that he helped plan.

He worked so hard in his spare time as a fossil preparator that some people feel he defined that job. There was nothing he didn’t do and nothing he didn’t want to do. He eagerly performed everything, from the chores of packing and unpacking, to spending five years prepping a single magnificent Missouri River specimen: a giant marine lizard now known as *Globidens schurmanni*. Yes, that’s his name tagging the mosasaur you can see right here in the museum.

Bill liked to play the part of a cranky curmudgeon—but that didn’t fool the hundreds of students he unofficially mentored—and some of them use a familiar phrase: “He taught me everything I know about paleontology.”

Experts say museums with paleontology preparation laboratories visible to the public draw increased visitors to the labs and then to the museums themselves—as well as increasing numbers of volunteers. We are taking that into consideration. Our museum’s newest paleontology preparation lab will be open for everyone to see. And it will be easy for everyone to remember who inspired it.

It will bear the name of Bill Schurmann.

We think that says it all.

—Sally Shelton and Ralph Shelton

Bill Schurmann (center) with USFS PIT Project volunteers, guiding preparation of a field jacket. Photo by Barbara Beasley.

Introduction

Welcome to South Dakota and the 10th Conference on Fossil Resources (CFR). The genesis of this series of conferences, focused specifically on the management, protection, curation, research, and educational values of paleontological resources from public lands, dates back 28 years to the First Fossil Resources Conference hosted at Dinosaur National Monument. In 1986, NPS paleontologists Dan Chure and Ted Fremd laid a foundation for advancing federal paleontology that has endured nearly three decades. This 10th Conference on Fossil Resources will include presentations by young paleontologists who were not yet born at the time of the first conference at Dinosaur National Monument.

The history of the Conference on Fossil Resources has evolved and expanded to include presentations, posters and publications addressing new management practices, technologies and discoveries. The 10th CFR continues to expand the identity of this important venue for paleontology and for public land managers. We are proud to include in this conference a series of talks and papers focused on Mitigation Paleontology. This session was proposed by Paul Murphey and Scott Foss, and it seems likely that Mitigation Paleontology will continue to be part of future CFRs.

The Conference on Fossil Resources is designed to bring together professional paleontologists and public land managers to incorporate science into management practices. New and innovative technologies applied to paleontology have been part of the CFRs for the past two decades. BLM has pioneered state-of-the-art digital data collection techniques utilizing photogrammetry for the documentation, management, preservation and curation of paleontological resources. Many of these methods are currently in use around the world. We want to recognize not only these innovations in the science, but also the generosity of Neffra Matthews, Tommy Noble and Brent Breithaupt in sharing and teaching these methods and techniques to others.

We return to Rapid City for a second Conference on Fossil Resources. The proximity to the Museum of Geology at the South Dakota School of Mines and Technology, Badlands National Park, Wind Cave National Park, Buffalo Gap National Grasslands, Black Hills National Forest, Toadstool Geologic Park (Ogallala National Grassland), the Mammoth Site of Hot Springs, Inc. and the nearly forgotten Fossil Cycad National Monument (abolished), makes Rapid City and its region an ideally suited place for paleontologists to convene. We extend many thanks to Sally Shelton and the local conference planning committee, including Samantha Hustoft, Judy Chilstrom, and Dr. Laurie Anderson of the SDSM&T Museum of Geology, Barb Beasley of the U.S. Forest Service, and Justin Wilkins, Monica Bubgee, Dr. Larry Agenbroad and Olga Potapova of the Mammoth Site of Hot Springs, Inc., for their support of the 10th CFR. We also greatly appreciate the willingness of Dennis Terry and Emmett Evanoff to lead a field adventure into the White River Badlands and share their insight into these important fossil beds.

Below is a chronological list of the Conferences on Fossil Resources.

- Dinosaur National Monument, Vernal, UT (1986)
- Petrified Forest National Park, Holbrook, AZ (1989)
- Fossil Butte National Monument, Kemmerer, WY (1992)
- Florissant Fossil Beds National Monument, Colorado Springs, CO (1994)
- Badlands National Park and South Dakota School of Mines and Technology, Rapid City, SD (1998)
- Colorado Bureau of Land Management, Gunnison National Forest, Colorado National Monument, Grand Junction, CO (2001)
- New Mexico Museum of Natural History and the New Mexico Bureau of Land Management, Albuquerque, NM (2006)
- Utah Friends of Paleontology, the Utah Bureau of Land Management, and the Utah Geological Survey, St. George, UT (2009)
- Fossil Butte National Monument, Kemmerer, Wyoming (2011)

Thank you to all the authors who contributed original manuscripts for publication the Proceedings of the 10th Conference on Fossil Resources. We would also like to thank all the individuals who reviewed the manuscripts and provided suggestions to the authors. Finally, it was a pleasure to work with the conference planning team including Barbara Beasley (USFS), Brent Breithaupt (BLM), Scott Foss (BLM), Emmett Evanoff (University of Northern Colorado), Mike Fracasso (USFS), Greg McDonald (NPS), Sally Shelton (SDSM&T) and Dennis O. Terry (Temple University).

—Vincent L. Santucci and Greg Liggett

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ORAL PRESENTATION

*PRESERVING THE PYGMY MAMMOTH: TWENTY YEARS OF COLLABORATION BETWEEN CHANNEL ISLANDS NATIONAL PARK AND THE MAMMOTH SITE OF HOT SPRINGS, S. D., INC.

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ABSTRACT—Channel Islands National Park (CHIS) encompasses five islands off the coast of southern California. Though the park has numerous paleontological deposits, there is currently no paleontologist on staff to manage this resource. In the past, the Park Archaeologist has acted as de facto paleontologist, conducting limited salvage collection and alerting interested scientists to significant finds. Discovery of a nearly complete pygmy mammoth (*Mammuthus exilis*) skeleton in 1994 on Santa Rosa Island spurred the involvement of the Mammoth Site of Hot Springs, SD, Inc. (MSHS). A twenty-year volunteer-based collaboration between MSHS and CHIS has helped to alleviate the resource management gap in regards to proboscidean remains. Since 1994, MSHS has led several salvage trips, performed survey of Pleistocene mammoth localities, prepared many recovered specimens, and conducted research resulting in numerous publications. The latest excursion culminated with the collection of a M. exilis tusk and giant deer mouse (*Peromyscus nesodytes*) tibia from ~80,000 year old sediments Garañon Canyon, Santa Rosa Island.

KEYWORDS: pygmy mammoth, *Mammuthus exilis,* Channel Islands National Park

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ORAL PRESENTATION

PERMITS AND PALEONTOLOGY ON BLM COLORADO: RESULTS FROM 2009 TO 2013

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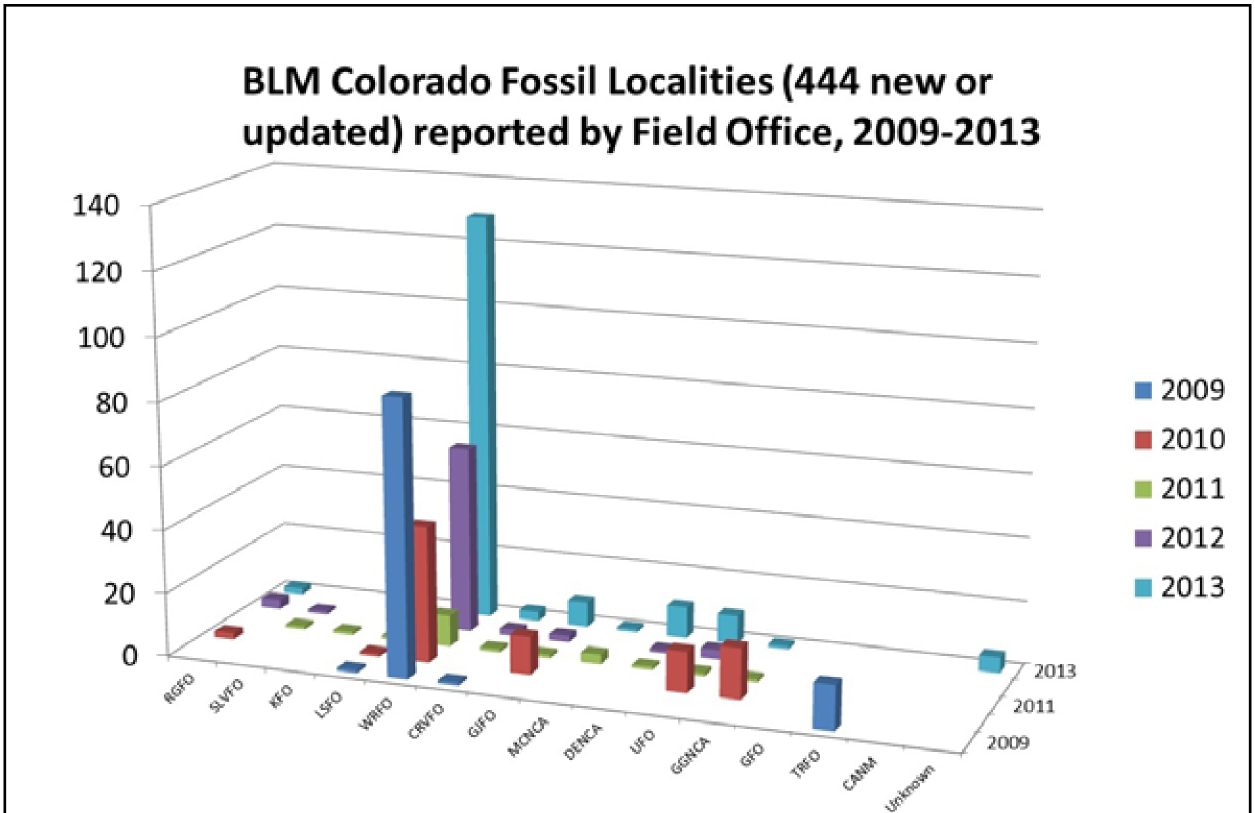
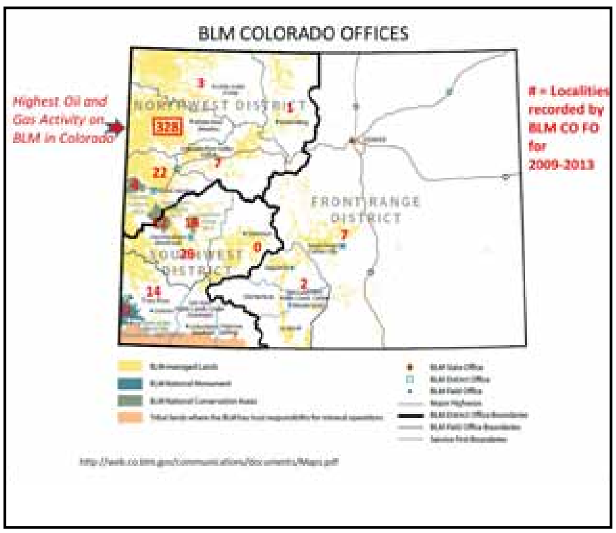
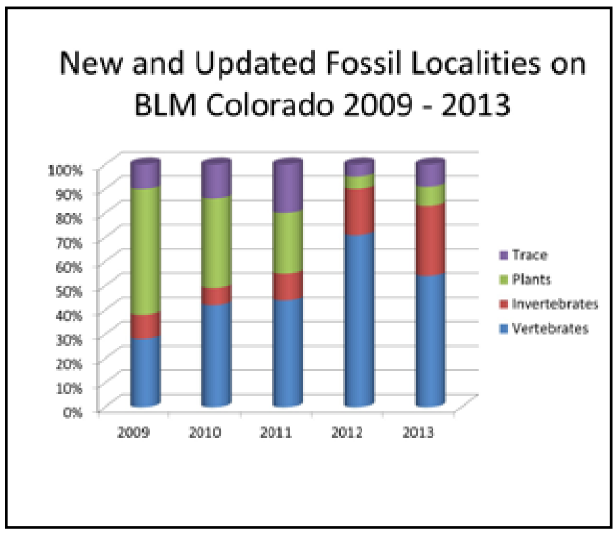
ABSTRACT—From 2009 to 2013, the Bureau of Land Management in Colorado has overseen the work of hundreds of BLM Paleontological Resources Use Permits. Besides continued paleontological fieldwork on many known fossil localities, during this time 444 new localities were reported from BLM lands in Colorado. Each year, the number of new localities is reported through the BLM Washington D.C. Office to the public. Due to better tracking of this information in recent years, it is now possible to make comparisons and identify ‘hot spots’ of scientific paleontological activity in Colorado on BLM-administered lands. In analyzing information from permit reports and locality forms, a number of insights are now possible. By far, the most new paleontological work is in the oil and gas fields of northwestern Colorado, in and around the Piceance Basin within the BLM White River Field Office area (Figs. 1 and 2). Records of localities have slowly migrated from mostly paleobotanical fossil areas to vertebrate fossil localities [Attachment 3]. Important paleontological work has also occurred in other parts of Colorado and in other aspects of paleontology, such as with invertebrates and tracks and other trace fossils. Much of this permit fieldwork varies from year to year as based on the interests of industry and proponent-driven field surveys and mitigation work. However, continued long-term quarry work and research survey needs also serve as a good part of this foundation of scientific and educational paleontological yields in Colorado. As these data are compared, clarity of the overall permits and fossil yield situation is shown, and proposals for areas and themes for future paleontological research on Colorado BLM can be suggested.

KEYWORDS: Bureau of Land Management, Permits, Paleontology Localities



RGFO = Royal Gorge Field Office, Canon City, CO; **SLVFO** = San Luis Valley Field Office, Saguache, CO; **KFO** = Kremmling Field Office, Kremmling, CO; **LSFO** = Little Snake Field Office, Craig, CO; **WRFO** = White River Field Office, Meeker, CO; **CRVFO** = Colorado River Valley Field Office, Silt, CO; **GJFO** = Grand Junction Field Office, Grand Junction, CO; **MCNCA** = McInnis Canyons National Conservation Area, Grand Junction, CO; **DENCA** = Dominguez-Escalante National Conservation Area, Grand Junction and Montrose, CO; **UFO** = Uncompahgre Field Office, Montrose, CO; **GGNCA** = Gunnison Gorge National Conservation Area, Montrose, CO; **GFO** = Gunnison Field Office, Gunnison, CO; **TRFO** = Tres Rios Field Office, Dolores, CO; **CANM** = Canyons of the Ancients National Monument, Dolores, CO; **Unknown** = Unknown source or area





ORAL PRESENTATION

DEVIL'S COULEE DINOSAUR EGG SITE AND THE WILLOW CREEK HOODOOS: HOW SITE VARIABLES INFLUENCE DECISIONS MADE REGARDING PUBLIC ACCESS AND USE AT TWO DESIGNATED PROVINCIAL HISTORIC SITES IN ALBERTA, CANADA

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ABSTRACT—Recently in Alberta significant changes have been made to both the protection and interpretation surrounding two provincially designated sites, the Willow Creek Hoodoos and Devil's Coulee Dinosaur Egg Site. While changes to both of these sites followed the same legislation and guidelines, the outcomes for each were very different.

Fossil legislation in Alberta, Canada has been regulated under the Historical Resources Act (HRA) since 1978 (Alberta Culture, 2000). The HRA controls the collection, ownership, sale of fossils and protects significant sites within the province, providing similar restrictions and penalties as those in Canadian national parks. Visitors are not allowed to remove any items from these significant sites. Vandalism of fossils or geologic features can be met with penalties, including up to $50,000 and/or up to one year in prison. Currently there are three sites designated under the HRA: the Grande Cache Trackways, the Willow Creek Hoodoos (the Hoodoos), and Devil's Coulee Dinosaur Egg Site (Devil's Coulee).

The Hoodoos and Devil's Coulee are not only provincially protected, but are also owned by Alberta Culture, a ministry of the provincial government. The government is not only responsible for applying the legislation to protect the sites, but is also responsible for all aspects of their management. As a branch of Alberta Culture and with a specialty in palaeontology, the Royal Tyrrell Museum of Palaeontology (RTMP) has been placed in charge of managing these two sites.

In addition to the HRA, the Standards and Guidelines for the Conservation of Historic Places in Canada are used to direct those who wish to make changes to significant sites within Canada (Parks Canada, 2010). The Standards and Guidelines provide details on methods and techniques that should be used when making changes to any site, ensuring its integrity. Each site is given a Statement of Significance. This statement outlines the importance of the site and includes a description, heritage value and character defining elements (the elements at a make a site significant; if these elements were lost the site would no longer hold its integrity). The main Standards and Guidelines considerations used for managing Devil's Coulee and the Hoodoos were: the impact any change would have on character defining elements, the need for reversibility and the visual impact to the landscape (ie. the colours or sizes of any new elements impede or detract from the importance of the landscape). Aside from strategies outlined in the HRA and the Standards and Guidelines other factors that were considered included accessibility, visitor numbers and sensitivity, distribution and abundance of the character defining elements.

THE WILLOW CREEK HOODOOS

The Willow Creek Hoodoos are a grouping of Hoodoos located approximately 15km east of Drumheller (Fig. 1). Hoodoos are geological features in the shape of a pillar or column, created by the differential weathering of softer sediment at the base, capped by harder, more weather-resistant rock. The Willow Creek Hoodoos were carved out by the Laurentide ice sheet approximately 14,000 years ago (Eberth, 1986). The base of the pillars is comprised of the Bearpaw Formation while the upper part of the pillars and capstones are in the Horseshoe Canyon Formation. In Alberta, it is rare to find an occurrence of Hoodoos in the size range (18-20ft) and density (10) seen here.

Despite being a popular tourist destination since the early 1900's, the Hoodoos were only designated as a Provincial Historic Resource in January 2001. They are a provincial symbol, having been depicted on coins and are continually featured on tourism brochures. Filming and photography at the Hoodoos is quite common, the most recent filming being a stop on the Amazing Race Canada. This core set of ten Hoodoos became the character defining element in the site's Statement of Significance.

Their symbolism and close proximity to other tourist destinations such as the RTMP have made the Hoodoos a popular spot for visitors. The site receives on average 50,000 visitors during the high tourist season (May through August). Until 2011, a rock path led up through the Hoodoos and into the badlands (Figure 2A). With this path eroding away and no railings, it was unclear where people were allowed to go and what was considered proper visitor conduct at the site. This led to vandalism, commonly in the form of people carving their name in a hoodoo. Damage also included people inadvertently walking through the restricted area. This was a particular problem after hours once staff had left the Hoodoos.

In 2005, six interpretive panels were put up throughout the site. In addition, during the high season, staff (one during the week and two on weekends) was at the Hoodoos seven days a week from 10:00am until 6:00pm to provide interpretation. However, with the high number of visitors and absent security structures, staff had a hard time keeping people from damaging the Hoodoos while providing quality interpretation. With mounting complaints regarding the destruction of the Hoodoos, the RTMP decided

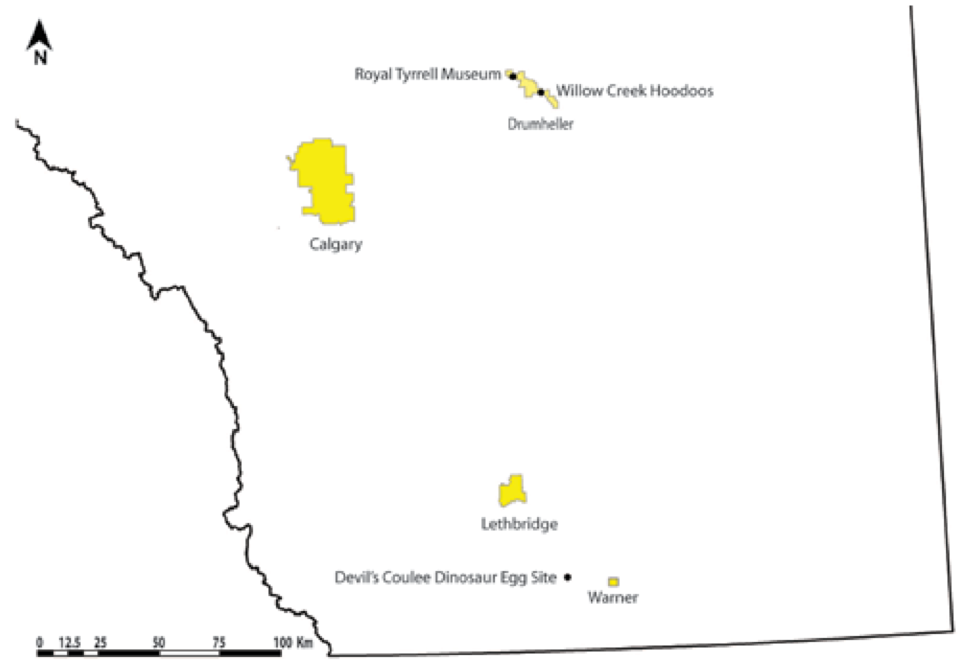

Figure 1: Southern Alberta. The Willow Creek Hoodoos are within the boundary of the the Town of Drumheller and only a 20 minute drive from the Royal Tyrrell Museum. of Palaeontology. Being within this tourist area allows for a greater number of visitors and easier access to the site. Devil's Coulee is 4 hours south of Drumheller and about 20 minutes from the nearest town, Warner. The remote location provides less access to the site and in turn recieves less visitors. The differing locations and accessibility of the two sites provides part of the explanation for the varying security and interpretive strategies.

to make improvements to the site. The goal was to lead people through the site but still have the focus be on the hoodoos.

Being next to a major highway, the Hoodoos are easily accessible to the public. This made it virtually impossible to close the area while staff was not present. As a result of this and the high visitation, the RTMP felt that the best course of action would be to formalize a barrier between the Hoodoos and the public. It is important to note that outside the core set of Hoodoos there are virtually no historical resources on the property (the area is barren of fossils or any other type of resource of significance). With the abundance of character defining elements (Hoodoos) being low and concentrated, it was feasible to create a permanent barrier without damaging the resource. The Standards and Guidelines, also required that the view of the Hoodoos not be impeded. The permanent barriers are heavier steel features placed in the ground with concrete pilings for long term stability. To ensure the structures would not detract from the site, the barriers are low cables in viewing areas and steel railings in areas that are not impeding views (Fig. 2B and Fig. 3A). Brown colours were chosen so the walkways would blend with the landscape.

The new barriers also allowed the site to be self-sufficient. Hiring staff for the site each year was a large cost, one that was no longer needed with the new fences and boardwalks. With an interpreter no longer on site, the older signs were updated and new signs were added to enhance the self-interpretive experience. These signs included information based on the most frequently asked questions over the years. To avoid confusion, each sign also includes a map showing all other interpretive panel locations and the interpretive trail. After two years of review (having staff occasionally on site to observe and survey visitors) the interpretive and security changes seem to be fulfilling the RTMP's expectations.

DEVIL'S COULEE DINOSAUR EGG SITE

Devil's Coulee is the richest dinosaur nesting site found in Canada and the third nesting site discovered in North America (Francois Therrien pers.comm., 2012). The site is approximately 693 acres in size and was discovered in May 1987 near the town of Warner, Alberta (Figure 1). The fossils are from the Oldman Formation and are approximately 75 million years in age. A core nesting site (Little Diablo's Hill) was originally found and included egg shells of a hadrosaur known as Hypacrosaurus stebingeri. Since then, on-going research has led to the discovery of nests and embryos of other animals not only on Little Diablo's Hill but throughout the site. Many microsites are prevalent in the protected area as well and Devil's Coulee has also produced a Hypacrosaurus stebingeri juvenile bonebed, excavated in 1988 and 1989, which represents the only non-embryonic material for Hypacrosaurus stebingeri in Canada. All of these components are noted character-defining elements within the site's Statement of Significance.

Devil's Coulee was designated as a Provincial Historic Resource in 1987, shortly after its discovery. At the time the site was fenced off and inaccessible to visitors. In 1995, the Devil's Coulee Cooperating Society (DCCS) was created by residents of Warner and the surrounding area to promote tourism to the site. The RTMP has since been working with the DCCS to provide interpretation at Devil's Coulee. Prompted by what appeared to be outdated signs and information, a review of the interpretation and site protection was started by Resource Management staff at the RTMP in 2012. This led to the creation and implementation of an interpretation plan.

While the museum run by the DCCS is on a major highway, Devil's Coulee itself is remote and receives only about 750 visitors from May until September (about half of the people visiting the DCCS museum). The site is still producing valuable specimens and research is on-going. This remote and sensitive nature dictates that visitors only tour the site with a guide (provided by DCCS). With a variety of resources distributed throughout the site and a guide to lead the way, Devil's Coulee in a very interactive interpretive experience, despite its sensitive nature. Activities include hiking with interpretive stops and prospecting for microvertebrate fossils. The site provides the opportunity to teach through a number of different learning styles such as visuals on signs, interaction with an interpreter, hands on activities and seeing specimens in their original context. This interaction is considered important but should not sacrifice the protection of the site as was being seen after the RTMP site review. For security reasons the main outer boundary of the site has always been fenced with "Permission Only" signs. Due to its location there had been little incident of people entering on their own. The security issues were seen more when visitors were actually on site. The lack of restricted areas and strict supervision at the microsite left the site venerable to destruction and pillaging. The goal of the interpretation plan was to find a balance between protection and interpretation and to add any other quality learning opportunities if possible.

Due to the abundance and large distribution of fossils as well as on-going research, any new structures such as fences needed to be low impact and reversible. A simple system was needed around Little Diablo's Hill to ensure that visitors and guides would not accidentally walk into an extremely sensitive area while on their hike. Thin cable and Polyflex posts (fiberglass) which could be hand pounded and would not rust were used (Figure 3B). A simple clip and cable gate was installed so that researchers could easily access Little Diablo's Hill if they needed to remove jacketed specimens. Post colours and sizes were chosen to blend in with the sandstone environment.

From an interpretive standpoint, new training materials with accurate and up to date information were given to staff. One of the microsites is being developed into an educational stop where visitors use real fossils to identify what they have found. Not only will this be more engaging but it also forces visitors to bring the fossils they find to the guide, hopefully preventing theft from the site. Also, visitors are now given an explanation of a microsite and its importance. The interpretive panels are being updated to better reflect the information at Devil's Coulee and will now include text.

CONCLUSIONS

It is imperative to have a balance between security and interpretation at significant palaeontological sites. Considering the accessibility, visitor numbers and abundance/distribution of the resources is critical to achieving this balance. The Hoodoos, a very accessible, highly visited, and low resource distribution site allowed for more permanent and contained security measures, while still maintaining the integrity of the site as outlined through the Standards and Guidelines. This led to a self-interpretive visitor experience with more enhanced text panels and viewing platforms.

In comparison, Devil's Coulee being a sensitive and remote location required a guide. Having a guide allowed for a more interactive experience with visitors through a hike and microsite activity. This interactive model still needed boundaries to meet the integrity levels of the Standards and Guidelines. However, due to the abundance, greater distribution and sensitivity of the resources different barriers were required (removable if necessary and low impact). At this point with the low number of visitors it is possible to have this interaction at Devil's Coulee. If visitor numbers ever increased to those at the Hoodoos, the impact to such a sensitive area may be too great and a re-evaluation of the interpretation versus preservation balance would need to be made. Despite the differences in methods used, both sited incorporated colours and styles that would blend into the environment rather than detract from it.

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KEYWORDS: Devil's Coulee, Dinosaur eggs; Willow Creek Hoodoos, Alberta, Canada

Figure 2: Picture A shows the old path at the Hoodoos with no barriers between the Hoodoos themselves and the visitors. This led to confusion about where access was allowed and provided the opportunity for vandalism. Picture B shows the new walkways (red shale and grating), railings and staircases (arrow 1) which clearly lead people around the hoodoos. These new stuctures provide security but still allow for viewing. Arrow 2 shows where the old path from Picture A would have been.

A

B

Figure 3: Picture A is an example of the new staircases at the Willow Creek Hoodoos, while picture B is an example of the new fence put up at Devil's Coulee Dinosaur Egg site. The structure in picture A is more robust to keep people out of the site. It is also a permanent structure that required invasive installation. The fence in picture B was less invasive to install (preventing damage to a sensitive area during installaiton) and is easily reversible if continued research requires that it be removed.

ORAL PRESENTATION

USDA FOREST SERVICE PALEONTOLOGY PASSPORT IN TIME PROGRAM: COST EFFECTIVE WAY TO GET FEDERAL PALEONTOLOGY PROJECTS COMPLETED

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ABSTRACT—Passport in Time (PIT) is a USDA Forest Service (USFS) generated volunteer program, established in 1988, to complete archeological projects using volunteers during these times of diminishing federal funding. Since then the program has expanded to include paleontology projects.

The first paleontology project hosted in 1998 between PIT, USDS Forest Service and University of Wyoming was a late Cretaceous micro-vertebrate project held at University of Wyoming, Geological Museum. For two weeks, volunteers sorted micro-vertebrates under a microscope.

As one of two field bound Forest Service paleontologists, I've hosted 16 Paleontology Passport in Time (PIT) projects since 2007. Other projects have been to assess Paleontological Special Interest Areas, mitigation, and pedestrian resource inventories, to name a few. Projects lead by the North Zone Paleontologist was located in Wyoming, South Dakota, and Nebraska. Geologic ages have included Late Cretaceous terrestrial and marine localities and Tertiary terrestrial localities including vertebrate track way photogrammetry at Toadstool Geologic Park.

All of the PIT projects produced numerous field jackets; which are housed at the South Dakota School of Mines and Technology, Paleontology Resource Lab (PRL) and Eleanor Cook Museum, Chadron State College, Chadron, Nebraska. Over the years fossil jackets were piling up, taking up valuable space, and causing me to be derelict in my duties as a federal paleontologist. In the meantime, some USFS field jackets were being prepared at Dinosaur Depot. To resolve this challenge, PRL and USFS collaborated to conduct a PIT in the PRL for a two week preparation session. Mindy Householder was contracted by USFS, to teach the preparation course. After two weeks and 35 volunteers (1,755 volunteer hours) later, the USFS field jacket backlog at PRL had gone the way of the dodo and specimens were ready for accessioning into the museum collections.

There were negative and positive results from the "Getting' Fossils Outta Field Jackets" project. One negative issue resulted in the loss of a few federal specimens, as some people should never prepare fossils. However, this experiment had many positive results including: cementing a mutually beneficial partnership between USFS and PRL; generating a cadre of professionally trained preparators (as some are now welcome to prep at PRL anytime); meeting mutual goals of USFS and PRL toward responsible public resource conservation; eliminating the backlog at an efficient cost for the public; giving the PRL a through shakedown, providing prepared, public specimens to foster research, and, educating me as to better the fossil collecting procedures and documentation.

Since 2007, there are some PIT volunteers that are very capable of documenting and excavating paleontological material without direct paleontological oversight. These volunteers are crucial to getting paleontological work done when the project spans a large geographic area with multiple collecting sites. I created a form for each excavation with information to be recorded and the site mapped on a grid. This form is used and at least the minimal information is recorded instead of the unused field notebooks. Each site is GPS'd with a Trimble 6000 GeoExplorer XT and a data dictionary with fields from the USFS PaleoEx Geodoatabase.

An issue I hoped to have resolved is the worn off or illegible labeled field jacket. Typically, field jackets are moved a few times and the labels on the exterior are worn off or jackets or were labelled illegibly. I now specify that each exposed skeletal element in a field jacket is labeled with the site/number, North arrow on the bone surface on top of a Paraloid barrier; a USFS label in a plastic bag placed inside the jacket, the jacket labeled on the exterior; and photos taken at each of these steps. It least there may be a label in the jacket to correspond to the information on the exterior and field notes. I now predominately use reversible consolidants such as Butvar 76 and or Acryloid (Paraloid).

PITs conducted by the North Zone Paleontology Program are typically in remote areas. Thus creating a need for a traveling base camp providing: Base camp tent; Northern Great Plains wind tolerant shades, two hot water shower stalls built by Pine Ridge Job Corps; On-demand hot water showers with water provided; Solar and Gas generators; contract for caterer and for porta potties; a Polaris UTV, and equipment and supplies needed for excavation, documentation, collection; all hauled by a one ton Ford to the site in a 16' enclosed trailer. Base costs for each project ranges from \$3.5k to \$5k. Forest Service estimates volunteer pay rate at a GS7 S5 (\$20/hr). Since the preparation PIT project, I've attached a week of lab work to each field project; each project is two weeks with at least 15 volunteers can accrue about 1.2k hours (\$24k). Therefore with a base cost of \$5k for each project there is a \$19k savings to USFS for each PIT project. For the three PIT projects in FY13 created a savings to the USFS of approximately \$76,140.

KEYWORDS: Passport in Time, Partnerships

ORAL PRESENTATION

PALEONTOLOGICAL INVENTORY AT GREAT BASIN NATIONAL PARK, NEVADA

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ABSTRACT—Great Basin National Park straddles the crest of the southern Snake Range in the eastern Nevada portion of the Basin and Range Geologic Province. The mountains themselves are a metamorphic core complex with highly faulted but appreciable expanses of lower Paleozoic sedimentary rocks. Yet, in 2010 there was only one publication that identified paleontological resources within the park and only one park fossil specimen cataloged into the collections. Previous geologic mapping showed large areas of early to mid-Paleozoic lithostratigraphic units occurred within the park. These units in surrounding areas have produced a wealth of paleontological information and are even considered regional series- and stage-level stratotypes, such as the Ibexian in nearby Utah and the Whiterockian in central Nevada. Thus it seemed likely that Great Basin was one of those parks hiding an undiscovered wealth of paleontological resources. Preliminary field forays in late 2010 and 2011 produced a few localities confirming there are a number of significant paleontological resources to be documented. During the summer of 2012 and 2013, with the able assistance of three GIPs from the Geological Society of America GeoCorps program, considerable field work identified an additional 60 paleontological localities. Virtually all of these produce marine invertebrate faunas, however one site produced the first vertebrate fossils known from the park, a fin spine of a Devonian acanthodian fish and some dermal scales.

The inventory results has sparked the interest of researchers, one of whom has since applied for a research permit and performed field work in the park in 2013 and others who will visit the park in the summer of 2014. During the fall of 2012 park staff investigated a cave that yielded the first Pleistocene fauna from the park. This generated a cooperative effort between the park and researchers eager to discover what vertebrates were present in the Snake Range during that time. The chronologic distribution of Paleozoic localities inventoried in the park ranges from Early Cambrian to Middle Devonian. We have documented 11 Cambrian localities producing mainly trilobites, trace fossils, and inarticulate brachiopods, as well as a few rare articulate brachiopods. Stratigraphic units in which these localities occur are the Prospect Mountain Quartzite, Pioche Shale, Pole Canyon Limestone, Lincoln Peak Formation, Corset Spring Shale, and the Notch Peak limestone. One is apparently a locality in the Lincoln Peak Fm. published by Drewes and Palmer in 1957. Ordovician localities are by far the most common and prolific with 47 currently documented from all formations within the Pogonip Group. These localities contain the common marine invertebrates of the time including: sponges, gastropods, bivalves, straight cephalopods, bryozoans, brachiopods, trilobites, ostracods, and echinoderms, as well as at least three forms of receptaculitid algae. Rare taxa include a polyplacophoran, a coiled nautiloid, planispiral gastropods, carpoids, and stelleroids. Among the more significant results of the inventory include discovery of a concentration of tabulate corals in a very thin zone at the top of the Pogonip Group, where *Eofletcheria* coralla formed a solid biostrome 50-70 cm thick that can be traced through outcrops spanning a distance of 1.6 km. Small dispersed coralla of Lichenaria and Foerstephyllum are found above this in a zone two meters thick. The *Eofletcheria* biostrome was reported in western Utah, in the White Pine Range west of Ely, Nevada, and specimens of this coral are reported as far south as Pioche, Nevada. Using a paleonspastic correction for extension in the Basin and Range, the known distribution suggests this coral may have formed large biohermal patches that at one time or another spread across an area of the Middle Ordovician marine shelf measuring as much as 144 km long by 160 km wide. Five Silurian localities in the undifferentiated Fish Haven and Laketown dolomites expose numerous large mounds of stromatolites and a few rugose corals. Some of the exhumed stromatolite heads stand more than a meter above the surrounding land surface and potentially provide excellent opportunities to develop an interpretive trail. Devonian localities include two exposures of silicified stromatolites and the acanthodian fish locality previously noted, all in the Sevy Dolomite. One locality in the Simonson Dolomite contains colonial rugose corals replaced with white calcite. To date, three summers of paleontological inventory efforts in Great Basin National Park have documented 71 localities and approximately 1500 individual fossils. The database contains 674 photographs of fossils and outcrops, as well as approximately 700 GPS points. The inventory effort will continue through summer 2014 utilizing the assistance of two GeoCorps GIPs.

KEYWORDS: Great Bain National Park, Inventory

FIGURE 1. A portion of the *Eofletcheria* biostrome at locality GRBA PAL 00040, Lehman Formation, Pogonip Group, Middle Ordovician. Numerous small heads of the colonial tabulate coral, *Eofletcheria*, form a biostromal layer 40 cm thick at this point..

FIGURE 2. A partial starfish, probably *Stibaraster*, from locality GRBA PAL 00040, Lehman Formation, Pogonip Group, Middle Ordovician. The specimen preserves two arms and a partial central disc..

ORAL PRESENTATION

*DESCRIPTION OF THE FIRST ORELLAN FAUNA DEFINED IN BADLANDS NATIONAL PARK, INTERIOR, SOUTH DAKOTA AND IMPLICATIONS FOR THE STRATIGRAPHIC POSITION OF THE BLOOM BASIN LIMESTONE BED

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ABSTRACT—Three new vertebrate localities are reported from within the Bloom Basin of the North Unit of Badlands National Park, Interior, South Dakota. These sites were discovered during paleontological surveys and monitoring of the park's boundary fence construction activities. This report focuses on a new fauna recovered from one of these localities (BADL-LOC-0293) that is designated the Bloom Basin Local Fauna. This locality is situated approximately three meters below the Bloom Basin Limestone Bed, a geographically restricted stratigraphic unit only present within the Bloom Basin. Previous researchers have placed the Bloom Basin Limestone Bed at the contact between the Chadron and Brule formations. Given the unconformity known to occur between these formations in South Dakota, the recovery of a Chadronian (late Eocene) fauna was expected from this locality. However, detailed collection and examination of fossils from BADL-LOC-0293 reveals an abundance of specimens referable to the characteristic Orellan taxa *Hypertragulus calcaratus* and *Leptomeryx evansi*. This fauna also includes new records for the taxa *Adjidaumo lophatus* and *Brachygaulus*, a biostratigraphic verification for the biochronologically ambiguous taxon *Megaleptictis*, and the possible presence of new leporid and hypertragulid taxa. The Bloom Basin Local Fauna represents the first Orellan local fauna described from the Big Badlands of South Dakota and provides crucial insights into the age and stratigraphic position of the Bloom Basin Limestone Bed. The results of this study emphasize the vital importance of paleontological monitoring of high impact activities as a tool for discovering significant new localities and faunas and protecting crucial natural resources.

KEYWORDS: Badlands National Park, South Dakota, Eocene, Chadronian

ORAL PRESENTATION

A NEW METHOD FOR THE IDENTIFICATION OF FOSSIL FROGS (ANURA) WITH APPLICATION TO LATE CENOZOIC SITES FROM THE WESTERN UNITED STATES

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ABSTRACT—Anurans (frogs) are an important component of modern ecosystems, and many taxa are considered indicator species significant to conservation of biodiversity. The fossil record of frogs is critical to understanding the geographic and evolutionary history of living frogs, and knowledge or their taxonomic diversity and habitat preference in the past can inform current conservation efforts. However, fossil frogs tend to be little-studied, especially in the western United States. This may be due in part to the difficulty of identifying anuran fossils past the generic level. In the past, many species level identifications of anuran fossils were made on the basis of the modern ranges of related living species. While the assumption that the descendants of a fossil animal should still occupy the same area may be sound for some Pleistocene or more recent fossil taxa, this assumption becomes more problematic as the age of the fossils involved increases. An identification made on the basis of modern range is also unsuitable for drawing inferences about past ecology or climatic conditions. Here we use a geometric morphometric approach to evaluate the taxonomic affiliations of a sample of fossil anurans from the western United States, in an attempt to decouple fossil identification from the modern ranges of extant frogs and to provide better resolution of fossil taxon identification. The anuran ilium is frequently found as a fossil, is considered morphologically informative, and has been used extensively in descriptions of fossil taxa, so we selected it for use in the analysis. 150 ilia from 18 modern anuran ranid species were digitized using 10 landmarks for comparison with fossil ilia from the late Miocene through Pleistocene sites in California, Idaho, Nevada, and Oregon. Data were analyzed using relative warp and canonical variates analyses in the tps series of programs and SPSS. The analyses showed a reliable classification of species groups, with greater than 80% accuracy in all cases. Species show differences in the shape of the acetabulum, position of the iliac shaft and supra-acetabular fossa, and the angle of between the dorsal acetabular expansion and dorsal prominence; all of these features have been used previously in diagnoses of fossil species, but have not previously been quantified. Fossil specimens were placed into a number of species groups, including the bullfrog Rana catesbeiana, which is considered not to be native but rather were historically introduced to the western US. The identification of frogs at well-known and biostratigraphically significant sites like Hagerman and Irvington is important to understanding the evolution of fossil herpetofaunas in North America.

KEYWORDS: frog, Ranidae, geometric morphometrics

ORAL PRESENTATION

FOSSIL TRACKS AND FUTURE SCIENCE: MANAGING ICHNOLOGICAL RESOURCES ON BLM'S PUBLIC LAND

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ABSTRACT—Some of the most valuable clues to Earth's history may be found in the western United States on public lands entrusted to the Bureau of Land Management (BLM). Not only are these lands managed to safeguard these priceless resources spanning billions of years, but also are among the world's best outdoor laboratories for studying the fossilized remains of plant and animal life. More kinds of fossils can be found on the 245 million surface acres of public land that BLM manages than on any other Federal or State lands. In 2009, Congress passed the Omnibus Public Land Management Act, which includes the Paleontological Resources Preservation subtitle (PRPA). In this legislation Congress recognized the value of and provided the authority to protect paleontological resources on public lands as natural and irreplaceable parts of America's heritage. Thus, strengthening BLM's mandate to protect and interpret scientifically significant paleontological resources as Heritage Resources.

In order to manage and protect paleontological resources for the public trust, it is important to understand

how they may be threatened. Inexperienced collecting or failure to maintain precise information on the original location, rock type, and other conditions related to paleontological resource occurrence, can damage fossils or cause them to lose their context, and thus, much of their scientific value. Proper documentation, collection, storage, and care of paleontological resources are key to resource protection; which is why scientifically significant paleontological resources from Federal lands are studied and collected under a Paleontological Resources Use Permit. These resources and their associated information remain the property of the United States and are preserved for the public in approved repositories, where they are available for scientific research and public education.

PRPA defines paleontological resources as any fossilized remains, traces, or imprints of organisms, preserved in or on the earth's crust, that are of paleontological interest and that provide information about the history of life on earth. As trace fossils are considered paleontological resources, any fossil (vertebrate and invertebrate) ichnology work requires a Paleontological Resources Use Permit. Trace Fossils found on Federal public lands range from Precambrian (1.7 billion years old) traces of blue-green algae to Jurassic (150 million years old) footprints of dinosaurs to Pleistocene (20,000 years old) footprints of mammoths.

While some invertebrate and plant fossils may be considered common, all vertebrate body and trace fossils are considered scientifically significant paleontological resources. Vertebrate trace fossils are managed in a similar fashion to vertebrate body fossils and, for management purposes, are considered a type of vertebrate fossil. However, management strategies for vertebrate trace fossils vary from those for body fossils. Unlike fossilized bones and teeth (which once discovered are removed from the ground), BLM strongly encourages that the tracks and traces of vertebrate animals be left in situ and not collected. In the case of loose specimens, collection of material is authorized under a Paleontological Resources Use Permit. Removal of in situ tracks and trackways requires proper justification and authorization; in such cases a BLM Paleontological Resources Use Excavation Permit is required. Any destructive analysis (e.g., coring, thin sections, etc.) of tracks (just as with body fossils), whether done in the field or lab, often requires additional BLM authorization. In addition, exposing a track-bearing surface prior to documentation needs to be considered during the permitting process. While a researcher may wish to expose a track surface for research and documentation, it is BLM's responsibility to manage for the longevity and multiple use of paleontological resources and the areas where they are found. Thus, it may be determined that it is not in the best interest of the resource to expose it at a particular time, as paleontological resources that remained naturally buried are protected. Once exposed, trace fossils are susceptible to natural erosion (even if reburied), unintentional or intentional damage by humans, and impacts by various animals and plants.

As molding and casting of trace fossils can damage a trace-bearing surface, this activity also often requires authorization. Sometimes, the terms molding and casting are confusing, as they are used interchangeably. Herein, molding is defined as the application of some substance on a trace fossil to obtain a negative replica of the surface. Once the mold is created, a hard cast can be made. A cast is defined herein as the application of some substance into the mold to obtain a hard replica of the original molded fossil. It must be noted, that the term natural cast refers to those situations where a natural depression (e.g., footprint) has been filled in with other sediment, which hardens and creates a natural relief replica of the depression. State-of-the-art molding techniques utilize some type of liquid (e.g., latex, silicone) or soft putty applied to the surface. Because these materials are pliable, they can often be easily removed from the trace-bearing surface, providing that the surface is properly prepared (e.g., cleaned, stabilized, cracks/overhangs filled, and separator applied) prior to molding. Even in the best cases, this activity may inevitably affect the surface chemically, mechanically or biologically. In all cases, only permitted researchers should be allowed to perform this activity on scientifically significant trace fossils (e.g., dinosaur footprints). In addition, a tradition exists where materials that cure to a hardened state (e.g., plaster, resin, etc.) are applied directly onto the trace-bearing surface. A great deal of preparation must be done to the surface before this activity can be properly done, and in most cases the trace-bearing surface is permanently scarred, lost, or remnants of cured material left in place. In some cases, entire footprints have been completely removed from trackways, as a result of this procedure. Although relatively cheap and easy to do, hard "molding" (i.e., casting) of trace fossils is an archaic method for collecting 3D data and today should rarely be done. Currently, BLM rarely authorizes this activity. Conducting molding and casting without prior approval, especially is cases where the trace-bearing surface is damaged, may be considered vandalism. PRPA provides authority for the protection of paleontological resources on Federal lands, including criminal and civil penalties for fossil theft and vandalism of paleontological resources.

Trace fossils are unique in that they provide valuable scientific information about the activities and behaviors of animals beyond the knowledge gained from body fossils. For this reason, one of the important aspects of vertebrate ichnology is the context of the tracks in their preservational environment and their relationship to other tracks and traces in the area. Removing a single footprint from its context often reduces greatly its scientific, educational, and interpretative value, as well as the values of other associated tracks (such as in a trackway) and diminishes the information value of both. Thus, to maintain that contextual relationship, an entire tracksite would need to be collected. However, as many tracksites can extend for miles (e.g., megatracksites), it is impractical and unrealistic that an entire track-bearing surface be collected; as time, resources, weight, transportation, and storage need to be considered. Molding of ichnites is a possibly, but may have some effect on the track-bearing surface, which may increase erosion or aesthetic appeal of the site. As with collection of the fossils themselves, it is also impractical to collect molds of more than just a small portion of a tracksite. In addition, molds and the associated first generation casts of tracks made under permit must meet the same curation requirements as collected fossils (i.e., proper documentation and storage in an approved repository). However, with the arrival of the digital age, there are other mechanisms for capturing and preserving the 3D data associated with trace fossils. Over the past 15 years, mechanisms for collecting 3D digital imagery of track-bearing surfaces have been successfully used. Although laser scanning and Lidar have been experimented with, currently the most cost efficient and high resolution mechanism to collect digital data is that using photogrammetry. Current legislation (i.e., PRPA) mandates that appropriate plans be developed for inventory, monitoring, and the scientific and educational use of paleontological resources. To that end, BLM has pioneered the advancement of state-of-the-art, noninvasive, digital data capture methods (i.e., photogrammetry) for the collection of 3D data of trace and body fossils of all shapes and sizes. The photogrammetric data yield high-resolution topographic maps and orthophoto images. These photos and maps, along with microtopographic profiles, can be used for measurement and analysis of trace fossils at a submillimeter level.

Authorization through a BLM Paleontological Resources Use Survey and Limited Surface Collection Permit is usually required for any scientific study of ichnological material, whether fossils are collected or not. Thus, even relatively noninvasive documentation methods (e.g., photography, measurements, drawings, and digital scanning) may require a permit. In addition, BLM may amend stipulations to any Paleontological Resources Use Permits to better preserve, protect, and manage the paleontological and other resources in an area. In general, individuals conducting research or educational studies on paleontological resources should contact the BLM prior to undertaking activities. In some cases, BLM recreation permits may also be required, as well as other permits (e.g. Federal Aviation Administration Certificate of Authorization for use of Unmanned Aircraft Systems). Although, PRPA allows the public to hobby collect common invertebrate and plant without a permit. This material may only be collected within a reasonable amount, creating only negligible disturbance for noncommercial personal use. Collection of common fossils for other purposes (e.g., research or education) may require a Paleontological Resources Use Permit. As per current legislation, programs to increase public awareness about significance of paleontological resources have been developed by the BLM. In many cases, vertebrate tracksites (especially those created by dinosaurs) are excellent forums for the public to experience their public resources. Walking alongside the footprints of prehistoric beasts that once roamed the very same area millions of years ago is an exhilarating experience. Examples of developed public sites can be found in Wyoming, Colorado, Utah, and New Mexico. These tracksites are some of the premier public paleontology sites currently managed by the BLM, and are excellent examples of providing access and information about America's Natural Heritage on America's Public Lands.

Key Words: Trace fossils, tracks, Bureau of Land Management, PRPA, Paleontological Resources Use Permit

ORAL PRESENTATION

PODCASTS AND THE PUBLIC: PALEONTOLOGICAL EDUCATION AT THE RED GULCH DINOSAUR TRACKSITE, WYOMING

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ABSTRACT—The vast public lands entrusted to the BLM (245 million surface acres) were once the home of some of the best known prehistoric animals ever to roam the American West and contain some of the world's most significant evidence of past life. With more kinds of fossils found on BLM-managed public lands than on any other federal or state lands, these areas count among the world's best outdoor laboratories for studying the fossilized remains of plants and animals. These fossils range from two-billion-year-old traces of blue-green algae that once lived in Precambrian seas to the 13,000-year-old mammoths of the Pleistocene. Because of the abundance of these fossils, for the past 150 years scientists from around the world have traveled to this region of North America to explore, discover, and collect the rich paleontological resources located there. Many fossils from BLM's public lands are currently on display in museums around the country. These fossils remain pivotal in our understanding of life on our planet and many scientific concepts related to evolution and environmental change come from paleontological resources found in the West. Safeguarding the scientific and educational values, as well as promoting public benefit and enjoyment of these resources is key to BLM fossil resource managers. The BLM has a mandate to protect and interpret heritage resources, including scientifically significant paleontological resources. In 2009, Congress passed the Omnibus Public Land Management Act, which includes the Paleontological Resources Preservation subtitle (PRPA). In this legislation congress recognized the value of and provides the authority to protect paleontological resources on public lands as a natural and irreplaceable part of America's heritage.

The BLM paleontology program ensures that appropriate plans are developed for the inventory, monitoring, and scientific and educational use of paleontological resources. The BLM manages these resources emphasizing interagency coordination and collaboration efforts with various partners, including the scientific community and the general public. In addition, as per current legislation, programs to increase public awareness about the significance of paleontological resources are being developed. For example in Wyoming, the BLM is establishing opportunities and updating existing programs and projects to highlight the world-class Jurassic dinosaur footprints at the Red Gulch Dinosaur Tracksite (RGDT) in the Bighorn Basin. These include the development of interpretive signage, a website, a Junior Explorer Booklet, and a podcast. The RGDT is one of the premier public paleontology sites currently managed by the BLM and is being used as an example in the development of other publically interpreted tracksites around the country.

The Red Gulch Dinosaur Tracksite is the most thoroughly documented dinosaur tracksite in the world. The RGDT lies along the Red Gulch/Alkali National Backcountry Byway in the Bighorn Basin of northern Wyoming. Here over 1000 Middle Jurassic dinosaur tracks are preserved in a limestone surface exposed at the bottom of a dry wash, representing a time when a large community of meat-eating dinosaurs walked across an ancient tidal flat 167 million years ago. This site provides unique evidence of gregarious behavior in meat-eating dinosaurs of various ages. In addition, the RGDT was used by the BLM in pioneering state-of-the-art techniques for digitizing paleontological resources utilizing stereo photos (e.g., photogrammetry). These techniques are currently used around the world. The BLM and is actively developing, testing, promoting, implanting photogrammetry as a proper documentation procedure related to the preservation and management of paleontological resources on public lands using scientific principles and expertise.

As the RGDT is BLM Wyoming's primary, public, paleontological site, it has been developed for public visitation with picnic structures, a boardwalk, interpretive signs, and restroom facilities; which make it an excellent outdoor classroom to teach the public about paleontological resources and their proper management. This site provides a wonderful opportunity for "Middle Jurassic Explorers" to practice their fossil footprint sleuthing skills. The RGDT is an Area of Critical Environmental Concern managed by the BLM Worland Field Office for recreational, educational, and scientific uses. The site is valuable in that it allows the public to see and experience public paleontological resources in an outdoor setting. One of the most engaging and exhilarating aspects of this site, is the opportunity for the public to walk along the footsteps of prehistoric beasts. Being able to discover and observe firsthand the dynamics of extinct animal activities and behavior is certainly a unique experience.

Following on the successes of paleontology podcasts done at various sites in Colorado, Utah, and New Mexico, the BLM has found podcasts to be an effective method for providing information about its resources and enticing the public to visit and learn about paleontological resources.

The RGDT Podcast was completed for National Fossil Day on Oct. 16, 2013 and is available for download from the BLM's YouTube site. The focus of the podcast is to

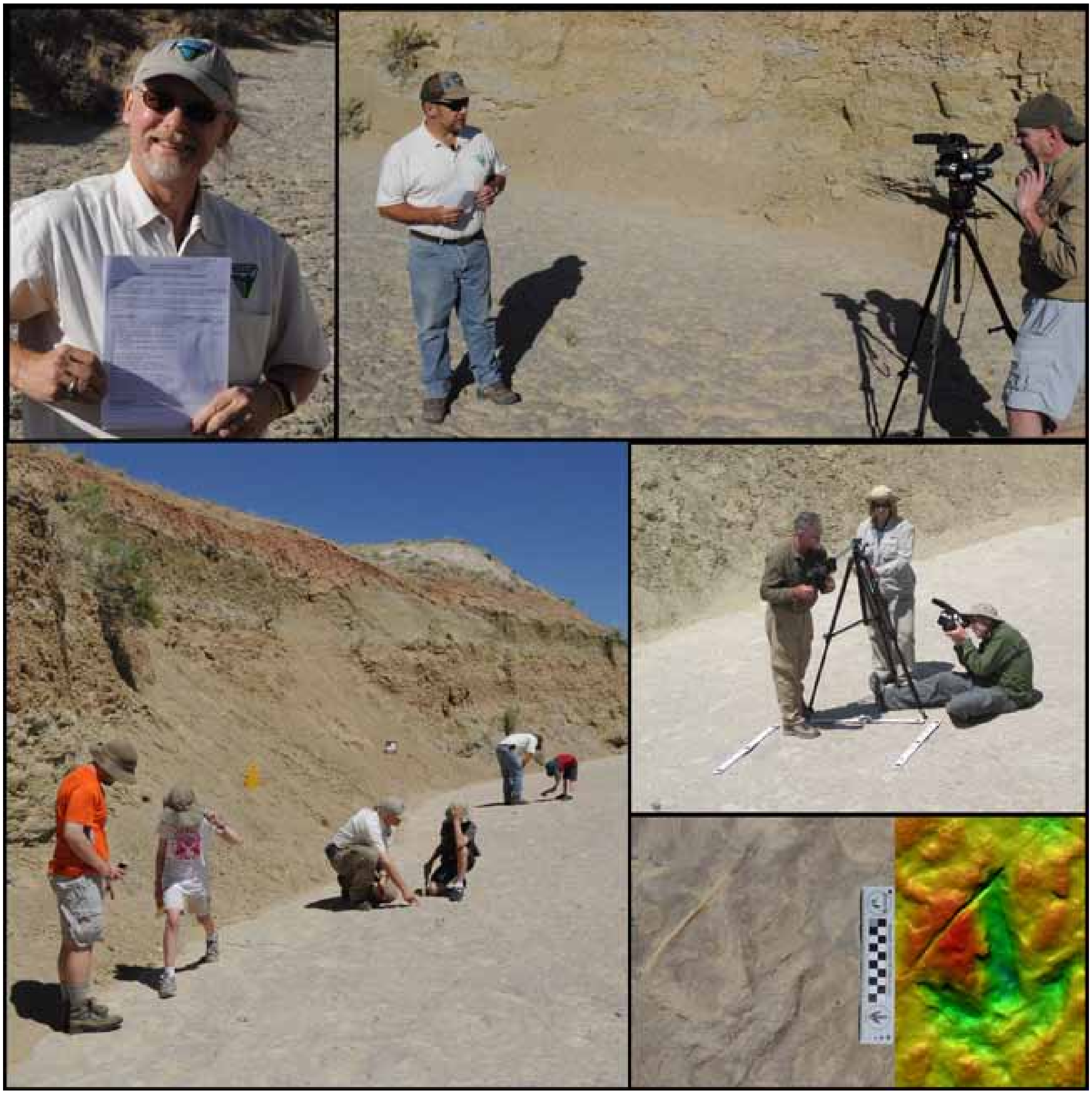

FIGURE 1. Images related to the Red Gulch Dinosaur Tracksite (RGDT) Podcast Project. Clockwise from upper left: Script and safety plan for podcast filming; District Manager Steve Dondero on camera with Randy Hayes filming; Tommy Noble, Neffra Matthews showcasing photogrammetric documentation techniques with Randy Hayes filming; RGDT theropod footprint (i.e., *Carmelopodus*) photo (left) and color contour orthophoto (right); and BLM staff members showing visitors at the RGDT the steps and strides of dinosaurs.

highlight the educational and recreational opportunities at the RGDT. Contents include a brief discussion of track and trackway formation, as well as highlighting the technology used at the site. Close-range photogrammetric documentation of the RGDT was conducted using both ground-based and low-altitude aerial imagery. These images and 3D data not only form the basis for maps of the site, but also enhance the interpretation by providing virtual renderings of footprints and trackways in the podcast. BLM personnel from the Wyoming State Office, Wind River/Bighorn Basin District Office, Worland Field Office, and the National Operations Center in Denver were intimately involved with the development of the podcast and also provided on-camera talent. They gave evocative descriptions of what can be seen and learned by visiting the track-site. In addition, BLM personnel with their families and actual visitors to the site participated in the video shoot, which accentuated the interactive nature of a visit to the locality. The podcast: a) encourages interaction both with family members and friends, as well as with the site and surroundings; b) highlights the paleontological resources (fossil footprints) and provide information on the importance of the site; c) provides information on how the fossil footprints were formed and how they relate to our scientific understanding of Jurassic life; d) encourages resource preservation and protection; and e) provides information on the location and how to travel to the site, as well as site etiquette, and how to enjoy and be safe at the site. Finally, the podcast encourages the public to learn more paleontological resources on public lands, which are natural and irreplaceable parts of America's Natural Heritage. Hopefully, it will be an effective tool for presenting the uniqueness of the RGDT and encourage the public of all ages to explore the paleontological wonders of America's Great Outdoors.

KEYWORDS: Podcast, Paleontology, Wyoming, Red Gulch Dinosaur Tracksite, Education/Outreach

POSTER PRESENTATION

+EFFICIENT PALEONTOLOGICAL RECORD-KEEPING: WHAT'S THE BEST APPROACH?

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ABSTRACT—All of our responsibilities to properly record, manage, and protect fossil resources on Federal lands have greatly increased as paleontological resources have become the focus of federal laws and regulations in the last several years. In 2007 the Bureau of Land Management adopted the Potential Fossil Yield Classification (PFYC) system, formalized requirements for paleontological inventories ahead of approving federal undertakings, and in 2009 the Paleontological Resources Preservation Act (PRPA) was passed. Land management agencies now have new responsibilities to manage paleontological resources; and institutions and researchers now have new responsibilities to share the information they gather with those agencies. All of us would be wise to adopt logical and efficient ways to organize and store information on fossil resources. Agencies will be tasked with developing new organizational systems, and institutions and researchers would be wise to be involved in devising those systems. In the end, we believe the ideal would be a system which allows all of us to easily and efficiently access the information and collections necessary for research and management. We, the authors of this poster board, believe we can help paleontologists in the development of organizational systems for fossil resources. As archaeologists, we have been responsible for managing archaeological resources and information for decades. Over those years, we have learned about good and bad ways to organize the various types of information we receive: site forms, inventory reports, data recovery plans, excavation reports, inventory and excavation permits, and so on. We feel that the system we are now using is efficient and provides an easy way to manage archaeological information. We also feel that our system allows for qualified researchers to efficiently access that information for their own needs, while maintaining confidentiality so the general public or potential looters do not have access to sensitive information. Over the last several decades, we have also been responsible for managing paleontological resources on public lands under the Federal Land Policy and Management Act (FLPMA). Having dealt with both archaeological and paleontological resources, we have seen that the management requirements for each resource type are actually quite similar. Because of this fact, we are now proposing that paleontologists borrow from our own experience in developing a logical and efficient system for listing and organizing paleontological information. We will attempt to show the following: (1) How a standardized locality numbering system can greatly simplify how information from a particular locality is accessed and stored, and how collections from a particular locality are organized and stored. We will show how the standardized Smithsonian Site Numbering System, used by almost the entire nation, simplifies how archaeological site information is managed and stored, and simplifies how collections from those sites are managed and stored. We will also show how using other less logical site numbering systems, such as Arizona's, can cause confusion and delays in organizing, storing, and accessing site information. We will then show how a numbering system like the Smithsonian Site Numbering System could be a good model to be followed by paleontologists as well; (2) How a standardized report numbering system can greatly simplify how project information is organized and stored. We will show how the standardized Wyoming report numbering system, used by all BLM offices in Wyoming, simplifies how reports on inventory, testing, and excavation projects are organized, stored, and accessed. We will also show how other less logical report numbering systems can cause confusion and delays in organizing, storing, and accessing project information. We will then show how a report numbering system like that used by the BLM in Wyoming could be a good model to be followed by paleontologists as well; and (3) How a standardized filing system can greatly simplify how the information on both localities and projects is accessed, used, and stored. We will show how the standardized Wyoming report and site filing system, used by most BLM offices in Wyoming, simplifies how project and site information is organized, stored, and accessed. We will also show how other less logical filing systems can cause confusion and delays in organizing, storing, and accessing project and site information. We will then show how a standardized filing system like that used by BLM in Wyoming could be a good model to be followed by paleontologists as well. Adoption of the above systems, as useful as they could be, will of course have some downsides. To this end, we will explain how these standardized numbering and filing systems will require a centralized database (or databases) to ensure that the system works smoothly.

Furthermore, if the paleontological community also desires to have a central repository for paleontological information, and even collections, we will show how this was done for archeological resources in Wyoming, and how it required institutional and governmental buy-in. We feel adoption of the systems describ ed above will facilitate data sharing amongst paleontological researchers and managers. Having seen these systems developed for archaeological resources and having enjoyed the subsequent benefits, we recommend an immediate adoption of similar systems for paleontological information.

KEYWORDS: Record keeping

POSTER PRESENTATION

*+VERTEBRATE PALEONTOLOGY AND STRATIGRAPHY OF THE LATE CRETACEOUS HOLMDEL PARK SITE, MONMOUTH COUNTY, NEW JERSEY

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ABSTACT—The New Jersey State Museum and the County of Monmouth have successfully partnered in the study of two exceptional fossil sites, Ellisdale and Holmdel Park. The County owns the tracts in question, provides a permit system, and retains ownership of the fossils (primarily in order to determine the proper repository). The Museum conducts field studies and makes the collections, serves as repository, performs research, and provides interpretive and education information, making specimens available for exhibition. The Ellisdale Site, recently featured in many technical papers at a symposium of the Society of Vertebrate Paleontology, is especially noted for pioneering studies on fossil mammals of Cretaceous age in the eastern North American subcontinent. The methods and permit systems developed for the Ellisdale Site are now being applied to the Holmdel Park Site, the subject of this summary report. More than sixty taxa of fossil vertebrates have been recovered from this site, and the project is on-going.

KEYWORDS: New Jersey, Late Cretaceous

ORAL PRESENTATION

UTILIZING NATIONAL PARKS AND BUREAU OF LAND MANAGEMENT LANDS FOR A TWO WEEK COMMUNITY COLLEGE FIELD GEOLOGY COURSE -IT'S LIKE HERDING CATS!

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ABSTRACT—Many community college students must balance work and family with their academic priorities. And many have not had the experience of travelling far beyond their local environment. More than eight million (or 45%) of all undergraduates are enrolled as full-time students at 1,132 community colleges. Only 17% of those institutions offer a geoscience program. Field based geology courses at community colleges are even rarer. St. Louis Community College has a strong geoscience program with three full-time and seven adjunct faculty. We make a special effort to identify students with the desire and aptitude to pursue a degree and career in geosciences. Starting in 2009 the College offered a two week, three credit, introductory course in field geology (GEO 123 Geologic Field Experience in North America). More than thirty students have taken the course with approximately 40% moving on to pursue a degree in geoscience at the university level. The other 60% had the vacation of a life-

GEO 123 GEOLOGIC FIELD EXPERIENCE IN NORTH AMERICA

3 CREDITS (2 LAB, 1 LECTURE)

Figure 1

Strike and Dip: Denver, Colorado

Figure 2

Columnar Basalt: Yellowstone N.P.

Figure 3

Snow Creek Paleoecology Project: Montana "Badlands"

Figure 4

Excavating Dinosaurs: Montana "Badlands"

Figure 5

time! Offering a field geology course presents challenges for both the student and institution. For the students it is cost and time away from their summer jobs. For the institution it is cost and logistics. All trip costs, excluding tuition, are included in the trip fee of approximately $1,500 per student. A bargain at approximately $100/day considering we stay in motels (the professor is too old to camp out anymore), eat most evening meals in restaurants, rent at least one van and pay for 4,000 miles worth of gas. The course consists of a loop starting in St. Louis and heading west through the Rockies, the Tetons, Yellowstone, Montana, South Dakota, Nebraska and back to St. Louis. The focus is on the geologic history of western U.S. and the paleontology of eastern Montana. Evening lectures prepare the students for the next day's activities. Students research specific topics and give short presentations to their colleagues. They learn basic geologic measuring and mapping skills, participate in an ongoing research program and help prospect for and excavate dinosaurs in the Hell Creek Formation of northeast Montana. For most of the students who have never ventured beyond their home base it is an eye-opening experience. Those that continue their studies in geoscience gain valuable experience and an advantage in the more in-depth and required field courses offered at a four year institution.

KEYWORDS: Community College, Geologic Field Course, Tetons, Yellowstone, Hell Creek Formation

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POSTER PRESENTATION

+GEOCHEMICAL ANALYSIS OF FOSSIL BONE FROM BADLANDS NATIONAL PARK: A TEST OF THE RARE EARTH ELEMENT FINGERPRINTING METHOD TO COMBAT FOSSIL POACHING

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ABSTRACT—Prosecution of individuals who have poached fossils from Federal lands is often precluded because, unless they are caught in the act, the source (provenience) of the fossil cannot be readily proven. During fossilization, vertebrate remains incorporate trace elements and isotopes from groundwater and surrounding sediments (e.g., Trueman and Benton, 1997), the concentrations and patterns of which may be distinctive enough to allow the origin of a poached fossil to be determined. In this study, vertebrate fossils collected from Badlands National Park were chemically analyzed to determine whether distinct geochemical signatures could be used as a tool to combat fossil poaching.

Previous research has shown that fossils from different locations and geologic ages preserve unique, statistically distinct rare earth element (REE) signatures that are a function of local burial conditions and depositional environments (e.g. Metzger et al., 2004; Suarez et al., 2007; Grandstaff and Terry, 2009; Lukens et al, 2010). To test the hypothesis that geochemical signatures imparted to the bones during fossilization will be unique to temporally and geologically diverse locations, in situ fossil bones were collected by pedestrian survey in Badlands National Park from four sites in the Paleogene Brule and Chadron Formations (Figures 1, 2): Chamberlain Pass (CP), Sheep Mountain Table (SMT), Old Northeast Road (ONR), and Doors and Windows Overlook (DWO). These sites represent a mixture of age, depositional environments, and taphonomic states.

Bone samples were prepared according to methods of Suarez et al. (2007) and Grandstaff and Terry (2009) and analyzed by inductively coupled plasma-mass spectrometry (ICP-MS). Bones were sampled throughout their entire cortical layer to obtain a complete rare earth and trace element signature. Rare earth element (REE) concentrations were normalized to the North American Shale Composite (NASC) of Gromet et al. (1984) and plotted for visual analysis of geochemical signatures for each site. REE signatures of bones within each specific site were similar, but varied between sites.

Representative signatures from each site are shown in Figure 3. Because bones from a single site may incorporate different amounts of REE, differences in REE concentrations in these representative bone signatures (Figure 3) are not significant. Bones from ONR and DWO are light- (LREE) and middle- (MREE) REE enriched, with greater normalized concentrations (e.g., La to Gd) compared to heavy-REE (HREE) (e.g., Ho to Yb) and small positive Ce anomalies. In contrast, bones from CP and SMT are strongly depleted in middle REE (e.g. Nd to Gd). Most bones from these sites also have slight negative Ce anomalies (Figure 4).

The REE signature of SMT (floodplain) differs significantly from the Brian Maebius Site (channel/oxbow) sampled by Metzger et al. (2004), although both sites are stratigraphically located within one meter of the Hay Butte Marker Bed (HBM) (Figure 2). Visually, REE signatures of bones from SMT are similar to those from CP, and signatures from DWO are similar to ONR; however, signatures from CP and SMT differ greatly from DWO and ONR. The DWO and ONR sites are within the same stratigraphic interval in the Poleslide Member (Figure 2)

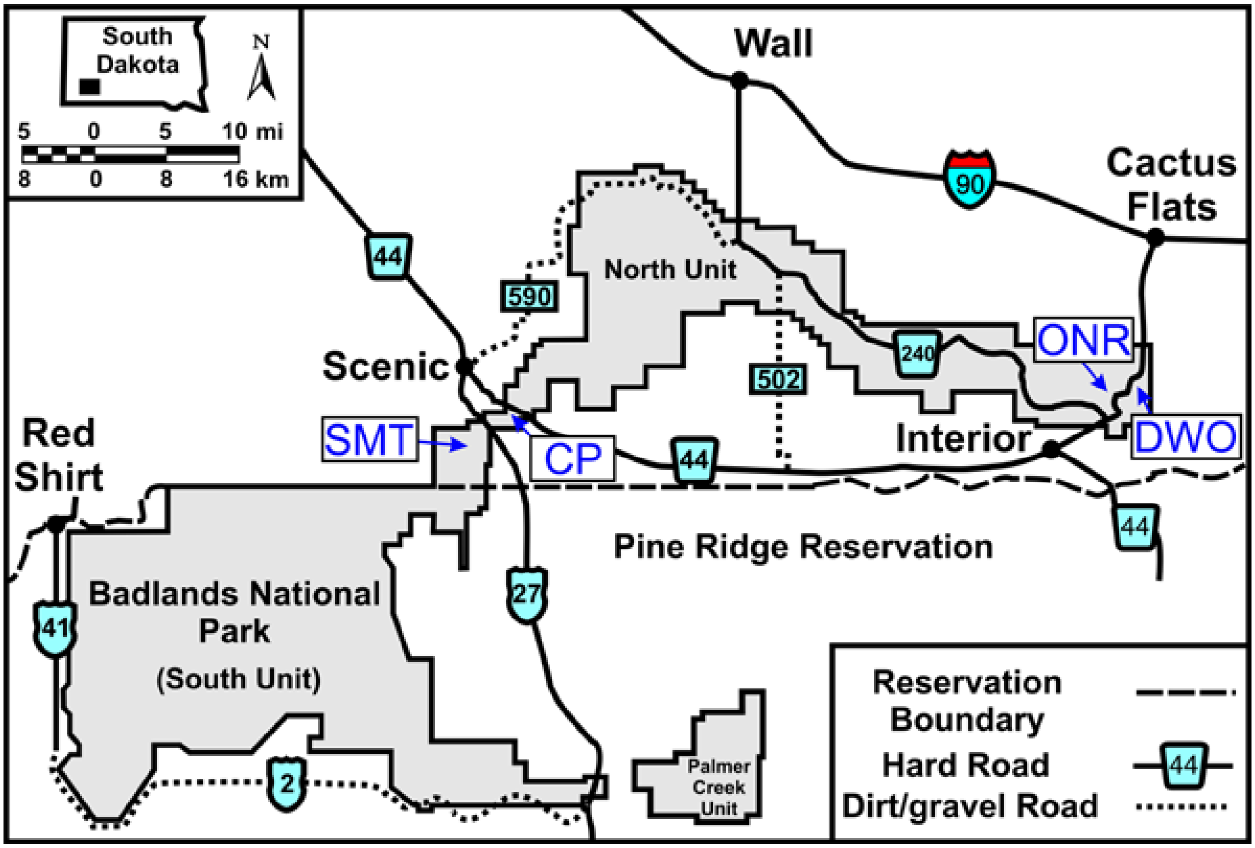

FIGURE 1. Location map of sampled localities within Badlands National Park, SD. .

and are separated by only about 1 km. Therefore, sedimentologic and paleo-environmental conditions affecting the REE signatures were likely very similar. CP and SMT are close stratigraphically (Figure 2), but separated by an unconformity that removed up to 1.5 million years in places between the Chadron and Brule Formations (E. Evanoff in Benton et al., 2007).

Bones were also analyzed for uranium and cerium. U concentrations and U/Ce ratios in bones from CP and SMT were much greater than those from ONR and DWO (Figure 4). ONR and DWO bones contain low U (<150 ppm) and positive Ce anomalies while CP and SMT bones contain high U (250 - 1100 ppm) and negative Ce anomalies. Discriminant analysis was able to statistically distinguish fossils from the ONR and DWO sites from those collected at SMT and CP based on U concentrations and the Gd/Ho ratio. However, fossils from within those paired sites could not be distinguished. This preliminary data set, paired with the small archive of previous data (e.g. Metzger et al., 2004), are the building blocks for a forensic geochemical analytical database. Our data suggest that unique REE signatures of fossil bone can be used to help determine the provenience of poached fossils.

ACKNOWLEDGEMENTS

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KEYWORDS: Rare Earth Elements, Prosecution, Chemical signatures

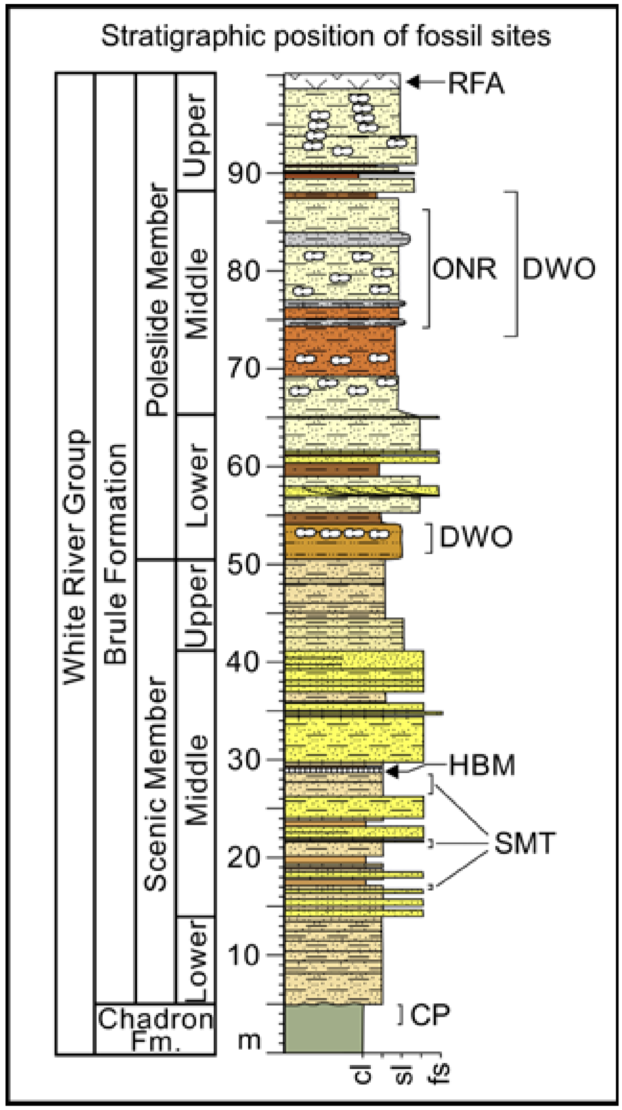

FIGURE 2. Stratigraphic column of Paleogene White River Group in Badlands National Park, South Dakota. HBM = Hay Butte Marker Bed, and RFA = Rockyford Ash Layer. Modified from data of Evanoff in Benton et al. (2007, 2009).

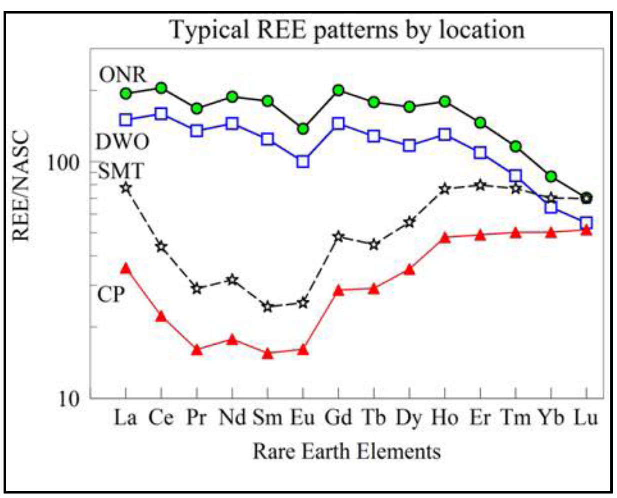

FIGURE 3. Example of NASC-normalized REE concentration by location. ONR and DWO show LREE and MREE enrichment relative to HREE. CP and SMT show LREE and HREE enrichment relative to MREE. CP shows a more dramatic enrichment of HREE relative to LREE than SMT.

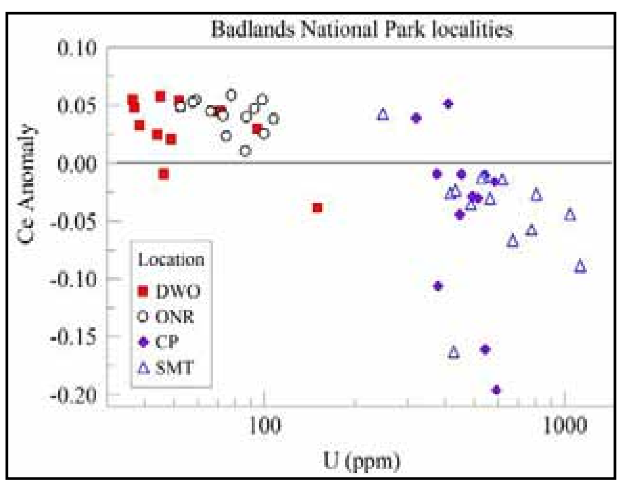

FIGURE 4. Ce anomalies plotted against U show distinct groupings by location .

POSTER PRESENTATION

+PROYECTO DINOSAURIOS – ENGAGING UNDER-REPRESENTED STUDENTS IN PALEONTOLOGICAL RESEARCH

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ABSTRACT—Community colleges are key targets to mitigate the severe under representation of ethnic minorities in the geosciences. Proyecto Dinosaurios is a National Science Foundation-funded project of the Opportunities for Enhancing Diversity in the Geosciences (OEDG) program that aims to build a network of cooperation between community colleges in Los Angeles and the Dinosaur Institute, using the appeal of dinosaurs to engage under-represented undergraduates in geoscience research. Proyecto Dinosaurios successfully recruited seven minority community college students, each of whom conducted an independent research project, presented their results at a local conference, and participated in numerous field expeditions throughout the American West. Today, all participants have continued their undergraduate education and either have transferred or plan to transfer to a 4-year school, with the majority majoring in a STEM field. Some students have also continued on to graduate school or careers in the geosciences. Proyecto Dinosaurios was recently selected as a Best Practices program by the National Science Foundation.

KEYWORDS: Ethnic minorities, community colleges, geosciences, research

ORAL PRESENTATION

UNIVERSITY OF CALIFORNIA MUSEUM OF PALEONTOLOGY LOCALITY DATABASE—A NEW PORTAL FOR ACCESSING NATIONAL PARK SERVICE INFORMATION

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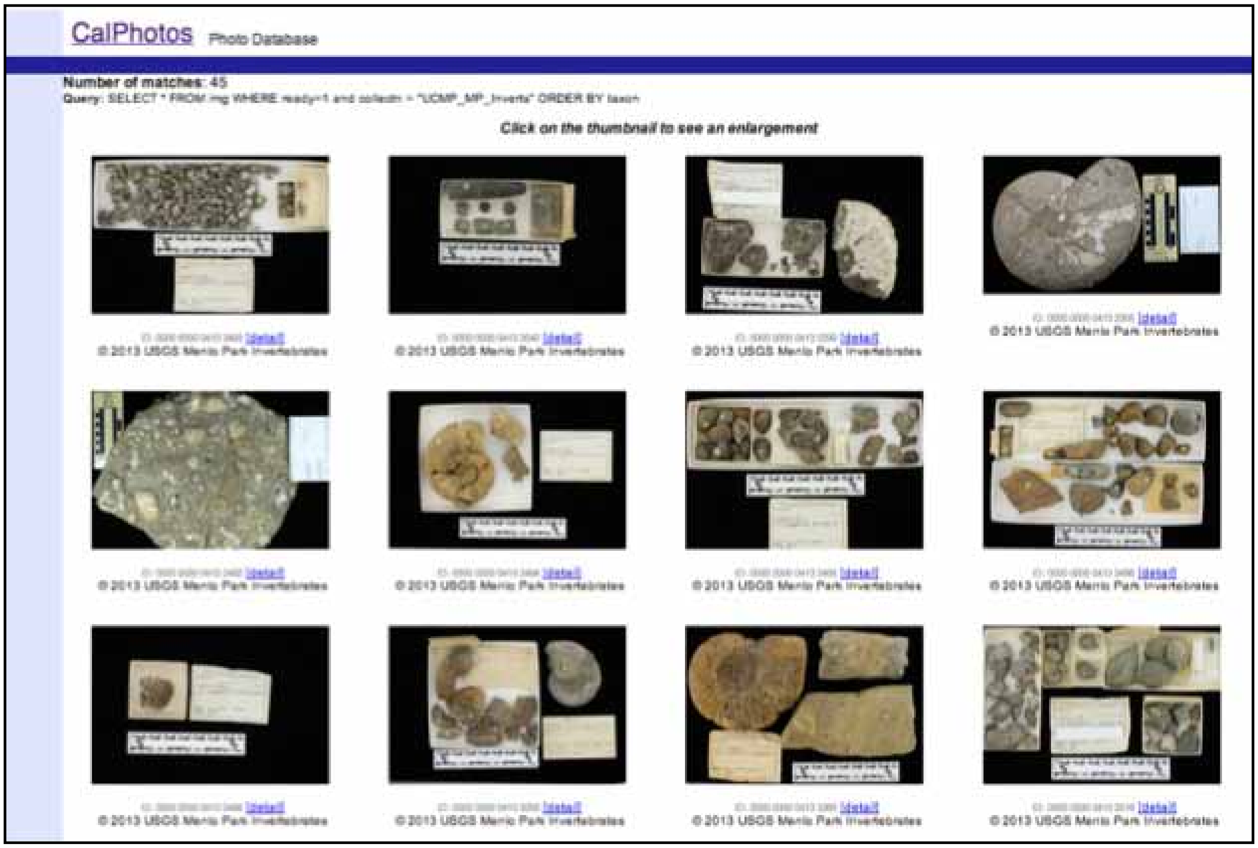
ABSTRACT—The University of California Museum of Paleontology (UCMP) and the National Park Service Pacific West Region recently began a collaborative project to make locality information available to parks for natural resource management. This involved building a portal in the UCMP Locality Database (http://ucmpdb.berkeley.edu/loc.html) to allow selected National Park Service staff to view full locality records. The portal provides a browse list by state and park, as well as the ability to text search each field in the locality record. Localities are added to the portal by comparing park boundary maps with georeferenced localities, as well as through text searches for popular park destinations. The initial effort to populate the portal is an extension of an on-going NSF-funded project to rehouse and digitize part of the former US Geological Survey (USGS) Menlo Park Invertebrate Collection, donated to and housed at UCMP in Berkeley, CA.

For about half a century, the USGS staff at Menlo Park built a unique and irreplaceable collection of 170,000 fossils from ca. 20,000 localities from western North America. With earlier NSF support, 1998-2000, material from the ~13,000 Alaskan and Arctic localities were integrated into the UCMP collection on the Berkeley campus. The portion of the collection currently being rehoused consists primarily of Neogene mollusks from California, Washington and Oregon, with select Mesozoic faunas, from ~7000 localities. As fossils are rehoused into acid-free paper trays, their records are added to the UCMP database. Rehoused specimens are photographed in a LED-lit light box using a digital SLR camera. The light box facilitates rapid processing of high-resolution photographs taken by undergraduate students and volunteers. These photographs are added to CalPhotos (http://calphotos.berkeley.edu/) and attached to the online locality records. Many of the USGS localities occur in or near park service areas, for example, Channel Islands National Park and the Santa Monica Mountains National Recreation Area. Providing information about fossil occurrences to park staff enhances a number of park operations, including assessing the impact on localities during ground disturbing activities and facilitating field surveys to re-locate sites for future monitoring. By partnering with the National Park

Service, UCMP may also be able to provide relevant fossils or casts for interpretive programs or exhibits. Parks may wish to notify UCMP in the event of future fossil discoveries. UCMP staff can provide expertise in excavation, stabilization or other administrative actions parks may wish to undertake. Building collaboration between the park service-administered areas of the Pacific West Region and UCMP, as initiated with this locality portal, will continue to improve the management of fossils within the museum and those that remain in the field.

KEYWORDS: museum collection, collections database, National Park Service, University of California Museum of Paleontology (UCMP), invertebrate fossils



ORAL PRESENTATION

FOSSIL CYCAD NATIONAL MONUMENT: A GEOLOGIC STORY

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ABSTRACT—The National Park Service Geologic Resources Division recently digitized a 1957 USGS Mineral Investigations Field Studies Map MF-70 entitled "Preliminary geologic map of the southwest part of the Minnekahta quadrangle, Fall River County, South Dakota" that shows the location of Fossil Cycad National Monument and the corresponding geology. Coincidently this is the same year that the monument was deauthorized; 35 years after it was proclaimed in 1922. This map will be a useful tool in examining the former location of the deauthorized monument as well as pinpointing the locations of the now lost paleontological resources. The map is now GIS based and can be used to overlay with Google Earth images of today's landscape as well as other historical imagery to better understand the science of the abolished Fossil Cycad National Monument. The history of Fossil Cycad provides an important lesson to be learned about our geologic heritage, both good and not so good.

KEYWORDS: Fossil Cycad National Monument

ORAL PRESENTATION

LOCATING HISTORICAL PHOTOGRAPH SITES AS AN AID TO NATURAL RESOURCE MANAGEMENT

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ABSTRACT—After the Civil War and into the early Twentieth Century, the early geological and paleontological surveys included photographers that recorded the landscape and places of geologic and paleontologic interest. The locality information that the early geologists and paleontologist recorded was very generalized considering that they had no detailed topographic maps, aerial photographs, or (of course) GPS units as we have today. Photography in the early days was a very laborious and time consuming task.

For example, William Henry Jackson, photographer with the Hayden Survey in the 1870's, was proud to actually take 16 photographs in a day. However, the photographs that were taken are a valuable resource of what specific areas they visited, where they made their geologic observations, and where they collected important fossils. Many of the historic photographs from these expeditions are now available online through such organizations as the U.S. Geological Survey, the National Park Service, and the American Museum of Natural History. Once copies of the original photographs are gathered, the photographed sites are located on the ground using knowledge of the overall field areas gained from past field experience and historical descriptions. Once the general areas have been determined, we search the areas with paper copies of the historical images looking for prominent features in the

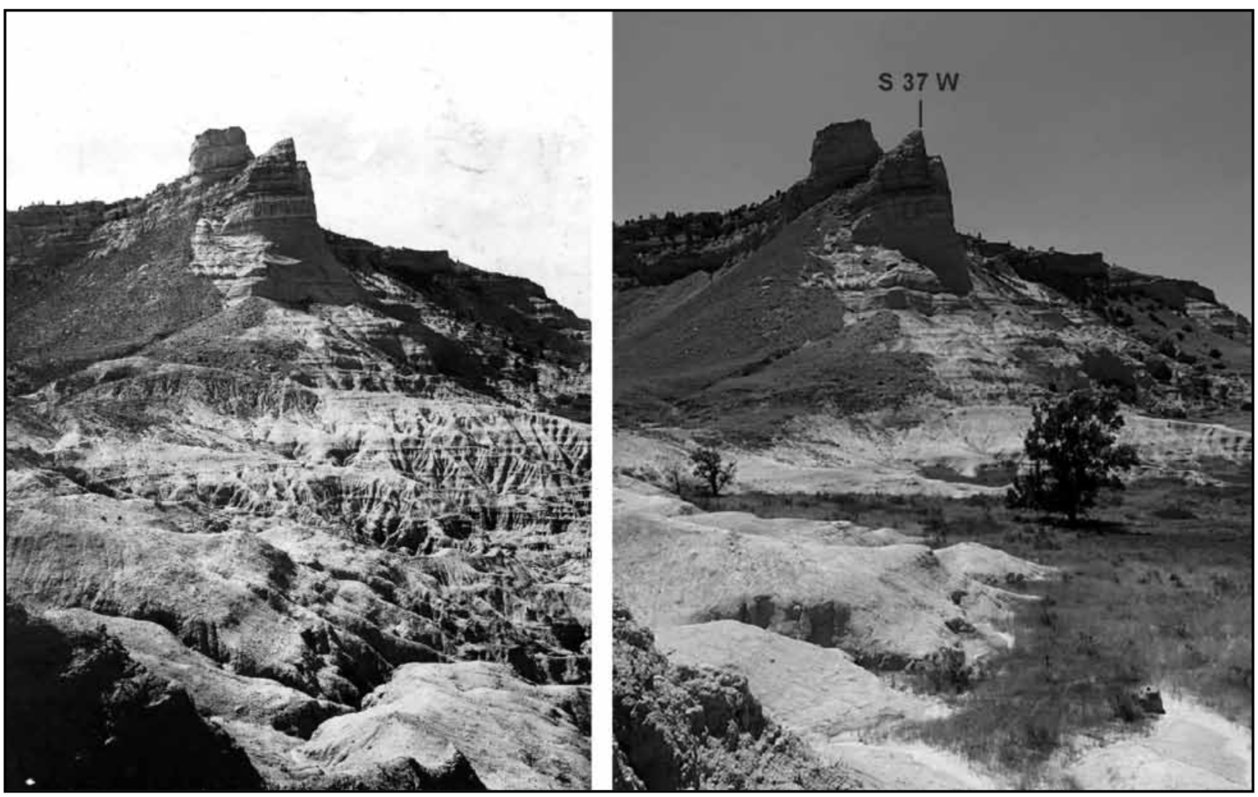

FIGURE 1. Comparative images of the north side of Scotts Bluff, Nebraska. The photograph on the left was taken by N. H. Darton of the U.S. Geological Survey in about 1900 (USGS Photo DNH 350). The image on the right was taken at 1:20 PM, 16 July 2013 at the same spot. Between the intervening 113 years, the extensive badlands shown in the Darton photo have been filled by sediment accumulating behind the Gering water ditch that was built in 1903. Notice the increase in the number of trees and grass on the bluff and alluvial fill since 1900. The photograph site is located in Scotts Bluff National Monument at 41° 50.628' N, 103° 41.694' W. (WGS84 datum).

landscape that can be matched to the original photograph.

Finding the exact sites often takes much shifting of viewpoints to match features in the foreground and in the background, but locating a photo site is very satisfying, resulting in an "Aha" moment. Views of the original photographic image are duplicated by modern digital cameras, typically using a wide angle lens ranging from 18 mm to 25 mm covering a slightly wider area than the original photograph. The date and time of day of the new image is recorded, along with GPS readings of the site (in latitude/longitude and UTM coordinates), and the azimuths of prominent features on the landscape horizon or in the midground from the photo sites are measured using a Brunton compass. Multiple images from slightly different angles can also be taken to make photogrammetric analyses of the images. The sites are also recorded on topographic maps in the field and these locations are then checked in the office using modern topographic map data bases and the GPS data.

Many kinds of information can be gained from locating historical photographic sites. As mentioned above, areas where paleontologists collected new taxa for the first time can be documented. Often the photographer took images of the campsites that can be located which may contain artifacts (such as empty cans). These campsites are historic archeological sites. In many places the main differences between the historic and modern landscapes are in the vegetation, providing information concerning biotic changes over the past century. Finally, using either photogrammetric or LIDAR techniques at the actual photographic sites can be used to determine century-long erosion rates of badland exposures or depositional rates of modern streams and slope wash. Our work has been in the Bridger badlands of southwest Wyoming, in Badlands National Park in South Dakota, and at Scotts Bluff National Monument in Nebraska. We have been working closely with NPS and Bureau of Land Management resource managers on this project by providing detailed locality information of the photograph sites.

KEYWORDS: Historic photography

ORAL PRESENTATION

*ARROYO DEL VIZCAÍNO, URUGUAY

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ABSTRACT—Found in 1997 during a severe drought, the Arroyo del Vizcaíno site is a rich fossiliferous Pleistocene locality in a stream near the town of Sauce, Uruguay that is usually covered by water. Some of the bones show marks with the features of those made by human tools. Radiocarbon dates yielded an unexpectedly old age, ca. 30,000 years before present, which makes it the oldest age for a site with human evidence in the Americas. Apart from its scientific importance, several activities are in progress or planned to share knowledge of the site with the general public. They include creation of a museum, in which the recovered material will be kept and exhibited, but will also serve as a place of research and cultural events. Also, a project is being developed to involve the local high school students (and, through them, also their families) to expand community awareness of the value of the discovery, both in terms of its contribution to scientific knowledge and as an important part of their cultural heritage.

ORAL PRESENTATION

MULTI-YEAR PALEONTOLOGICAL MITIGATION AT THE KETTLEMAN HILLS LANDFILL—CHALLENGES, OPPORTUNITIES AND PRELIMINARY RESULTS

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ABSTRACT—This presentation will summarize the challenges, opportunities, and present some preliminary results of 12 years of paleontological mitigation at the Kettleman Hills Landfill (KHL) located in the Kettleman Hills near Kettleman City in the Central Valley of Northern California. Since the early 1900s, when the Kettleman Hills area became an important oil and gas-producing region, this area has received extensive geological and paleontological investigations resulting in the discovery of numerous invertebrate, vertebrate, and plant fossil localities, including several within the footprint of future cells of the expanding landfill. Consequently, Kings County (the lead agency for environmental compliance) required KHL to implement a paleontological mitigation program

to preserve a representative sample of the fossils being destroyed by landfill development.

The stratigraphy impacted by KHL excavations includes both the San Joaquin Formation and the Tulare Formation. The middle to late Pliocene San Joaquin Formation is a thick sequence of mostly marine claystones, siltstones, sandstones, and conglomerates that have been informally divided into five zones based primarily on invertebrate fossils. The most common fossils found in the San Joaquin Formation are invertebrates, including echinoids (sea urchins, sand dollars, and brittle stars), mollusks (clams and snails), bryozoans, tubeworms, corals, ostracods, and barnacles. Also present, but much rarer, are the bones and teeth of both terrestrial and marine vertebrates, including those of mammoths, mastodons, camels, horses, beaver, whales, porpoises, seals, sharks, rays, turtles, birds, and various fishes. Plant fossils reported from the San Joaquin Formation include leaves, wood, and diatoms. The late Pliocene to early Pleistocene Tulare Formation is composed of siltstones and sandstones that are primarily non-marine in origin. The Tulare Formation has produced fossils of land mammals in the past, including mammoths, mastodons, camels, horses, tapirs, deer, elk, ground sloths, coyotes, gophers, mice, and squirrels. The Tulare Formation also contains the largest fossil fauna of fresh-water mollusks in California. Plant fossils include leaves, wood, pollen, spores, and diatoms. For interpreting the paleoenvironment, these stratigraphic units are unique because they contain such a wide variety of both animal and plant fossils.

To protect these paleontological resources from impacts caused by KHL excavations, the professional standards established by the Society of Vertebrate Paleontology (SVP 1991, 1995, 1996, 2010) have been followed. Implementation of these mitigation measures has reduced the adverse impacts on paleontological resources to an insignificant level by allowing for the recovery of fossil remains and associated specimen data and corresponding geologic and geographic site data. The recovery and study of the salvaged fossil remains have helped answer some important questions regarding the stratigraphic distribution of some taxa, their age, paleoenvironment, and depositional setting. In addition, the fossils collected have contributed important information for reconstructing the geological and paleobiological history of central California.

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ORAL PRESENTATION

*THE FEDERAL MANDATE FOR MITIGATION PALEONTOLOGY

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ABSTRACT—Mitigation paleontology is a subdiscipline of paleontology that attempts to preserve paleontological resources and associated data where they would otherwise be lost to land use actions including land use development, mineral extraction, or land status adjustments. In recent years this is the only area of paleontology where employment has expanded. However, the business of mitigation paleontology also follows the same boom-bust cycle that is associated with the development of natural resources on America's public lands. Mitigation paleontologists develop technical reports that allow agencies to make scientifically informed land use decisions. Laws that govern mitigation paleontology on public lands include the National Environmental Policy Act of 1969, the Federal Land Policy and Management Act of 1976, and the Paleontological Resources Preservation act of 2009. Assessing the potential effects to paleontological resources prior to land-disturbing activities and mitigating those effects during and after activities requires a combination of paleontological knowledge and field experience. Not all paleontologists are trained or prepared for this type of work, and non-paleontological specialists are rarely educated in recognizing both the identity and paleontological significance of fossils. This is why it is critical that all aspects of mitigation paleontology be carried out by experienced mitigation paleontologists. When done correctly, mitigation paleontology anticipates future research needs; preserves some of the original paleontological context through technical reports, salvage of specimens, and the production of pre-work photos and maps; and allows agencies to successfully manage paleontological resources using scientific principles and expertise.

ORAL PRESENTATION

FOSSIL CYCAD NATIONAL MONUMENT: PRESERVING THE HISTORYOF A FORGOTTEN TREASURE

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ABSTRACT—The Fossil Cycad National Monument located near Hot Springs, South Dakota was created in 1922 by President Warren G. Harding from land donated to the government by Dr. George R. Wieland of Yale University. By 1957 at the monument's deauthorization, all the fossil cycads were gone (at least ones that were visible) scattered around the country and world in museum and university collections. The museum envisioned by Wieland to stand on the monument site to house all of the cycads and the information derived from them failed to materialize. With no centralized location available to store these data, and with the death of the Fossil Cycad's only champion George Wieland in the 1950s, photographs, maps, specimens, and articles were soon scattered, misplaced, lost, or forgotten. An effort has been undertaken to "recollect" the monument's information, history, and data into a coherent collection that preserves the history of this forgotten treasure. A database, a sort of virtual museum, has been constructed containing copies of all known documents, letters, articles, photographs, fossil specimen information, maps, and scientific information related to the Fossil Cycad National Monument.

KEYWORDS: Fossil Cycad National Monument

ORAL PRESENTATION

ADVENTURES IN PALEONTOLOGY: USING BLM LANDS AND FOSSILS TO CREATE UNIQUE LEARNING EXPERIENCES FOR THE PUBLIC

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ABSTRACT—The field of paleontology is an exciting endeavor that appeals to children and adults alike. Dinosaurs are at an all-time high in engaging the public, and museums utilize this interest to stimulate life-long learning among their visitors. One way to impact hundreds of thousands of individuals utilizing fossils found on BLM land is through interactive exhibits and prep labs designed to engage museum visitors.

A more substantive means to impact on our public is through experiential field programs. During these programs participants assist in the process of finding and excavating fossils. We have found this means to be very successful with general public. However we have also found these programs to work with high school students who are in the career decision-making points in their lives and educators who use the experiences to become more comfortable in teaching paleontology and geology in their classrooms. Join us as we discuss how both exhibits and programs using fossils found on BLM lands are used to create meaningful experiences for general public, students, and educators.

KEYWORDS: Lifelong Learning, Authentic Experiences

ORAL PRESENTATION

*PRESERVING THE FALLS OF THE OHIO'S FOSSIL BEDS —A SUCCESSFUL INTER-GOVERNMENTAL EFFORT

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ABSTRACT—The Falls of the Ohio State Park was established as a partnership with the U. S. Army Corps of Engineers and other community organizations to preserve, protect and interpret the Devonian fossil beds, the largest of its type in North America with easy public access. It is located in the midst of a major metropolitan area and is used as an educational resource by schools and the public at large.

KEYWORDS: Falls of the Ohio

ORAL PRESENTATION

THE ROLE OF AN INTERACTIVE FOSSIL PREPARATION LAB IN CROWD SOURCING PALEONTOLOGICAL RESOURCE PRESERVATION

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ABSTRACT—Badlands National Park boasts 244,000 acres of rich, fossil-bearing sediments where the public can actively explore the striking deposits. While the park employs seasonal paleontologists to survey the land and recover the most significant specimens, it is extremely difficult to cover all of the needed territory. Annual surveys concentrate paleontological efforts in one chosen area of the park, usually restricted to a section or two. This is especially limiting due to the accelerated rates of erosion and exposure that occur each spring. For the first time in 2012, Badlands National Park opened an active, seasonal Fossil Preparation Lab, housed in the Ben Reifel Visitor Center. The original purpose of the Lab was to demonstrate the process of fossil preparation, but demonstration quickly evolved into something more: an interactive exchange between the lab staff and all who had an interest in paleontology, including many of the park employees. It provided an opportunity to educate the public regarding the importance of paleontology and the fossils found throughout the Badlands. The Lab elicited an unexpected enthusiasm from the visitors, evoking a feeling of stewardship to help protect both the fossil resource as well as the indispensable scientific information contained within the context of the rock. To that end, the park has long encouraged the reporting of any fossil find via a "Visitor Site Report," a form originally implemented by the Park Paleontologist. The form is available at every entrance station and the Visitor Center. In the past, most of the forms were completed and submitted by visitors with the hope of identification of their fossil discovery. However, once the Prep Lab opened, the importance of this form was stressed to visitors in a one-on-one setting, allowing the public to realize the significance of their contributions. As appreciation, the lab staff and the Resource Education interpreters established a display, "They Did the Right Thing," highlighting those individuals who took on the role of public steward. Here, pictures of the fossil and the person who discovered it were posted. As a result of more personal engagement with the public, the number of Visitor Site Reports submitted to the park experienced a sharp escalation, evidenced by a 300% increase from 2010 to 2013. Ultimately, this has led to the discovery, excavation, and preparation of several scientifically important specimens, expanding our knowledge daily of the White River Group fauna. Without such visitor involvement, crucial discoveries of noteworthy specimens would rarely happen. In two short seasons, the Fossil Preparation Lab at Badlands National Park has shown that the public is eager to take part in the cooperative objective of stewardship, proving that a positive partnership with the public is pivotal to the future preservation of fossil resources.

KEYWORDS: Fossils, Preparation, Resource Management, Resource Protection, Visitor Interaction.

POSTER PRESENTATION

+TAPHOFACIES OF SELECTED FOSSIL SITES WITHIN THE EARLY CRETACEOUS CEDAR MOUNTAIN FORMATION IN EAST-CENTRAL UTAH

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ABSTRACT—Taphofacies can be recognized based on correlation between lithostratigraphic beds and vertebrate preservation within the lower Cretaceous Cedar Mountain Formation of Utah (north of Arches National Park and Moab). Selected paleontological sites, from Bureau of Land Management and state-owned land, with established fossil collections are targeted, including: Doelling's Bowl, Dalton Wells, and Gaston/Yellow Cat Quarries (Yellow Cat Member); Tony's Bone Bed (Poison Strip Sandstone); and Lorrie's Site (Ruby's Ranch Member). Paleontologists have previously conducted taphonomic studies of the fossil beds found within the Cedar Mountain Formation (both in-situ and post recovery), but there has never been an attempt to map the preservation style relative to multiple localities present within the unit. This research is primarily motivated by increasing paleontological interest in the region and increasing awareness of paleontology resource management issues faced by federal and state agencies. The localities were revisited and the geology and stratigraphy of the sites was re-examined for a complete sedimentological background. Sediment samples were collected from each locality at notable stratigraphic intervals and analyzed at the James E. Martin Paleontology Research Laboratory at the South Dakota School of Mines and Technology, Rapid City, South Dakota. Utilizing methods developed by Behrensmeyer (1978), Fiorillo (1988), and others, an analysis of taphonomic variables was conducted on specimens excavated from the fossil sites, focusing on weathering and abrasion-stage conditions. Further analysis on the degree of fracture and breakage of the fossils was also conducted to better interpret the nature of the localities. The data obtained from this investigation were analyzed using several statistical methods including standard F- and Welch T-tests to examine the differences and/or similarities in variance and means, chi-squared randomization of the permutation for significant p-values (randomized 10,000 times), and linear trend analysis for positive or negative trending associations between the localities (Agresti, 2002; Reed and Denys, 2011). These methods were employed to compare the taphonomic characters 1) between localities, and 2) between element classes (ex. rod-shaped vs. flat) within each locality. Previously compiled stratigraphic sections were used to enhance the collected sedimentological data, and prior taphonomic investigations were used for more descriptive and resolute definitions of taphofacies (Kirkland and Madsen, 2007; Britt et al. 2009; Senter et al., 2012). While these localities share a number of features, the distinctions between the preservational characteristics and unit lithologies have provided a noteworthy basis for the description of taphofacies corresponding to the environments of deposition and stratigraphy of the Cedar Mountain Formation. The resulting interpretation of taphofacies are described and based on a framework set by Boessenecker (2011).

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ORAL PRESENTATION

FOSSILS ON THE FRONTLINES: A FOCUSED APPROACH TO PALEONTOLOGICAL RESOURCES MAPPING, MITIGATION AND PROTECTION: BUREAU OF LAND MANAGEMENT CODY AND WORLAND FIELD OFFICES, WYOMING, USA

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ABSTRACT—Wyoming is a state rich in multiple types of trace and body fossils dating from Precambrian to Pleistocene time. These fossils vary in size and significance from the smallest pollen grain or traces of algae to ancient fossil fern meadows and forests, from delicate traces of worms in marine shale, to elegant trackways and the skeletons of dinosaurs and Ice Age mammals. With its extensive stratigraphic record, the Bighorn Basin in northwestern Wyoming contains over three million acres of public land, presenting outstanding opportunities to study and collect these resources; which in turn furthers our knowledge of ancient ecosystems. However, because these same public lands are managed for multiple uses (such as mineral extraction and right-of-ways) by the BLM, fossil resources can be put at risk, or lost to science and the general public, as a result of surface disturbance, looting, vandalism, theft, and over-collection. These paleontological resources are truly on the front lines of public land use throughout Wyoming. In response to these concerns, and in the interests of protecting these world-class resources, staff from the BLM Cody Field, BLM Worland Field, and Wyoming State offices have developed a collaborative and interdisciplinary approach to paleontological resource management and protection. Our approach integrates stringent permitting procedures for research and consulting, diligent field reconnaissance, and the use of Global Positioning Systems (GPS) and Geographic Information Systems (GIS) to record and map localities on a continuous basis. Management of fossil resources is vastly improved when specialists employ continuous entry of data from annual reports, field and monitoring reports, and our own field surveys into the GIS. Paleontological resources receive regular scrutiny during review of proposed actions on federal lands administered by the BLM.

The Potential Fossil Yield Classification (PFYC) system is used daily, along with GIS mapping, to analyze and mitigate potential effects of proposed activities ranging from recreational uses, to fencing projects, to pipeline rights-of-way, to oil and gas exploration, to bentonite mining. Field surveys and construction monitoring, conducted by BLM staff or BLM-approved paleontological consultants, are closely tracked in a seamless process of communication between the consultant and BLM paleontology coordinators. Since 2009, on-site paleontological monitoring during surface disturbing activities has resulted

FIGURE 2. Marine trace fossils beautifully preserved in the Mowry Shale, BLM Cody Field Office, Bighorn Basin, Wyoming.

FIGURE 1. Lisa Marks, BLM Geologist, inspects a vandalized track site in the Gypsum Spring Formation, BLM Cody Field Office, Bighorn Basin, Wyoming.

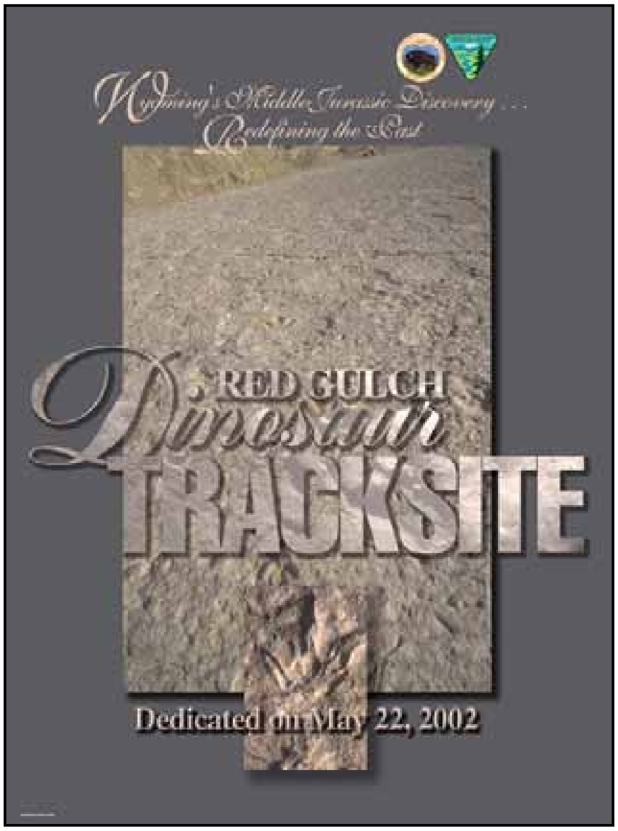


FIGURE 3. Red Gulch Dinosaur Tracksite dedication poster, BLM Worland Field Office.

FIGURE 4 (below). Cretaceous Meeteetse Formation, Big Cedar Ridge ACEC, BLM Worland Field Office.

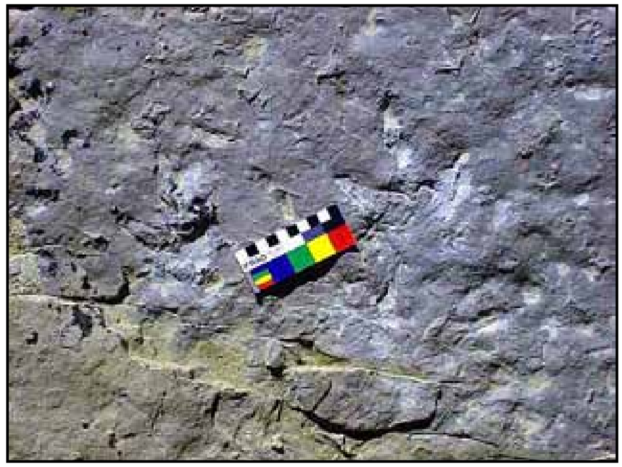
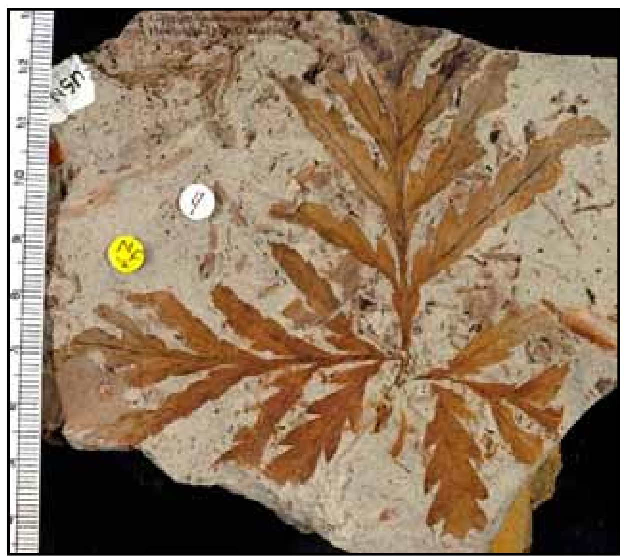


FIGURE 5. Three-toed dinosaur track, Red Gulch Dinosaur Tracksite ACEC, BLM Worland Field Office.

FIGURE 6 (below). Fossil fern from the Big Cedar Ridge ACEC, BLM Worland Field Office, Bighorn Basin, Wyoming (Source: Wing et al., 1993, and Smithsonian National Museum of Natural History).



in several outstanding fossil finds on BLM-administered public lands. With our enhanced proprietary GIS database of known paleontological sites, updated regularly, BLM staff can apply appropriate mitigation and monitoring requirements, as well as more stringent stipulations on project authorizations prior to fossils being lost or damaged in the field.

Unfortunately, reports of fossil looting, vandalism and theft continue to come in, as black market activity involving fossils continues to be lucrative. Dinosaur tracks and vertebrate fossils are at particular risk from these illegal activities. In such cases, BLM promptly engages the appropriate Law Enforcement personnel, who then conduct rigorous and thorough investigations. This interdisciplinary approach provides for a sound system of mitigation and protection of fossil resources that is ever improving. In addition to the above, one of the most exciting applications of our paleontology program is to highlight areas of keen scientific interest via the land use planning process. Currently the Cody and Worland field offices are updating the Bighorn Basin Resource Management Plan (RMP), also known as the "Land Use Plan," for BLM-administered public land and mineral estate in the Bighorn Basin. As a result of public and internal scoping, several areas of

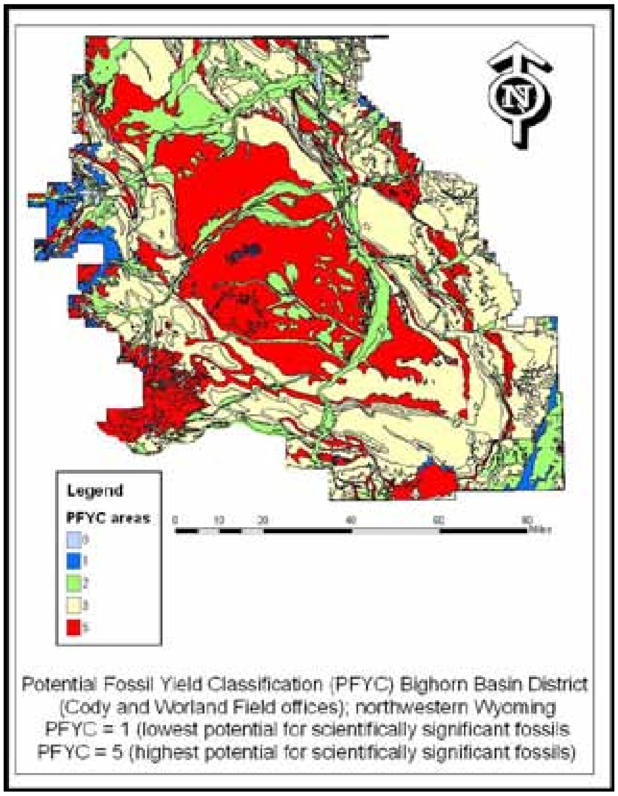


FIGURE 7. Potential Fossil Yield Classification Map used to protect vertebrate and scientifically significant paleontological resources, BLM Cody and Worland field offices, Bighorn Basin, Wyoming.

rich paleontological significance have been delineated in both field offices. These areas, known as Areas of Critical Environmental Concern or ACECs, are delineated based on their important paleontological resources and opportunities for scientific research. Existing ACECs in the basin include the Brown-Howe Dinosaur Area ACEC (where the skeleton of "Big Al" the Allosaurus was found), the Red Gulch Dinosaur Tracksite ACEC, and the Big Cedar Ridge ACEC. These areas of significant fossils from the Mesozoic Era are frequent destinations for school field trips, research groups, and tourists.

In addition to many sites from the Age of Dinosaurs, exciting new discoveries are being made in the fields of Cenozoic (Paleocene-Eocene) geochemistry, mammalian evolution and biostratigraphy, paleoclimatology and numerous other aspects of paleontology in the Bighorn Basin. Excellent and accessible exposures of the contact between the Paleocene Fort Union Formation and the Eocene Willwood Formation are found here. These strata, which have been dated at approximately 56 million years old, offer opportunities to study a time interval known as the "Paleocene-Eocene Thermal Maximum" or PETM. Scientific research and publications involving the PETM and related stratigraphic intervals has steadily increased in the Bighorn Basin since about 2000. Only a few sites exist worldwide where the PETM interval is exposed on land, and several such sites are located on BLM-administered land in the Bighorn Basin. The PETM interval represents a 100,000 to 200,000 year-long period of rapid global warming that occurred at the beginning of the Eocene Epoch. Publications describing the findings of this research, correlated with information from ocean drilling programs, generate the need for additional studies to refine paleoclimatological and paleontological data and events on a global scale. Most research in the Bighorn Basin has been conducted on public lands administered by the BLM, including surface sampling and detailed stratigraphic coring studies. Because of ongoing interest in this important geological contact on public lands, the Cody Field Office has proposed, with public support, to designate three key areas of this exposure as a new "PETM ACEC." Such a designation would elevate the importance of these world-class geological and paleontological values relative to other land uses, allowing for protection of these strata in the interests of science, thus enhancing and encouraging a thriving future for geoscience research on these public lands for many years to come.

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Key Words: Paleontology, fossils, Wyoming, mitigation, protection, law enforcement

ORAL PRESENTATION

THE BURGESS SHALE IN YOHO AND KOOTENAY NATIONAL PARKS, BRITISH COLUMBIA, CANADA: AN INTEGRATED MANAGEMENT APPROACH FOR A GROWING PORTFOLIO OF FOSSIL RESOURCES

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ABSTRACT—The 505 million year old Burgess Shale, located within Yoho and Kootenay national parks in British Columbia, Canada, is widely recognized as one of the most important fossil sites in the world. Since its discovery 105 years ago, it has yielded an abundant and diverse assemblage of mostly soft-bodied biota with exceptional quality of preservation. This collection has provided an un-paralleled window into the early evolutionary history of marine animals in the time following the Cambrian Explosion. The Burgess Shale was inscribed on the UNESCO World Heritage List in 1980 because of its palaeontological significance. It was subsequently incorporated into the larger Canadian Rocky Mountain Parks World Heritage Site in 1984. Fossils that we now recognize as Burgess Shale-type were first recorded from the Mount Stephen Trilobite Beds in the late 1800`s. Charles D. Walcott made his famous discovery in 1909, approximately 5km north of Mount Stephen. Research throughout the 20th century, which concentrated mainly around these original localities, led to the discovery of numerous additional fossil horizons. Field research in the early 21st century, led by the Royal Ontario Museum, has focused on investigating less-well known stratigraphic equivalents, culminating in the discovery of a significant new fossil site in 2012. There are now more than a dozen known Burgess Shale-type fossil localities within Yoho and Kootenay national parks. Parks Canada is responsible for protecting these resources while also providing access for scientific research and public education. Management strategies include land use designations, access restrictions, surveillance and monitoring techniques, guided educational opportunities, law enforcement activities, and scientific research review procedures. Future research provides the potential for the discovery of new species and new fossil sites that will continue to expand the understanding of this unique period in earth's history. With the identification of new fossil sites comes the opportunity for new learning experiences, but also the challenge of protecting a growing list of dispersed sites that are an irreplaceable part of our unique global heritage.

KEYWORDS: Bugess Shale, Canada

ORAL PRESENTATION

*THE DEMOGRAPHICS OF MITIGATION PALEONTOLOGY: RESULTS OF AN ONLINE SURVERY

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ABSTRACT—Mitigation paleontology is a rapidly evolving subfield of paleontology which is focused on the management, recovery, and preservation of fossils and associated data threatened by human activities. In order to discuss the need for and benefits of developing best practices in mitigation paleontology, a meeting of over 40 individuals with interest and/or employment in this field was held at the 2013 annual meeting of the Society of Vertebrate Paleontology (SVP) in Los Angeles. During this meeting, there was discussion of the need for a survey of those involved in mitigation in an attempt to learn more about the demographics of mitigation paleontologists. The purpose of the survey was to gather information that will be useful to mitigation paleontologists, land managers, and policy makers, including current practices, development of best practices, and interest in forming a professional organization. An overview of the survey results is shared here for those who are interested in learning more about mitigation paleontology, its contributions to the science of paleontology, and its growth as a source of employment for paleontologists.

KEYWORDS: Mitigation Paleontology, Mitigation

ORAL PRESENTATION

A PRIMER ON CASUAL COLLECTING ON FEDERAL LANDS

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ABSTRACT—Casual collecting on public lands seems to be an easy concept to understand. However, casual collecting is made more complex because of the different policies of different agencies with different missions. For paleontological resources, or fossils, causal collecting is even more complex because of their intrinsic connection with certain mineral resources. The Paleontological Resources Protection Act (PRPA) is the first statute to provide a legal definition of casual collecting, and subsequent regulatory clarification of the casual collecting policies by the federal land management agencies is forthcoming. Casual collecting [of paleontological resources] as defined in Title 16 U.S.C. 470aaa(1) of the PRPA means: "… the collecting of a reasonable amount of common invertebrate and plant paleontological resources for non-commercial personal use, either by surface collection or the use of non-powered hand tools resulting in only negligible disturbance to the Earth\'s surface and other resources." The PRPA requires that the Secretary of the Interior develop regulations implementing the legislation. These regulations will include definitions of such terms as "reasonable amounts" and "negligible disturbance."

Federal land management agencies did not have formal definitions of "casual collecting" prior to the PRPA. Instead, federal agency policies and/or regulations relating to hobby, casual, or other kinds of collecting, were usually described in terms of prohibitions to removing, disturbing, or destroying natural resources (e.g., federal property) unless otherwise provided for. Policies were further influenced by the agency's over-arching mission ranging from complete preservation and conservation to multiple uses.

Most notably, the National Park Service at Title 36 of the Code of Federal Regulations (CFR) Part 2.1 (36 CFR 2.1(a)(1)(iii)), prohibits "…possessing, destroying, injuring, defacing, removing, digging, or disturbing from its natural state…" paleontological (and all other natural and cultural) resources from National Park Service lands. The Bureau of Land Management (BLM), the U.S. Forest Service (USFS), the Bureau of Reclamation, and the U.S. Fish and Wildlife Service also have regulations prohibiting unlawful removal, destruction, or disturbance of natural resources.

The U.S. Fish and Wildlife Service prohibits all casual collecting on National Wildlife Refuges, and the Bureau of Reclamation also prohibits casual collecting. However, the BLM and the USFS have authorities that provide for multiple use of resources including casual (a.k.a. hobby) collecting.

For the BLM, their prohibition regulations at 43 CFR 8365.1-5 morphed into a hobby/ casual collecting agency policy for certain types of natural resources, including invertebrate and plant paleontological resources, with some caveats. This type of collecting on BLM administered lands relies on the Secretary of the Interior's authority to promulgate regulations as well as past practice that extends back to the settlement of the Western territories.

The legitimacy of hobby collecting has been reinforced in colloquies in the Congressional Record, particularly during the promulgation of the Archaeological Resources Protection Act of 1979, where hobby collecting was recognized by some members of Congress as a traditional recreational use of the public lands. Recreational use, including collecting, was also acknowledged as a legitimate use of the public lands under the concept of implied license in the Ninth Circuit Court of Appeals decision United States v. Curtis-Nevada Mines, Inc., 611 F.2d 1277 (1980) at 1283-1285.

Since the passage of the BLM's organic act in 1976—the Federal Land Policy and Management Act (FLPMA)—FLPMA is also cited as the authority for their hobby/ casual collecting policy. The BLM regulations read as follows: "… (b) Except on developed recreation sites and areas, or where otherwise prohibited and posted, it is permissible to collect from the public lands reasonable amounts of the following for noncommercial purposes… (2) Nonrenewable resources such as rock and mineral specimens, common invertebrate and common plant fossils, and semiprecious gemstones…" (43 CFR 8365.1-5(b)(2).

The U.S. Forest Service (USFS) prohibition regulations for natural resources and other property are at 36 CFR 261.9. These regulations are not as explicit about hobby/ casual collecting, and as a result, informal policies about casual collecting for personal use are developed on a forest by forest basis.

Further influencing the BLM's and the USFS's policy on casual collecting of paleontological resources is the fact that some economical mineral resources are composed of, or incorporate, fossils. One example is fossiliferous limestone used as building or decorative stone—a mineral material or salable mineral under the 1947 Mineral Materials Act as amended. Certain fossil-bearing energy mineral resources, such as coal and petroleum, are leasable minerals under the 1920 Leasing Act as amended.

Most problematical is petrified wood, which is by its nature a paleontological resource, but, by legislation is a mineral material under the 1947 Act as amended in 1962 (P.L. 87-713, 76 Stat. 652). Prior to the 1962 amendment, petrified wood was regulated as a locatable mineral subject to the 1872 Mining Law as amended. The USFS took the initiative of trying to sort out this conundrum by being the first and only agency to define "paleontological resource," as follows: "Paleontological resource means any evidence of fossilized remains of multicellular invertebrate and vertebrate animals and multicellular plants, including imprints thereof. Organic remains primarily collected for use as fuel such as coal and oil are Paleontological Resources, but are excluded from the prohibitions under the rule." (36 CFR 261.2)

The management of the hobby collecting of petrified wood is a special case in itself. As mentioned above, petrified wood is legally a mineral material resource. In the 1962 amendment, there is a provision for the collection of limited quantities of petrified without charge from public lands. This type of collection is known as "free use" under the authority of the 1947 Mineral Materials Act, and not as "casual collecting." The BLM and the USFS have their own regulations for the management of the free use of petrified wood. One difference in the regulations is that the BLM does not require a permit for free-use collection up to certain amounts, but the USFS does require a permit for free-use.

The federal land management agencies' policies related to casual collecting of paleontological resources has been superseded by the PRPA. The PRPA has maintained existing prohibitions for casual collecting, particularly for the National Park Service and the U.S. Fish and Wildlife Service. The regulations being promulgated under the PRPA will further clarify the policies of the BLM and the USFS for casual collecting of paleontological resources specifically by defining certain terms in the definition of casual collecting as required by the statute.

In the meantime, the BLM has formalized the casual collecting policy for paleontological resources under the PRPA through instruction memoranda until such time the Department of the Interior paleontological resources regulations under the PRPA are finalized. The USFS published draft regulations for the PRPA in the Federal Register on May 23, 2013, and is in the process of finalizing their regulations.

KeyWords: Casual collecting, paleontological resources, Paleontological Resources Preservation Act

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POSTER PRESENTATION

THE USE OF NONDESTRUCTIVE X-RAY FLUORESCENCE AS A FORENSIC TOOL FOR GEOCHEMICALLY FINGERPRINTING FOSSIL RESOURCES

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ABSTRACT—The Paleogene terrestrial deposits in Badlands National Park, SD are among the richest fossil vertebrate sites in the world, as well as frequent targets of fossil poaching (Terry, 1998). To discourage poaching, aid in recovery of lost fossils, and have a successful prosecution of offenders it is necessary to have a method of determining a displaced fossil's provenance. During fossilization, vertebrate remains incorporate a suite of trace elements characteristic of their diagenetic environment. This chemical fingerprint is dependent on factors such as sedimentary matrix, groundwater type, burial depth, and duration of fossilization (Metzger et al., 2004; Suarez et al., 2007; Grandstaff and Terry, 2009). Thus, fossils from different stratigraphic horizons and geographical locations will have distinctive chemical signatures which can be used to identify specimens that have been illegally removed from federal lands.

This study investigated the usefulness of nondestructive X-Ray Fluorescence (XRF) as a forensic tool to chemically fingerprint fossil-rich localities. There are two parts to this analysis: to test whether the XRF can detect unique chemical signatures to sufficiently distinguish fossil localities, and to determine the convenience of nondestructive XRF as a field tool. XRF can determine near-surface concentrations of a range of elements in a given sample. The analysis is surficial, as the X-rays only penetrate to ca. 50 μm into the bone.

One hundred fossil bones were collected from four localities in Badlands National Park (Figure 1): Chamberlain Pass (CP), Sheep Mountain Table (SMT), Doors and Windows Overlook (DWO), and Old Northeast Road (ONR). CP is within the Chadron Formation, SMT is within the Scenic Member of the Brule Formation, and DWO and ONR are within the Poleslide Member of the Brule Formation (Figure 2).

Samples were analyzed with a bench-top mounted, He purged, Niton XL3t XRF Spectrometer to determine whether locality-specific geochemical fingerprints could be obtained. Each sample was scanned for 180 seconds in duplicate. The surface area analyzed is about 1 cm2 and must be flat and clear of sediment. Eighteen of the bones were not analyzed due to lack of a flat, clean surface of exposed cortical bone.

RESULTS

Some elements are distinctly different between sites. In general, greater geographic and stratigraphic distances correlate with greater differences in chemical composition.

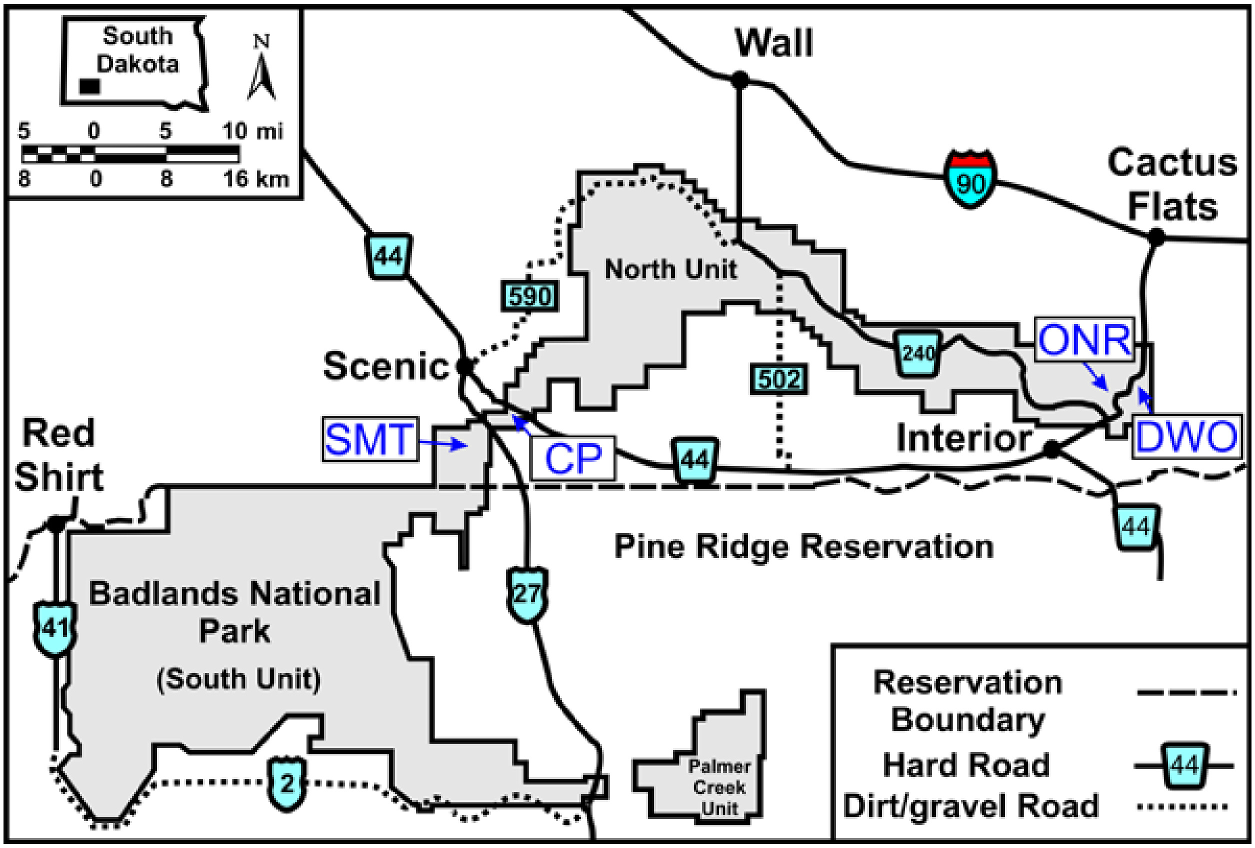

FIGURE 1. Location map of sample collection sites.

Fossils from ONR and DWO were collected from sites in the same stratigraphic unit and within one km of each other (Figure 2). In contrast, fossils from CP and SMT were collected about 50 km further west and are separated by about 5 km. Their compositions are distinctly different from the ONR and DWO fossils. Fossils from SMT also differ visually from those of the other sites because they are commonly coated in an iron-rich precipitate. This coating is not as common or well developed on fossils from CP, and nonexistent at the ONR and DWO sites, making it useful as a qualitative distinction for the SMT locality. Molybdenum, lead, and uranium appear to have the greatest utility for differentiating the four sample sites (Figures 3, 4).

Data from ONR and DWO tend to cluster with low concentrations of these metals, and are distinctly different from CP and SMT. CP and SMT have significant overlap, but SMT tends to have wider ranges for each element. Fossils from CP have a small range of concentrations, which may be due to their location in a different formation than the rest of the samples (Figure 2), or their restricted geographic distribution compared to the other sites. Although differences in element concentrations increase with increasing stratigraphic and geographic distance, it is difficult to extract a straightforward relationship. The ratios of several distinctive elements may be the best tool for diagnosing fossil provenance with nondestructive XRF.

Most previous studies of geochemical fingerprinting of fossil bone used Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and laser ablation to measure lanthanide (REE), actinide, and trace element concentrations (e.g., Trueman and Benton, 1997; Metzger et al., 2004; Suarez et al., 2007; Grandstaff and Terry, 2009). XRF results for uranium were compared with ICP-MS results of Cerruti et al. (this volume) for the same fossils to identify possible differences between the two methods (Figure 5). Concentrations for each fossil are similar, but the ICP-MS values were often slightly greater, possibly a result of irregularities in the bone surface or the higher sensitivity of the ICP-MS.

As a forensic method, XRF provides a rapid, non-destructive means of analysis for rare specimens, and may be preferable to destructive methods, such as ICP-MS, even if only small amounts of bone are removed. However, fewer elements can be detected by handheld XRF than ICP-MS, and excludes all light elements and REEs. Though some elements cannot be analyzed by XRF, elements within detection limits are equally effective for diagnosing fossil origins. Multiple analytical methods should be employed to build a comprehensive geochemical database of fossil bone chemistry. With further chemostratigraphic analysis, it may be possible to put lost fossils back into geologic context, and replace specimens that have been illegally removed from federal lands.

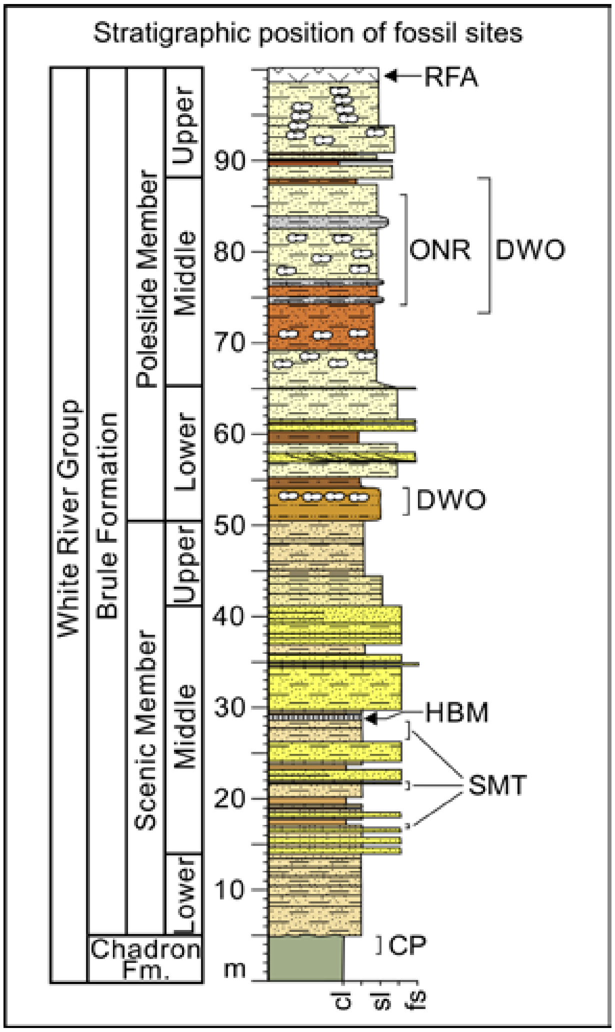

FIGURE 2. Stratigraphic column of the White River Group indicating location of samples. Modified from data of Evanoff in Benton et al. (2007, 2009). HBM = Hay Butte Marker Bed, RFA = Rockyford Ash.

FUTURE WORK

The Handheld XRF has the potential for use in a field setting and to catalog the chemical signatures of in-situ fossils on federal lands. However, it must still be determined if results of XRF analysis in the field are comparable to those in a laboratory setting. The next portion of this project will replicate field conditions in the lab by using the XRF as a handheld unit without a helium purge to test its fidelity as a significant tool for mitigating fossil poaching.

ACKNOWLEDGEMENTS

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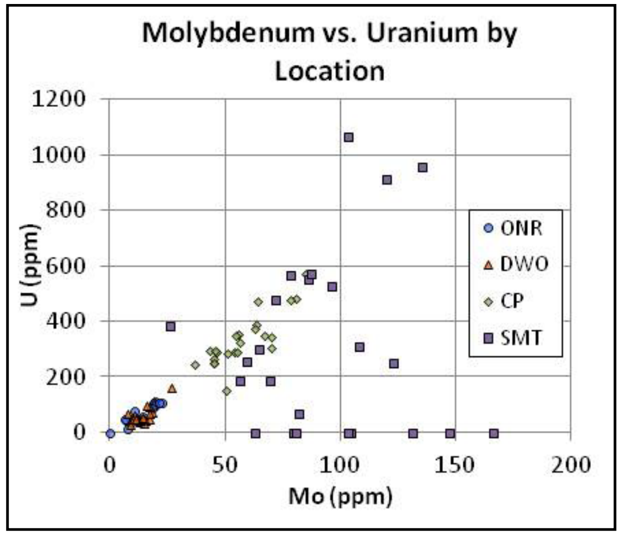

FIGURE 3. Concentrations of Mo and U in ONR and DWO overlap significantly and are less than CP and SMT, allowing fossils from the Poleslide Member to be distinguished from those in the lower part of the section. Although CP and SMT concentrations overlap, SMT concentrations are more variable than CP, possibly allowing some fossils from those areas to be distinguished. The data points with 0.0 ppm U are from an iron-rich precipitate that coats some of the samples, suggesting that U is only incorporated into bone and is not a constituent of the coating.

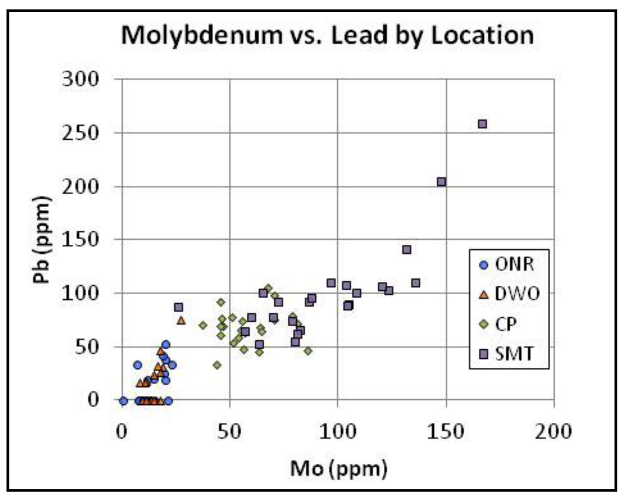

FIGURE 4. Concentrations of Mo and Pb show similar clusters as in Figure 3. ONR and DWO overlap one another with low concentrations of Pb and Mo. CP concentrations are internally consistent but show some overlap with SMT. SMT shows much less scatter in Pb concentrations than U, indicating that lead concentrations are less variable among fossils from this location. The positive correlation of these elements may indicate that specific diagenetic conditions favor the adsorption of both elements.

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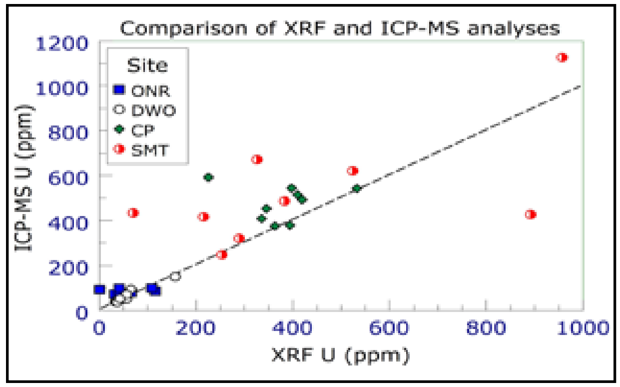

FIGURE 5. Uranium concentrations in the same samples determined by XRF and ICP-MS. Diagonal line indicates equal values for each method. Measured concentrations are generally similar, with ICP-MS concentrations slightly greater, possibly due to coatings or irregularities in the XRF sample surfaces and the higher sensitivity of ICP-MS.

KEYWORDS: Chemical signture, Badlands National Park

ORAL PRESENTATION

*THE CHESAPEAKE AND DELAWARE CANAL: TWO CENTURIES OF PALEONTOLOGY ON A PUBLIC TRACT

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ABSTRACT—The cuts and spoil piles of the Chesapeake and Delaware Canal, in New Castle County, Delaware have been productive sites for finding fossils since 1804. The canal is currently administered by the United States Army Corps of Engineers. Collecting along the canal is neither encouraged nor discouraged, thus providing a case study in unregulated public access to fossil collecting. The tracts are of little interest to commercial collecting, but have been widely exploited for scientific, personal, and recreational recovery of fossils, many of which have remained in personal collections. While many significant specimens have no doubt gone unrecognized by the scientific community, many others have been placed in public repositories, studied, and published. The assemblage described herein, a comprehensive study of a local fauna from one exposure, the Deep Cut, is exemplary of the importance of the scientific potential of the canal sites. It is worthy of consideration as to whether regulated collecting would have benefited the public interest. Largely based on one personal collection, conscientiously maintained and donated to a public repository, it includes more than sixty taxa of Cretaceous age, including one poriferan, twenty pelecypods, fifteen gastropods, six ammonites, eight arthropods, one echinoid, and eleven vertebrates.

KEYWORDS: Cretaceous, Delaware, Casual collection

ORAL PRESENTATION

*WAS CHARLES H. STERNBERG THE PROFESSIONAL ANCESTOR OF THE MODERN COMMERCIAL FOSSIL COLLECTOR?

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ABSTRACT—Charles H. Sternberg (1850-1943) was the patriarch of a family which for two generations was involved in collecting and selling fossils to wholly or partially financially support themselves. Sternberg began his collecting career in the early years of the 'dinosaur rush' of the nineteenth century, at times collecting for both Edward D. Cope and O. C. Marsh, as well as for various institutions. His three sons continued with an interest in paleontology, and all his sons ended up being employed with government or academic institutions (Rogers, 1991). Sternberg's name and career are often invoked by modern-day commercial collectors to make the claim that they are simply carrying on in Sternberg's legacy, that their collecting activities are little different in scope than his and that they similarly contribute to the science of paleontology. The November 19, 2013 public auction at Bonhams in New York is one example of recent commercial activity involving fossils. According to the auction catalogue of fossils specimens for sale, 35 lots had estimated values over $10,000. Thirty-seven percent of those lots (13) had values over $100,000; 9% (3) had values over $500,000; and the two headlining specimens were valued at $1.8 and $7 million respectively.

When compared to the commercial value of fossils at the turn of the twentieth century the prices sought for fossils today are orders of magnitude higher than what Sternberg could have sold fossils for in his time. Sternberg was clear that he collected strictly for the love of the science, and monetary gain was not his goal. So he is not similar to the many commercial collectors today who hope to gain significant profit from exceptional fossil finds.

KEYWORDS: Commercial Collection, Charles H. Sternberg

ORAL PRESENTATION

FOSSIL CYCAD NATIONAL MONUMENT: A HISTORY WITH A FUTURE

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ABSTRACT—On September 1, 1957, management of the former Fossil Cycad National Monument reverted to the Bureau of Land Management (BLM) under the general public land laws of the United States. After a great deal of effort to establish the monument in 1922, and despite the determination to develop it for the public, its 35 year history as a National Monument came to a close. The next event of significance during BLM's management of the land occurred in the 1980s when Highway 18 was being re-routed, passing through the middle of the old monument. During the construction, new fossil cycads were unearthed, and the BLM requested that work be temporarily suspended while it investigated. Some of the specimens discovered at that time were reported to be very large, 400 and 500 pounds, and one reported to be more than 1,000 pounds. Two tons of the recovered fossils were subsequently taken to the Museum of Geology at the South Dakota School of Mines and Technology. This event demonstrates that while the fossils on the surface of the monument may have disappeared long ago, significant resources likely still remain in the ground.

In 1998 the BLM nominated the former monument to be designated an Area of Critical Environmental Concern (ACEC). This formal designation can be applied to lands as part of the land management planning process, and nominated areas with special features can be given special management status. In the case of Fossil Cycad the land was closed to oil and gas leasing, timber sales, and rights-of-way. In addition, off-road vehicle travel was limited, and the casual collection of common invertebrates and plants was disallowed (Bureau of Land Management, 1999). With these actions, the BLM set the administrative structure to protect the site from uses that might damage or degrade the fossil resource.

The rich history of the monument, both its Mesozoic history preserved in the fossil cycads and geologic features on site, and the story of its management by the National Park Service and now the BLM provides an excellent foundation for outreach and education. Its history highlights the importance of active resource management. Through neglect the very resources for which the area was recognized were removed from the surface. Efforts to

develop the site for public interpretation were not realized. The BLM, with partners like the NPS, is exploring ways of bringing the story of this site to a wider audience. A wide range of options are being explored for that purpose and include potential on- or near-site signage, teacher educational material, the digital archive, online information, paleontology podcast, Jr. Explorer booklet and traveling exhibits. Input from all the stakeholders is welcome so that the story of Fossil Cycad National Monument can enlighten land managers, researchers, and the general public to the importance of managing our fossil resources for the full benefit of the public.

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KEYWORDS: Fossil Cycad National Monument

ORAL PRESENTATION

THE FUTURE OF BLM PERMIT PROCESSING AND REPORTING—YOU'RE GONNA LOVE IT

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ABSTRACT—The Bureau of Land Management (BLM) is charged with managing nearly 247 million surface acres of public land (U.S. Department of the Interior, 2013), about 11 percent of the total land surface of the United States, or an area roughly equal to Montana, California, and South Dakota combined. Most of those surface acres are in the arid western states, which are rich in fossil resources.

While the BLM has long managed fossils as a valued resource, explicit legislative direction to do so was only first provided in the Paleontological Resources Preservation Act (PRPA) of 2009. In that act, Congress directed federal land management agencies to manage fossils using scientific principles and expertise. Further, the act specified that agencies would develop plans for inventory, monitoring, and the scientific and educational use of fossil resources. With such clear direction, agencies are beginning to take steps toward achieving those goals. BLM "paleocrats," those whose responsibility it is to oversee how publicly-owned fossil resources will be managed, work to ensure the responsible collection and use of those resources. It is in the public interest to facilitate the accountable collection, documentation, storage, and educational use of fossils.

The BLM relies very heavily on strong partnerships with permittees and non-federal repositories to assist with this management. Those who apply for and receive permits to conduct work are collecting invaluable data for their own and future research, while also collecting resources for the public. Permittees report to the BLM about significant localities and finds, and the museums that house the resulting collections are caretakers of the fossils as part of a public trust. The permitting and reporting requirements are designed to be as straight-forward as possible, however, in the current paper-based system duplication and redundancies abound.

For many years, personnel from the BLM have envisioned a centralized and web-based system for more efficiently handling these processes (for example see Matthews et al., 2009), and creating a superior system for applicants, repositories, and bureau staff simultaneously. We are pleased to report significant strides in this direction have been made in the previous year. As currently envisioned, the Scientific Permit Application and Tracking System (SPATS) will be a national system for applications for permits on BLM lands.

This "one-stop-shop" will be web-based, and allow applicants to easily manage their own information, track applications, report on permit activities, and provide locality information to the BLM in a secure/confidential environment. SPATS is currently in a proof-of-concept phase of development within BLM. Essentially, this means that the foundations for the system are being built and tested in a functioning prototype before additional resources are expended on a larger fully-implemented system. System designers have developed "workflows" for the various functions of the system, and are designing a user interface and behind-the-scenes infrastructure to make the system work.

A brief overview of what the user experience is expected to be can now be outlined, and the BLM is eager to share the anticipation of its full implementation with our partners. Users will have a system login that will allow them to access their own customized dashboard that displays information of immediate need to them. Permit applicants will see their current applications, status on application processing, and a "to-do" list if further action is required of them and all their past applications and permits. System managers will see a similar dashboard of required actions for the smooth processing of permits. When starting an application, users will have a choice of a "pull-down" to selecting their area of interest or an in-

teractive map on which they can specify the areal extent of their work. They can upload all the documentation and fill in required information directly into the system. Applicants will be able to save an application and return to it to continue editing before final submission.

The BLM requires certification by a repository that agrees to take fossils collected under the permit, and so repository officials will be able to give that certification through a simple email system. Likewise, adding additional individuals to your application will be simply a matter of providing their email and basic credential information. On the review side, the applications will be processed entirely online, with the system keeping track of where it is in review process and who needs to interact with it next for processing. Applicants should still realize that there are certain steps required in the processing that will still require time for BLM to complete, and they are always encouraged to submit an application far in advance of actually needing to go into the field, but the system will significantly streamline the process. Likewise, after field work is conducted, permittees can build their reports directly in the system.

One of the most important elements provided to BLM is the locality data, with notes about what was collected. The system will allow for a map interface where locality data can be plotted from input coordinates (latitude/longitude, UTM) or entered directly on a map. Users can confirm immediately that the placement of their locality is correct, helping to eliminate errors of transcription to which our current paper forms are subject. Once locality data is confirmed and entered into the system it will be housed in a secure environment.

SPATS will be a powerful tool for management. With locality information in a centralized place, that can be shared as appropriate. For example, consultants working on a project can enquire with BLM as to known localities within the area of potential effect (APE). Repositories will have access to locality information and reports relative to their own collections, and will be able to further help BLM refine shared data. The BLM will have a comprehensive dataset of permitted work, localities, and fossils with which to better manage paleontological resources, both in and out of the ground. After years of contemplating a comprehensive system for application, permitting, and reporting, the near-perfect storm of technology, organizational will, and resources have come together to allow the BLM to move into these first steps. As now, the BLM will continue to need our partners fully on-board so we can co-manage the nation's treasure, and we are pleased to provide this glimpse into a system which we expect will make all of our lives a bit easier.

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ORAL PRESENTATION

*USING GEOGRAPHIC INFORMATION SYSTEM (GIS) TO UPDATE MONTANA GEOLOGY MAPS AND FACILITATE FOSSIL POTENTIAL DATA ANALYSES

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ABSTRACT—The Bureau of Land Management (BLM) is one of several federal agencies that manage public lands of the United States. Part of active management includes overseeing the fossil resources. A tool that the BLM uses to do this is the Potential Fossil Yield Classification (PFYC) system. The PFYC is a numerical rank from 1 (low potential) to 5 (very high potential) applied to geologic units, most often at the formation level. These ranks are assigned by BLM personnel with input from other knowledgeable individuals.

A concerted effort was undertaken to compile the best and most detailed geologic map for Montana, North Dakota, and South Dakota. Maps at a variety of scales were merged into a single Geographic Information System (GIS) data set. Completely unique codes for the various polygons across all the merged maps were created to eliminate ambiguous codes in the original maps. A database was created to assign each of the unique codes a PFYC rank. The result of these efforts is the most up-to-date and detailed PFYC map in GIS. Codes are easily updated in the database and are immediately reflected across all polygons in the map system. This data layer is used regularly to review parcels for land actions, such as oil and gas lease sales for example, and allows land managers to quickly evaluate potential impacts to paleontological resources.

KEYWORDS: Potential Fossil Yield Classification, GIS

ORAL PRESENTATION

TAPHONOMY OF A MULTI-TAXA BONE-BED IN THE HELL CREEK FORMATION (LATE CRETACEOUS) OF SOUTH DAKOTA (USA)

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ABSTRACT—The Hell Creek Formation (Late Cretaceous) is a productive succession of sediments containing the fossil remains of dinosaurs and contemporary fauna/flora (Pearson et al., 2002; Colson et al., 2004). A recently discovered site on BLM managed land in South Dakota is yielding vertebrate (dinosaur, bird, mammal, fish, crocodilian and turtle) and invertebrate material (arthropod cuticle, arthropod feeding traces, etc.) and a diverse flora (including seeds, leaves and amber), making this an important multi-taxa site. However, it is the presence of large numbers of ceratopsian bones in a single sedimentary unit that is of great interest. The material collected from the sites is being curated at the American Museum of Natural History (New York) and is the subject of a series of analytical techniques that aims to better constrain the taphonomic pathways of preservation.

Ceratopsian dinosaur remains from the Hell Creek Formation are usually found as isolated individuals or occasional pairs, but at this new site, there are at least twelve individuals exposed on the edges of an extensive bone-bed. The possibility that one or more ceratopsian species were associated in a single event has significant palaeoecological implications. However, considering recent arguments as to the validity of *Torosaurus* and its potential as a late ontogenetic stage of *Triceratops* (Scannella and Horner, 2010), it is possible that a multitaxa bone-bed (composed of *Triceratops* and *Torosaurus*) could shed critical light on the debate. The presence of both taxa in a single lithological unit (arguably a single event) could be linked to their being either different ontogenetic stages of one or two species coexisting or support the new hypotheses of the variation in form as a function of growth stage. The bone-bed site consists of an outcrop of approximately 150 meters long and 50 meters wide. Only approximately ~2-5% of this site has been exposed. It is likely that such a unit will continue to produce bone for many years in the future. This is the first opportunity to map, excavate, record and analyze a large Hell Creek ceratopsian bone bed. It is remarkable that such a find had not previously been made considering the large number of taphonomic and dinosaurian census studies already undertaken in the Hell Creek, which have largely focused upon the KT extinction. (White et al., 1998; Pearson et al., 2002; Colson et al., 2004). The Site also includes a well-preserved hadrosaur trackway preserved within a sand unit that abuts the bone-bed, which was studied and photographed during last summer's field season. The trackway is particularly important given the paucity of track evidence in the Hell Creek Formation (Manning et al., 2008) and will described and published shortly.

During the 2011-13 field seasons, the field team were able to excavate a large number of skeletal elements, including a well-preserved ceratopsian braincase, which will likely prove to be complete once prepared, opening another potential research direction. A large number of braincases from a variety of taxa have been scanned using X-ray computed tomography (XRT) (Rogers, 1998; Brochu, 2000; Evans, 2005; Franzosa and Rowe, 2005). However, ceratopsians are not well represented in this sample of dinosaurs with XRT endocast data. The best ceratopsian braincase with XRT data described is from a Pachyrhinosaurus (Witmer and Ridgely, 2008). Six specimens of *Psittacosaurus lujiatunensis* have also been scanned (Zhou et al., 2007), however, many of the interpretations in this analysis are problematic as the maxillary fossa was interpreted to be large olfactory lobes as first pointed out by Sereno (2010). Forster (1996) published an extensive analysis of the braincase of Triceratops consolidating previous analyses with new data, but this was done without XRT data. The braincase collected at the site in 2011 will be XRT scanned by the American Museum of Natural History and the University of Manchester teams in order to better understand ceratopsian braincases and add to the ceratopsian XRT-based endocast dataset. In addition to the morphological data that has been imaged through XRT, it is also possible to extract valuable information on the chemical controls to preservation. Previous studies have examined geochemical traces in Mesozoic feathers, squamate skin, and Hell Creek Formation dinosaur skin (Manning et al., 2009; Edwards et al., 2011; Bergmann et al 2010; Wogelius et al., 2011). The use of synchrotron-based XRF imaging to chemically map extremely rare fossils can enable a more complete understanding of the taphonomic pathways that led to their preservation. The technique combined the elemental sensitivity of X-rays with the high spatial resolution and intensity of synchrotron radiation. The new rapid-scan XRF imaging system (20-100 μm resolution, 3 ms readout per data point) was only recently developed at the Stanford Radiation Light Source (SSRL).

This research has shown that a combination of non-destructive imaging techniques can resolve biological control on the distribution of endogenous organic components within fossilized soft-tissue. Similar chemical

analyses have been performed on both vertebrate and plant samples collected from the Hell Creek site in South Dakota. Preliminary results indicate it is logical to employ both portable ramen spectroscopy and X-ray fluorescence in the field to help quantify possible chemical changes to samples during and post-collection. This will additionally permit the screening of samples that might show exceptional preservation and/or chemistry. Such an approach has already been successfully used when screening for potential specimens for synchrotron analyses (Wogelius et al., 2011; Bergmann et al., 2010). The application of analytical techniques to the taphonomy of the Hell Creek sites in South Dakota potentially offers great insight to the discrete pathways that have preserved many facets of the Earth's fossil heritage. Such analyses of each sample from similar bone-beds will provide information pertinent to both the environment of preservation and also the conservation of any bone and soft tissues; ultimately yielding a more robust taphonomic model by which the kinetics of mass transfer of elements and compounds in buried organisms can be better understood.

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KEYWORDS: Hell Creek Formation, South Dakota, Ceratopsian, Cretaceous

ORAL PRESENTATION

UP, UP, AND AWAY: THE USE OF UNMANNED AIRCRAFT SYSTEMS FOR PALEONTOLOGICAL DOCUMENTATION

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ABSTRACT—The Bureau of Land Management (BLM) has pioneered the use of photogrammetry for capturing detailed three-dimensional information on paleontological resources, as well as a variety of other natural resources found on public lands. Not only has BLM been at the forefront of this digital capture technology, but they have streamlined techniques for field use and have provided training in photogrammetric techniques to researchers around the world. While many subjects can be easily photographed from the ground, some sites require an elevated perspective, necessitating the use of a variety of different platforms to capture imagery for photogrammetric processes. The use of unmanned aircraft systems (UAS) for paleontological resource documentation was first used by the BLM at the Red Gulch Dinosaur Tracksite (RGDT) in Wyoming in 1998. A remote controlled hobby aircraft equipped with a 35 mm film camera was used to capture imagery over the main track-bearing surface at RGDT. These early flights provided both unique imagery and a wealth of valuable experience. For any photogrammetric method, ground-based or aerial, guiding principles still apply and include capturing high quality images with proper stereoscopic (66%) overlap, and accurately and completely control the subject.

Advancements, both in legislation (Paleontological Resources Preservation Act-2009) and unparalleled advancements in technology provide new and creative ways to find, document, and study paleontological resources. While a Secretarial order in 2003 placed limitations on the use of Government (federal, state, and local) and university owned and operated UAS in the national air space, advantages can be gained from utilizing this technology. By looking back at the techniques utilized by BLM to document in situ paleontological resources, we can look forward to the efficiencies gained through emerging technologies. Advancements in science and instrumentation have improved the level to which resources can be documented and monitored to better preserve and interpret our paleontological resources for current and future generations.

KEYWORDS: Paleontological documentation, Unmanned aircraft systems, photogrammetry, Red Gulch Dinosaur Tracksite, Aircarft Camera Blimp System

ORAL PRESENTATION

FOCUSING AROUND WITH PHOTOGRAMMETRY: CAPTURING 3D DATA ON DIMENSIONALLY COMPLEX SUBJECTS

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ABSTRACT—Photogrammetry has proven to be an excellent tool for capturing detailed three-dimensional data on dinosaur tracksites and other in situ paleontological resources. This technology has been utilized by the Bureau of Land Management (BLM) at sites across the western United States (Wyoming, Colorado, New Mexico, Idaho, Utah, Arizona, Nevada, Nebraska, California, Alaska, and South Dakota) and around the world (Tanzania, Germany, and the United Kingdom). The science and technology of photogrammetry (making measurements from imagery) came into being as a discipline in the mid-1800s and was applied fairly equally to both terrestrial and aerial strategies for image collection. However, through much of the early to mid-1900s the majority of advances came in the aerial arena developed for wartime reconnaissance and topographic mapping. In 1998 the Bureau of Land Management (BLM) began documenting paleontological resources at the Red Gulch Dinosaur Tracksite (RGDT)

in the Bighorn Basin of Wyoming. BLM pioneered hybrid techniques, which utilized the block photogrammetry methods traditionally utilized in aerial topographic applications with ground-based photogrammetric surveying techniques commonly associated with terrestrial or close-range photogrammetry (CRP). This hybrid process focused on taking a combined series of photos that satisfied the requirements of both techniques, while providing the flexibility for field use. Over the years, some ingenuity has come into play, as a variety of platforms including blimps, helicopters, remote–controlled planes, ladders, raised tripods and monopods have been utilized to obtain the needed photographic perspectives putting BLM at the forefront of the federal community in the use of photogrammetry.

Over the last 15 years, advancements in camera equipment, computer hardware, and software have facilitated a transition in approach and have opened up the technology to users from the resource community (e.g., paleontologists, archeologists, geologists, range technicians, etc.) with backgrounds outside the field of photogrammetry and mapping. These advancements not only streamline the field capture and processing time, but expand the complexity of subjects that can easily be captured. Historically, close-range photogrammetry was treated much in the same fashion as traditional aerial photogrammetry, in that photos were taken over a subject (such as a tracksite) from a nadir position to the surface and in a line-of-flight type configuration (Figure 1). While this strategy is still an efficient method for capturing information about a relatively flat surface, (such as a single fossil footprint or an entire trackway) the use of photogrammetry should not be confined to this limited view. Dimensionally complex subjects (such as quarries, outcrops, skeletal elements, museum mounts, etc.) may be captured in the field, laboratory, or museum setting. When capturing dimensionally complex subjects, it is often necessary to combine a number of strategies for camera location in relation to the subject. Imagery processing software (such as Agisoft Photoscan) have advanced structure from motion algorithms and are capable of making visually good models from a number of randomly taken photos. However, the best results are achieved when stereoscopic photographs are taken with strong geometric locations are considered. These geometrically strong relationships can be visualized more readily when the concepts of triangulation and redundancy, as well as proper base to height ratios are kept in mind (Figure 2). While every project has its own nuances based on the size, shape, lighting condition, and physical location; the basic concepts that have been in place since the beginning of the discipline remain constant. The final data set is still dependent on the camera-lens system used, the distance from the subject, proper image geometry (ideally 66% stereoscopic overlap), and effective removal of lens distortions throughout the mensuration process. And very importantly, good, clear pictures must be obtained.

The following five recommendations will ensure quality results for almost any subject. First, an object of known dimension must be in the stereo overlap of at least two photos. Second, images should be in focus with good contrast to accentuate subject texture. Third, consistent focus and focal length should be maintained during image capture. Fourth, appropriate stereoscopic overlap (i.e., 66% overlap), and geometrically complete coverage of the subject. Fifth, a redundant set of images should be taken with the camera turned at 90 and 270 degrees for camera calibration. An advantage in capturing dimensionally complex subjects, such cranial and post cranial elements in-the-round is that the redundancy mentioned above is satisfied when completely encircling a subject with photographs. In this case, photos can be taken at positions from 10 to 15 degrees around the subject (Figure 3). In-the-round photogrammetry can be accomplished for specimens of virtually any size, from smaller specimens mounted on a turntable to larger subjects lying on a table, in a cradle, or those that must be captured by walking around them. When capturing in-the-round subjects a variety of considerations must be made, scale, proper background, lighting of the subject and background, and the appropriate turntable and associated mounting, as well as the processing software. These most certainly are not daunting requirements, however it may take an investment in time to properly master the requirements in a logical progression of first achieving good photographs, understanding the requirements of scaling the subject, achieving good geometry for a relatively flat project, understanding the software processing workflow prior to moving to more dimensionally complex subjects. Once these skills are mastered, virtually any subject can be photogrammetrically documented. The reward for investing the time in learning and utilizing the photogrammetric technique is the resulting datasets which may be produced. While products traditionally associated with aerial photogrammetry, such as orthoimage maps, topographic contour maps, and color-coded elevation maps can be generated, output of a multi-dimensional point cloud of data is now available. Photogrammetric point cloud data (PPCD) contain both the exterior physical dimensionality of a subject and a high quality, natural color, image texture with a high level of quality, reliability, and authenticity. The PPCD can be exported into a variety of file formats consisting of hundreds of thousands of closely spaced x, y, z data points with precisely registered, high resolution RGB (Red, Green, Blue Color Model) values. Once a PPCD is generated, analytical tools support direct 3D comparison of anatomical features, such as individual skull bones or footprints within a trackway. As a scientific community, we can now build a library of photogrammetric image datasets. These 3D digital surrogates can be utilized in a virtual environment or "printed" as hardcopy replicas for research, management, preservation, and interpretation. The basic equipment (i.e., scale bar and camera) necessary to successfully create photogrammetric point cloud data digitally is most likely in the pack of every field resource specialist, giving them the ability to capture our natural world in 3D in any place at any time.

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KEYWORDS: Photogrammetry, dimensionally complex subjects, 3D data, paleontological resources

ORAL PRESENTATION

LAND MANAGERS AND REPOSITORIES: A CRITICAL PARTNERSHIP FOR THE LONG-TERM MANAGEMENT OF FOSSIL RESOURCES FROM PUBLIC LANDS

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ABSTRACT—Paleontology is an object based science. One cannot study the fossil record without examining fossils. Paleontology is also an extractive science since for the object of interest cannot be studied without first removing the fossils from the original context in which they were preserved. Whether through a large scale excavation which physically destroys the fossil's context in order to remove it or simply by picking up a fossil from the surface and leaving the context intact, in both cases the fossil must be first removed from its original context. Consequently when fossils are collected there is an equally important commitment by the collector not only to the fossils long-term preservation but also to the associated records such as field notes, photographs, maps, and stratigraphic sections as well. This is important, whether the specimens were collected as part of a research project, for the purposes or exhibit or interpretation, or as part of a project's mitigation. In all cases if fossils are collected the recording of original contextual information is equally important as the proper collection of the specimen as it is this information that ensures the fossil's scientific value. Because paleontology depends both on the object (the fossil) and the contextual information, both of which need to be preserved, paleontology is intimately linked to museums and collection management.

As part of a research project, any conclusions drawn based on the fossil(s) examined requires that anyone wishing to confirm or refute those conclusions be able to examine the original specimens. This is only possible when fossils are preserved as part of a public trust in a public repository. So the quality of research in paleontology is intimately and directly tied to both the long-term preservation and curation of the fossils and their associated data and their accessibility to the paleontological community. The placement of fossils from public lands into partner repositories, whether federal or non-federal, is therefore a critical component of any land management strategy in order to ensure that the fossils and their contextual information are preserved for future generations, whether for research, exhibition, or education, both formal or informal, and remain available to future generations, both professionals and the public, through the medium of exhibits. It should always be kept in mind that the land manager's responsibility for the fossils does not stop with the removal of the fossils from the ground, but that their removal is merely the first step of a perpetual stewardship responsibility. Since land managers usually have neither the facilities, resources, nor the staff to ensure the long-term and day-to-day care of these extracted fossils, it is fortunate that all of these resources exist in the form of public museums and educational institutions. A strong partnership between land managers and these public institutions are absolutely critical to ensure the proper curatorial care of fossil resources as part of a shared responsibility for preserving this aspect of our shared public heritage.

Since fossils collected on public federally managed lands as part of a research project remain federal property, land managers are still held accountable for those specimens even after they are out of the ground. As such land managers need to be actively engaged in the curatorial stewardship of the specimens, no matter where they are housed. It is a challenge to maintain a balance between demonstrating accountability to the American public as to the quality of care of the fossils and not impose an undue workload with the partner repository in order to achieve that accountability. In many ways land managers are like cuckoos in that the fossils are often placed in a repository and then left to the repository to provide the appropriate care, without any further involvement of the owner. While databases such as the Interior Collection Management System (ICMS) can be used to track specimens, such a system does not automatically ensure or improve the level of care given to the specimen in terms of environmental conditions, quality of storage cabinets, prevention of theft, pest control management or any of the other hallmarks of a professional museum or repository. Land managers cannot be "hands-off" with regard to these collection management issues and not fall into an "out of sight, out of mind" mentality with regard to the fossils originating from the lands for which they are responsible. To retain ownership is to retain primary responsibility for the specimens and a dynamic interaction with the partner repositories is necessary in order to ensure the highest level of care for this part of our shared heritage and its long-term preservation.

KEYWORDS: Collection Management, Curation

ORAL PRESENTATION

PRESENTING SCIENTIFIC RESEARCH TO THE PUBLIC THROUGH NEW EXHIBITS AND INTERACTIVE MEDIA AT FLORISSANT FOSSIL BEDS NATIONAL MONUMENT, COLORADO

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ABSTRACT—The opening of a new paleontology research facility and visitor center at Florissant Fossil Beds National Monument in 2013 catalyzed the development of innovative approaches to link the public with the Monument's paleontology program. The first area of the exhibit hall features dioramas and artwork that integrate the rock formations and fossil records to recreate Florissant's late Eocene environment and geologic processes. A second area is dedicated to the demonstration of historic and ongoing paleontological research activities. This portion of the exhibit required a substantial late-phase planning overhaul of an earlier ineffective draft design to bolster the presentation of robust scientific content. This design highlights the scientific process by featuring scientists who have investigated research questions at Florissant. The paleontology content for the Monument's website was extensively expanded to feature activities of the research center, including ongoing projects of the Monument's paleontologist and the large seasonal staff of GeoCorpsTM interns, as well as researchers from partnering institutions. A new video, Follow a Fossil, was created to demonstrate excavation, curation, and research.

Plans are underway to implement interactive digital content for a kiosk that will virtually link the paleontology lab to the exhibit area, providing a broader overview of activities than conventional "lab windows." Digital images of the Monument's paleontological specimens are central to some of the new media designs, and thousands of specimens, and their associated content, are currently being digitized to enhance visitor understanding, while supporting collection management activities. The photographs uploaded to the website also increase the accessibility of the Monument's collections to researchers and visitors. This digitization project is supported by visitor entry fees ("FLREA"). Visitors cannot access the paleontology research area, therefore the new exhibits and media presentations are intended to supplement public understanding of ongoing paleontological research and projects at the Monument.

KEYWORDS: Florissant Fossil Beds National Monument, Exhibition

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ORAL PRESENTATION

WEST OF THE MISSISSIPPI ANTHILLS REALLY HELP

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ABSTRACT—The history of anthill fossil collecting from harvester (*Pogonomyrymex occidentalis*) anthills goes back to the 1890's. Subsequent work continued in the 1930's and 1950's, into recent times (Robinson and Williams, 1997). Many researchers have used microfossils collected from anthills. Previously inaccessible areas are now opened by the oil and gas industry and are valuable sources of microfossils that should be utilized. In some cases, the anthills might be the only indications of fossil potential. The Easter Anthill (UCM 2006-039) from southern Wyoming produced a significant (>200 specimens), Wasatchian 4 micro-vertebrate fauna in the Washakie Basin.

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KEYWORDS: *Pogonomyrymex*, ant hills, microfossils

ORAL PRESENTATION

*A FOUNDATION FOR BEST PRACTICES IN MITIGATION PALEONTOLOGY

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ABSTRACT—Mitigation paleontology focuses on the recovery and preservation of non-renewable paleontological resources (fossils) that are threatened by ground disturbance associated with land and energy development projects. Mitigation includes the assessment of potential impacts and the development of measures to reduce or eliminate adverse impacts to scientifically important fossils, as well as the implementation of those measures. Despite several decades of steady progress with the development of standard procedures and regulatory guidelines for the assessment and mitigation of impacts, neither mitigation paleontologists nor the regulatory agencies that oversee their activities have been successful in developing industry-wide standard operating procedures. Best practices are methods and techniques that have consistently shown results superior to those achieved by other means, and are used as a benchmark. They are a standard way of doing things that multiple organizations can adhere to, although they evolve and improve over time. In this paper we propose comprehensive and detailed best practices for the mitigation paleontology industry that fall into ten categories: qualifications and permitting, analyses of existing data, research models and scientific context, field data collection, field surveys, construction monitoring, fossil salvage, data management and reporting, curation facilities, and business ethics and scientific rigor. Our purpose is, with input from the mitigation community, to establish procedures that are successful in maintaining a rigorous scientific standard while promoting integrity in the industry in order to accomplish the common goal of paleontological resource preservation via impact mitigation.

KEYWORDS: Mitigation

ORAL PRESENTATION

OPERATION EQUINOX – APPLICATION OF THE PALEONTOLOGICAL RESOURCE PRESERVATION ACT TO A CRIMINAL PROSECUTION

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ABSTRACT—Prior to the enactment of the Paleontological Resource Preservation Act (PRPA) of 2009, vertebrate paleontological resources on public lands were protected by a complex mosaic of federal regulations which relied heavily on value determinations of the fossils for successful prosecution. Many Vertebrate Paleontologists argued that all such fossils were priceless for their value to science making establishment of accurate and defensible appraisals difficult. With passage of the PRPA, prosecutors and law enforcement were given a consolidated regulation that essentially addressed these complexities while enhancing penalties for vertebrate paleontological resource violations. This presentation reviews a case which began prior to passage of PRPA in June of 2008. As a result of the investigation conducted by a Special Agent assigned to the Bureau of Land Management (BLM) in Fairbanks, Alaska, a professional river guide and well known author along with an outfitted client were federally indicted and ultimately plead guilty to conspiracy and vertebrate paleontological resource theft allegations. The court assessed criminal penalties for both defendants totaling $130,000.00. This case is believed to be the first felony indictment and successful criminal prosecution to cite PRPA. The fine represents a significant deviation from historical amounts and is attributed in part to the courts recognition of the ever increasing importance of the scientific value of vertebrate fossil reserves on federal lands.

KEYWORDS: PRPA, Law Enforcement

ORAL PRESENTATION

CURRENT AND FUTURE RESEARCH ON THE PALEOECOLOGY AND TAPHONOMY OF PLIOCENE MUSTELOIDS FROM HAGERMAN FOSSIL BEDS NATIONAL MONUMENT

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ABSTRACT—The Musteloidea is an exceptionally diverse superfamily of carnivorans with a long evolutionary history and cosmopolitan distribution. They exhibit great breadth in their ecology, behavior, and morphology and are increasingly taking on the role of apex predator in their respective ecosystems. However, modern musteloids are often difficult to study, and their fossil record is poor: much is still unknown about modern and fossil musteloid biogeography, ecology, and behavior. The Pliocene deposits of Hagerman Fossil Beds National Monument (HAFO) provide an exceptionally rich and abundant musteloid community. These fossils occur across a largely spatio-temporally continuous 800,000-year sequence of fluvial-lacustrine deposits. These deposits have produced a wealth of data on landscape and community change over time and provide an ideal setting for the study of Pliocene musteloid community structure and function. Presented here are results from ongoing re-analysis of Hagerman's musteloids, including new as well as previously collected specimens housed at HAFO and the National Museum of Natural History collections. Also discussed are plans for neotaphonomic projects that aim at better understanding musteloid paleoecology and the role of musteloids in shaping some of Hagerman's microvertebrate fossil assemblages. A study of otters as bone modifiers, set to begin later in 2014, will provide data with potential for both identifying latrine accumulations in fossil context and for better understanding wild otter diets. Paleontologists studying fauna of late Neogene and Quaternary age are in a unique position to conduct research that utilizes modern analogues and that can produce results applicable to the study of both fossil and modern taxa. This research aims to better understand the changing role of musteloids in past, present, and future ecosystems.

KEYWORDS: Musteloidea, Taphonomy, Pliocene, Paleoecology, Hagerman Fossil Beds National Monument

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ORAL PRESENTATION

SMALL MAMMAL DIVERSITY THROUGH THE CENOZOIC OF NORTH AMERICA AND THE IMPACTS OF PAST CLIMATIC CHANGE

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ABSTRACT—Paleoclimate records show a general trend of global cooling and increased aridity through the Cenozoic. These climate changes correspond with large scale changes in environment from predominantly forests to more open habitats. Phytolith and paleosol studies suggest these open habitats began to dominate some sites in the Oligocene. Previous studies of large mammalian herbivores (ungulates) have shown ecomorphological and community structure changes through time, but these changes occurred millions of years after the environmental shifts that were thought to have triggered them. Smaller mammals have received much less study, but should more closely track climate and habitat changes due to their shorter generation times and smaller ranges. Here, I have assembled and analyzed a large database of small mammals, including all 1135 rodent and lagomorph species occurring in the fossil record of North America. For each species, first and last appearance data were compiled using the MioMap and FaunMap databases, supplemented by literature sources. Tooth crown height (hypsodonty) and locomotion were categorized for each species based on published and unpublished data, along with phylogenetic inferences. Crown heights should have increased through the Cenozoic as habitats became more open and arid. Rodent adaptations for burrowing and jumping, and increased cursoriality in rabbits should also become more prevalent as environments changed. Analysis of this data found that the structure of small mammal communities changed dramatically through the Cenozoic. Most rodents and lagomorphs had brachydont dentition in the Eocene, but a few higher crowned taxa appeared at that time as well. The diversity and proportion of higher crowned taxa increased dramatically in the mid Oligocene. By 29.5 Ma more than half of rodents had increased crown heights, and the first hypselodont (ever-growing) toothed rabbit appeared at that time. The proportion of hypselodont taxa steadily increased from the late Miocene through the Pleistocene, ultimately representing nearly half of all species.

In the Eocene, arboreal rodents were abundant, and there were few burrowing and jumping species. In the mid Oligocene, burrowing taxa became substantial components of faunas and the first cursorial rabbits appeared. Jumping rodents diversified in the early Miocene, as did semiaquatic rodents. From the late Oligocene to recent, 30-50 percent of all species have displayed burrowing, jumping, or cursorial habits; adaptations for life in open habitats. These results suggest that rodents and lagomorphs have responded quickly to Cenozoic environmental changes. Over time, many small mammals adapted for feeding and moving in open environments. In the Oligocene, communities shifted from predominantly low crowned to higher crowned taxa. Similarly, the proportion of open habitat adapted species has been greater than 30 percent from the late Oligocene to Recent. These adaptations in rodents and lagomorphs appear about 10 million years earlier than in ungulates.

KEYWORDS:Cenozoic, small mammals, climate

ORAL PRESENTATION

PALEOHERITAGE, PALEOCONSERVATION, AND PRESERVING FOSSILS IN NATIONAL PARKS

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ABSTRACT—A billion year history of America's paleontological heritage is preserved in more than 245 National Park Service areas. Collectively the extraordinary paleobiodiversity represented in the national parks enables important opportunities for both public education and scientific research. Through the authority contained within the Antiquities Act, the birth of paleontological resource conservation was realized in 1906 with the establishment of Petrified Forest National Monument, Arizona. A few years later this authority was again used to preserve an important dinosaur quarry in Utah with the proclamation of Dinosaur National Monument in 1915.

In 1916, the National Park Service Organic Act formally established and defined the mission of a new federal park system within the Department of Interior. During the nearly 100 year history of the National Park Service, fourteen park units have been created by enabling legislation which specifically references paleontological resources. Nearly two dozen fossil localities have been designated as National Natural Landmarks based upon the paleontological significance of these sites. The Paleontological Resources Preservation Act was signed into law in 2009 providing the National Park Service and other federal land managing agencies specific authorities for the management, protection, curation and public education of America's paleontological heritage.

KEYWORDS: Law enforcement, National Park Service, Petrified Forest National Monument

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ORAL PRESENTATION

THEFT AND VANDALISM OF NATIONAL PARK SERVICE PALEONTOLOGICAL RESOURCES: ARE FOSSILS SAFE ANYWHERE?

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ABSTRACT—From souvenir collecting of petrified wood to systematic poaching of fossil vertebrates, the National Park Service faces many challenges in protecting paleontological resources in our nation's parks. During the past decade nearly 900 individual law enforcement reports document incidents of fossil theft or vandalism throughout the National Park System. At least three dozen national parks are known to have experienced unauthorized fossil collecting, but the actual magnitude of the loss of fossils through unauthorized collecting will never be fully understood. Unauthorized collecting of fossils was so extensive at one national monument, Congress eventually voted to abolish it as a unit of the National Park Service. The lessons learned and intelligence gathered through investigations and prosecution of fossil theft present opportunities for more proactive and cooperative measures to protect our fragile fossil heritage. Interagency cooperation, resource specific training and the authority provided through the Paleontological Resources Protection Act (2009) offer hope in our collective efforts to curtail both domestic and international paleontological resource crimes in the future.

KEYWORDS: Law enforcement, poaching, vandalism

ORAL PRESENTATION

*FOSSIL CYCAD NATIONAL MONUMENT: A HISTORY FROM DISCOVERY THOUGH DEAUTHORIZATION

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ABSTRACT—Through the authority provided in the Antiquities Act (1906), on October 21, 1922, President Warren G. Harding proclaimed Fossil Cycad National Monument. Scientists recognized that the fossil locality preserved a significant exposure of a Cretaceous cycadeoid forest. Hundreds of fossilized cycad specimens, one of the world's greatest concentrations, were exposed at the surface of the 320 acre site during the early 1920s. Years of negligent management at the monument resulted in adverse impacts on the finite paleontological resource. The fossils on the surface disappeared faster than erosion could expose other specimens from beneath. The loss of the exposed petrified plant remains eventually left the site devoid of fossils and ultimately without a purpose to justify its existence as a unit of the National Park Service. On August 1, 1957, the United States Congress voted to deauthorize Fossil Cycad National Monument.

KEYWORDS: Fossil Cycad National Monument

ORAL PRESENTATION

GYPSUM CAVE, NEVADA: A TREASURE TROVE OF FOSSILS OF LATE PLEISTOCENE EQUUS FROM THE MOJAVE DESERT

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ABSTRACT—Gypsum Cave is a late Pleistocene limestone cavern in the Frenchman Mountains of southern Nevada. Originally excavated in 1930-31, the cave yielded multiple well-preserved fossils of *Equus* and other late Pleistocene megafauna. Preservation is exceptional, including soft tissues, and fossils from the site have previously yielded both radiocarbon dates and DNA. Horse fossils from Gypsum Cave dating to ~13 ka were included in earlier molecular studies assessing late Pleistocene equid diversity in North America, even though the fossils had not been previously described in any detail. For this reason, quantifying the entire sample of horse fossils from the site was warranted.

Remains of *Equus* at Gypsum Cave are well represented in the overall large mammal assemblage from the locality. Multiple skeletal elements, both cranial and postcranial, are preserved, including a largely complete cranium recently rediscovered in museum collections. As

FIGURE 1. Left lateral view of LACM-CIT 109-156450

noted, some fossils retain soft tissues including ligaments, tendons, skin, and hooves. Based upon dental elements, the sample includes two adults, three subadults, and five juveniles. Four left metatarsals with fused distal epiphyses, when combined with the dental elements confirm a minimum number of ten individuals in the sample. All of these fossils represent a small stilt legged species, verified metrically and through previous mDNA analysis. Radiocarbon dates associated with these remains yielded ages of ~13 ka. Additionally, a single terminal phalanx encased within an intact hoof represents a large species; this fossil has been previously dated to ~25 ka. Based upon these data, two species of horse are present at Gypsum Cave: a large stout limbed species and a smaller stilt legged form. Lack of more diagnostic remains precludes specific assignment for any of these fossils at present. Apparent carnivoran damage on vertebral elements suggests predation and/or scavenging, offering a clue as to how the horses were introduced into the cave.

The small horse fossils from Gypsum Cave are the best-preserved remains of small stilt-legged horses presently known from anywhere in southwestern North America. In conjunction with other Pleistocene localities in the Mojave Desert (e.g., Tule Springs, Lake Manix, Kokoweef Cave, Tecopa) and the Colorado Desert (e.g., Pinto Basin), it is evident that at least three species of *Equus* inhabited this region in the late Pleistocene: the large *Equus scotti*, the smaller *E. conversidens*, and the as-yet-unnamed small stilt-legged horses. In contrast, more coastal assemblages (e.g., Rancho La Brea, Diamond Valley Lake) lack stilt-legged equids altogether, instead preserving remains of *E. conversidens* and the larger *Equus "occidentalis"*.

The fossil record of *Equus* from Gypsum Cave convincingly demonstrates the significance of this underutilized locality for advancing studies of late Pleistocene megafauna in southwestern North America. Continued investigation of fossils from the cave, potentially coupled with site-based education and outreach, offer a unique window into the end of the Ice Ages in southern Nevada.

KEYWORDS: Gypsum Cave, Pleistocene, Mojave Desert, stilt-legged *Equus*

ORAL PRESENTATION

FOSSIL REMAINS OF EQUUS FROM THE TULE SPRINGS LOCAL FAUNA, SOUTHERN NEVADA: IMPLICATIONS FOR THE DIVERSITY AND BIOGEOGRAPHY OF LATE PLEISTOCENE EQUIDS IN WESTERN NORTH AMERICA

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ABSTRACT—Late Pleistocene ground water discharge deposits in the upper Las Vegas Wash outside of Las Vegas, Nevada have yielded an abundant and diverse vertebrate fossil assemblage, the Tule Springs local fauna. The San Bernardino County Museum has documented over 600 discrete localities from the Las Vegas Formation in this region. Stratigraphically ascending units and nested subunits A-E of this formation span as much as the last 250 Ka, determined via radiocarbon and luminescence dating techniques. Most of these units have yielded fossils. The recovered fauna, dominated by remains of *Camelops* and *Mammuthus*, also includes relatively common remains of extinct *Equus* and *Bison* as well as rare carnivorans such as *Smilodon*, along with abundant vertebrate microfaunal fossils. The Tule Springs local fauna is the largest open-site vertebrate fossil assemblage dating to the Rancholabrean North American Land Mammal Age in the Mojave Desert and southern Great Basin.

Recent efforts by the San Bernardino County Museum under a multi-year Federal Assistance Agreement from the Bureau of Land Management, Southern Nevada District Office have yielded a partial skull, mandible, and metatarsal of a subadult individual of extinct large *Equus*.

These specimens, the first from the Las Vegas Formation to be assignable to species, represent the large horse *Equus scotti*. Diagnostic features include large size, stout metapodials, and infundibula in the lower incisors. Previous studies in the upper Las Vegas Wash yielded no equid remains sufficiently diagnostic to warrant defensible specific assignment; this find is therefore highly significant.

Pleistocene localities in northern Nevada (Wizard Beach, Rye Patch Reservoir) have previously yielded fossils of *Equus scotti* (as *E. pacificus*) dating to ~25.5 ka. The fossils from the Tule Springs local fauna, from high in the section of the Las Vegas Formation, are directly associated with a radiocarbon date of 11,880 +/- 60 14C ybp obtained from this discrete discharge event. The fossils are therefore the youngest and most southerly record of this species in Nevada and among the youngest recorded anywhere in North America.

In addition to *Equus scotti*, two other species of *Equus* can be discerned in the Tule Springs local fauna, based upon body size as inferred from measurements of pedal elements: a small stout-limbed form and likely a small stilt-legged species. The presence of this latter equid is buttressed by the occurrence of late Pleistocene small stilt-legged horses from the geographically proximate Gypsum Cave locality just outside of Las Vegas.

The presence of multiple species of horse in the Las Vegas region accords well with the fossil record from other

late Pleistocene localities in the American southwest, although not all sites have remains of all three species. At Mojave Desert localities such as Lake Manix, as well as Colorado Desert sites such as the Pinto Basin in Joshua Tree National Park, remains of both large and small horses have been identified. However, the presence of *Equus scotti* in the Tule Springs local fauna calls into question previous assumptions about which species of large *Equus* are represented at these other localities. In particular, inferences that the large late Pleistocene horse species *E. occidentalis* was present at multiple Mojave Desert fossil localities—an inference based on the relative geographic proximity of the Mojave to more coastal sites such as Rancho La Brea and Diamond Valley Lake, where *E. occidentalis* is abundant—merit reconsideration.

The co-occurrence of three species of *Equus* in the Tule Springs local fauna differs markedly from the present-day global distribution of equid species, where generally only one equid occurs in a given geographic region at any one time. Further, the record from the Las Vegas region contrasts with recent molecular studies suggesting only two horse lineages may have been present in late Pleistocene North America. The discrepancy may likely be traced to the more northern locales and limited sample size of the available genetic data.

KEYWORDS: Tule Springs, Pleistocene, Rancholabrean, Mojave Desert, *Equus*

ORAL PRESENTATION

COLLECTING AND DISPOSITION OF AMMONITE SHELL IN ALBERTA: A MODEL FOR PROVIDING PRIVATE OWNERSHIP OF GOVERNMENT-OWNED FOSSIL RESOURCES

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ABSTRACT—Ammonite shell (also known as Ammolite) has been collected for commercial purposes in Alberta since the 1960s (Baker and Hare, 2006; Mychaluk et al., 2001; Barnson, 2000; Barnson, 1996). Since ammonites and other palaeontological resources (fossils) are protected, government-owned resources in Alberta (Alberta Culture, 2000), the Government of Alberta (GOA) developed the Disposition Process to ensure that the ammonite shell industry could continue to operate in a regulated and legal manner. This process allows the GOA to provide ownership of government-owned resources in a manner that protects scientifically significant fossils and retains them in the public trust. The Disposition Process continues to provide benefits to commercial collectors and has resulted in many scientifically significant ammonites and associated fossils, such as mosasaurs, elasmosaurs and a variety of invertebrates being added to the Provincial Collection at the Royal Tyrrell Museum of Palaeontology (RTMP). This model can be applied by other jurisdictions trying to balance the protection of scientifically significant fossils with the desire for private ownership.

LEGISLATIVE OVERVIEW

In Alberta, all palaeontological resources are protected under the authority of the Historical Resources Act (HRA) and associated Regulations. One of the primary tenets of the HRA is that all palaeontological resources within Alberta are owned by the Crown in right of Alberta (Alberta Culture, 2000). These publicly owned resources are managed by Alberta Culture via the RTMP. The Dispositions (Ministerial) Regulation provides the framework by which ammonite shell collecting and ownership is regulated by Alberta Culture (Alberta Culture, 2010). Prior to 1998, ammonite shell was strictly considered a palaeontological resource and was regulated under the HRA. A 1998 court case (Hembroff, 1998) defined ammonite shell as both a mineable resource and a palaeontological resource (contra Mychaluk et al., 2001). Currently, ammonite shell collecting on lands with Crown-owned mineral rights is regulated under both the Mines and Minerals Act (Alberta Energy, 2009) and the HRA (Alberta Culture, 2000). The Ammonite Shell Regulation (Alberta Energy, 2004) provides the framework by which Alberta Energy manages its interests in ammonite shell.

COLLECTING AMMONITE SHELL

To obtain permission to collect ammonite shell on Crown-owned mineral title lands, a prospective collector must first receive an Ammonite Shell Agreement from Alberta Energy. This agreement, issued pursuant to the Ammonite Shell Regulation (Alberta Energy, 2004), ensures that the collector is compliant with all legal requirements to excavate for mineable resources in Alberta. Within four months of receiving an Ammonite Shell Agreement the prospective collector must apply to Alberta Culture for an exemption of section 30(1) of the HRA. Section 30(1) of the HRA requires anyone excavating for palaeontological resources to have a valid Permit to Excavate Palaeontological Resources. These permits are issued only for individuals with a post-graduate degree in palaeontology conducting mitigative studies or research programs. As most people applying to collect ammonite shell do not meet

Alberta Culture
HISTORICAL RESOURCES ACT

APPLICATION FOR REGISTRATION/CERTIFICATE OR DISPOSITION OF A PALAEONTOLOGICAL RESOURCE

I, ____
(Given Name) (Initial) (Surname)

____
(Address or Box No.) (City) (Province) (Postal Code)

____
(Phone Number) (E-mail address)

HEREBY APPLY TO THE MINISTER FOR:

☐ a Certificate confirming that property in the palaeontological resource described below is not vested in Her Majesty the Queen in Right of Alberta, pursuant to section 2 of the Dispositions (Ministerial) Regulation and I confirm that this palaeontological resource was collected before July 5, 1978.

SWORN before me this __________ day of ________________________, 20__

Applicant's Signature	A Commissioner for Oaths in and for the Province of Alberta	Notary Public (for applicants outside the province of Alberta)

OR

☐ a transfer of ownership of the palaeontological resource described below, pursuant to section 3 of the Dispositions (Ministerial) Regulation, from Her Majesty the Queen in Right of Alberta to

____
(Individual, company or institution)

I have an HRA Exemption No.: ______________________________ (if applicable)

Type and quantity of palaeontological resource (attach photographs): ______________________________

____
(Attach extra sheets if necessary)

To the best of my knowledge and belief, the palaeontological resource was collected at ____

____
(Include county or district, nearest city, town, village or hamlet; and legal description)

Applicant's Signature ______________________________ Date ____________________

FOR OFFICE USE ONLY

Date Received ________________ File Number ________________ Application Number ________________

Collection examined by: ____

Comments (attach sheets if necessary): ____

____

☐ APPLICATION APPROVED

☐ APPLICATION DENIED

Assistant Deputy Minister, Heritage Division	Date

FIGURE 1. Application for the Disposition of a Palaeontological Resource currently used by Alberta Culture.

Alberta Culture

Historical Resources Act
Section 3, Dispositions (Ministerial) Regulation (Alberta Regulation 101/98)

DISPOSITION CERTIFICATE

I, ADM Name, Assistant Deputy Minister of Heritage Division, having reviewed the application of ., Disposition Number 000000, am satisfied that the palaeontological resource described on the aforesaid application attached hereto:

(a) was acquired on or after July 5, 1978

(b) is listed on the Control List in Schedule 1 of the said regulation and

(c) does not have scientific value or is not of sufficient quantity or quality for scientific or display purposes;

I HEREBY DISPOSE of the property in the resource that is vested in Her Majesty the Queen in right of Alberta, by gift, to .

DATED at Edmonton, Alberta, this _______ day of ______________________, 20____.

____
Assistant Deputy Minister
Heritage Division

SAMPLE

FIGURE 2. Disposition Certificate currently used by Alberta Culture.

the minimum requirements to hold a Permit to Excavate Palaeontological Resources, an exemption must be issued to allow them to legally collect ammonite shell. An Ammonite Shell Agreement is not required to collect ammonite shell on freehold mineral title lands as Alberta Energy does not have jurisdiction over the mineable resources on these lands. In this circumstance, a prospective collector must secure an agreement with the freehold mineral title holder and apply to Alberta Culture for an exemption of section 30(1) of the HRA. The collector must also obtain surface rights holder permission to access the property for the purpose of collecting and/or mining for ammonite shell before any exploratory or mining activities can commence.

DISPOSITION

Even after the ammonite shell has been collected, it remains property of the Crown in right of Alberta. To obtain ownership of the fossils, the collector must apply to Alberta Culture, via the RTMP, for a Disposition Certificate. To initiate the Disposition Process, an ammonite shell collector must submit an Application for the Disposition of a Palaeontological Resource (Fig. 1) to the RTMP. The completed and signed application form must be accompanied by clear a photograph of all fossils for which Disposition is being requested. Once received by the RTMP, the application is reviewed by Resource Management Program staff to ensure that all required information has been provided, that all fossils in the application are eligible for Disposition, that all necessary photographs have been included and that the application has been signed by the applicant. After being satisfied that the application is complete, it is assigned a unique identification number and is forwarded to an RTMP curator for review. The role of the curator in this process is to review the application and accompanying photographs to determine whether any of the fossils included in the application are of scientific significance or display quality. There are three possible outcomes from the curator review: 1) recommendation for approval, 2) recommendation for approval but at least one fossil should be retained for the Provincial Collection and 3) approval is not recommended and that all fossils included in the application should be retained for the Provincial Collection. Following the curator review, the application is returned to Resource Management staff who drafted the Disposition Certificate (Fig. 2) and assemble an authorization package, which includes the application form, the Disposition Certificate and a covering memo. The authorization package is then sent to the Assistant Deputy Minister of Heritage Division, Alberta Culture for approval. The approved application form and Disposition Certificate are returned to the RTMP and correspondence with the applicant is drafted and sent to the applicant by Resource Management staff. The correspondence informs the applicant of the results of the Disposition Process and of any further requirements on their part, such as sending in any fossils retained during the Disposition Process. The applicant is responsible for sending all retained fossils, at their cost, to the RTMP where they are catalogued and incorporated into the Provincial Collection. Once the Disposition Certificate has been issued, the applicant becomes the legal owner of all the disposed fossils included in the application and may sell or trade the fossils as they see fit. Federal export permits may be required for exports and sales outside of Canada.

SUMMARY

The Disposition Process was developed in Alberta to manage, in part, an ammonite shell industry that had been operating prior to the introduction of provincial fossil protection legislation. The Disposition Process has allowed for the continuation of commercial ammonite shell collecting but ensures that significant fossils are maintained in the public trust for future scientific study and/or display. This process is currently being considered as a model by other jurisdictions and could be readily modified to regulate the collecting and ownership of any type of fossil(s) with a commercial interest.

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KEYWORDS: Ammonite, Ammolite, Alberta, Disposition, Legislation

ORAL PRESENTATION

REGIONAL VARIABILITY OF GEOCHEMICAL SIGNATURES IN FOSSILS FROM THE PALEOGENE WHITE RIVER SEQUENCE OF SOUTH DAKOTA, NEBRASKA, AND WYOMING

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ABSTRACT—Since 2005, Temple University has partnered with the Bureau of Land Management (BLM), National Park Service (NPS), and U.S. Forest Service (USFS) to test the utility of geochemical signatures locked in fossil bone as a means to mitigate poaching. Our results to date suggest that these signatures are stratigraphically distinct between regions and vary as a function of depositional environments, paleoclimate, associated changes in sedimentology, and with increased stratigraphic and geographic distance. Upon death and burial, bone material, a very fine grained carbonate-substituted bioapatite or dahllite (Ca5(PO4,CO3)3(O,OH)) reacts with groundwater and recrystallizes into more stable francolite (Ca5(PO4,CO3)3(F)) during which it incorporates rare earth elements (REE), fluoride, and uranium into the bone (e.g., Metzger et al., 2004; Grandstaff and Terry, 2009). The proportions of these newly incorporated elements create a distinct chemical fingerprint that changes as a function of environmental conditions (e.g., oxidizing vs. reducing and acidic vs. alkaline). In addition to bioapatite recrystallization, other minerals, such as calcite and quartz, may precipitate in void spaces in the bone.

METHODS

Bones were collected by pedestrian survey, measured into stratigraphic position, and located by GPS coordinates. Additional information on associated sedimentology, bone-specific taphonomic characteristics, such as degree of articulation and bone processing, and depositional environment were noted. Several different types of analyses can be performed to extract the geochemical fingerprint depending on the goal of the study. Most commonly (e.g. Suarez et al., 2007), bulk cortical bone is removed and cleaned of sediments and secondary minerals before dissolution in nitric acid. This solution is analyzed using inductively coupled plasma-mass spectrometry (ICP-MS) and results are normalized to the North American Shale Composite (NASC) of Gromet et al. (1984). Resulting REE signatures can be compared visually, or analyzed statistically to determine their uniqueness (e.g., Grandstaff and Terry, 2009; Lukens et al., 2010; Cerruti et al., this volume). Polished cross-sections of bone can be analyzed using laser ablation-ICP-MS to determine the period of fossilization, as well as differences between signatures (e.g., Drewicz et al., 2011). Most recently, nondestructive x-ray fluorescence (XRF) has been tested for discriminating chemical fingerprints in fossil bone (see Lalor et al., this volume).

RESULTS

Several hundred bones from sites in and around Toadstool Geologic Park (USFS) in northwest Nebraska were sampled to determine the variability of REE signatures as a function of stratigraphic position, and within/between specific bone beds commonly targeted by fossil poachers (Fig. 1). Our results indicate that REE signatures vary as a function of stratigraphic position (Fig. 2), and that individual bone beds can be distinguished at least 93% of the time, with some locations up to 100% (Terry and Grandstaff, 2010; Lukens et al., 2010). When compared with REE signatures from the Flagstaff Rim area (BLM) in east central WY (Figs. 1, 3), the combination of REE and carbon and oxygen isotope values produced a 100% success rate in distinguishing these two sites (Terry and Grandstaff, 2010). In South Dakota (Fig. 1), fossil sites are split between USFS holdings just southwest of Scenic in Indian Creek and seven individual sites in Badlands National Park (Metzger et al., 2004; Lukens et al., 2010; Cerruti et al., and Lalor et al., this volume). Sites in Indian Creek are distinct from those in the same stratigraphic unit in Nebraska. Differences within the Indian Creek site probably result from reworking and time averaging of fossil bone into stream channels (REF). Of the seven NPS sites, differences in REE signatures can be related to stratigraphic position, differences in ancient soil forming conditions within stratigraphic units (Metzger et al., 2004), and variability of depositional environments within the same tightly constrained stratigraphic interval across 25 km of outcrop (Cerruti et al., this volume).

APPLICATIONS TO RESEARCH

Based on the work of Drewicz et al. (2011), the amount of time required for fossilization in terrestrial environments varies from 3 to 70 ka depending on the depositional environment, which has implications for the preservation and recovery of biomolecules in deep time. Suarez et al. (2007) used REE signatures to interpret the taphonomy of an early Cretaceous bone bed, Grandstaff and Terry (2009) demonstrated Milankovitch-scale fluctuations in REE signatures, and MacFadden et al. (2007) used REE fingerprints of extant museum specimens to determine the provenance of a chronologically misplaced Titanis fossil, which in turn provided new interpretations of the timing

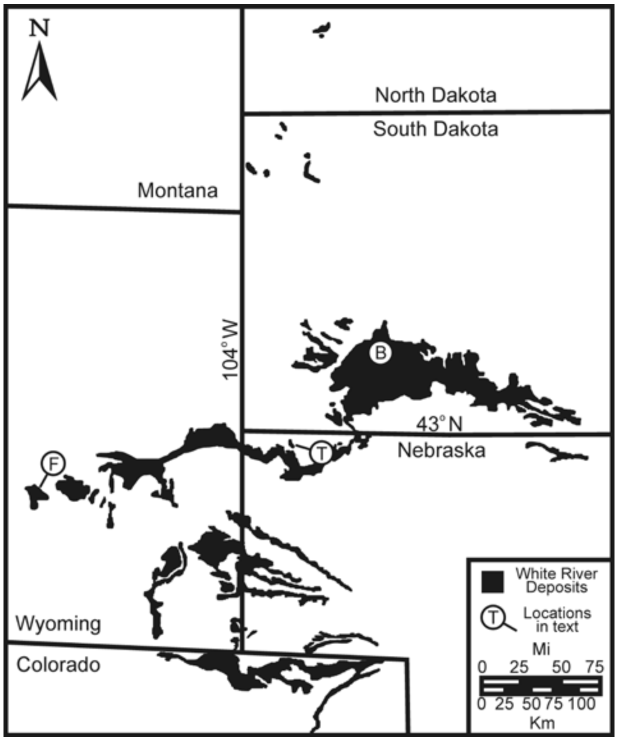

Figure 1. Exposures of the White River Sequence with study sites. B = Badlands National Park, F = Flagstaff Rim, and T = Toadstool Geologic Park.

of faunal interchange between South and North America during the Neogene.

APPLICATIONS TO RESOURCE MANAGEMENT

To fully utilize the REE methodology for management of fossil resources, protocols for establishment of a reference library of fossil bone from individual bone beds or areas particularly enriched in vertebrate fossils should be developed. This archive of representative bone samples can be used as a standard against which poached fossils can be compared, as well as providing a means to calibrate various methods of geochemical fingerprinting (e.g. ICP-MS vs. XRF). In addition to geochemical signatures, fossils from some localities may have particular diagenetic minerals or features, such as the chalcedony-enriched or iron oxide encrusted fossils near Scenic, SD (Cerruti et al. and Lalor et al., this volume). Such features, in addition to clay mineralogy and sediment type within the matrix on fossil bones, can also be used to establish provenance. Analyses of depositional environments and paleosols associated with fossil assemblages provides paleoenvironmental context for REE signatures and should be noted.

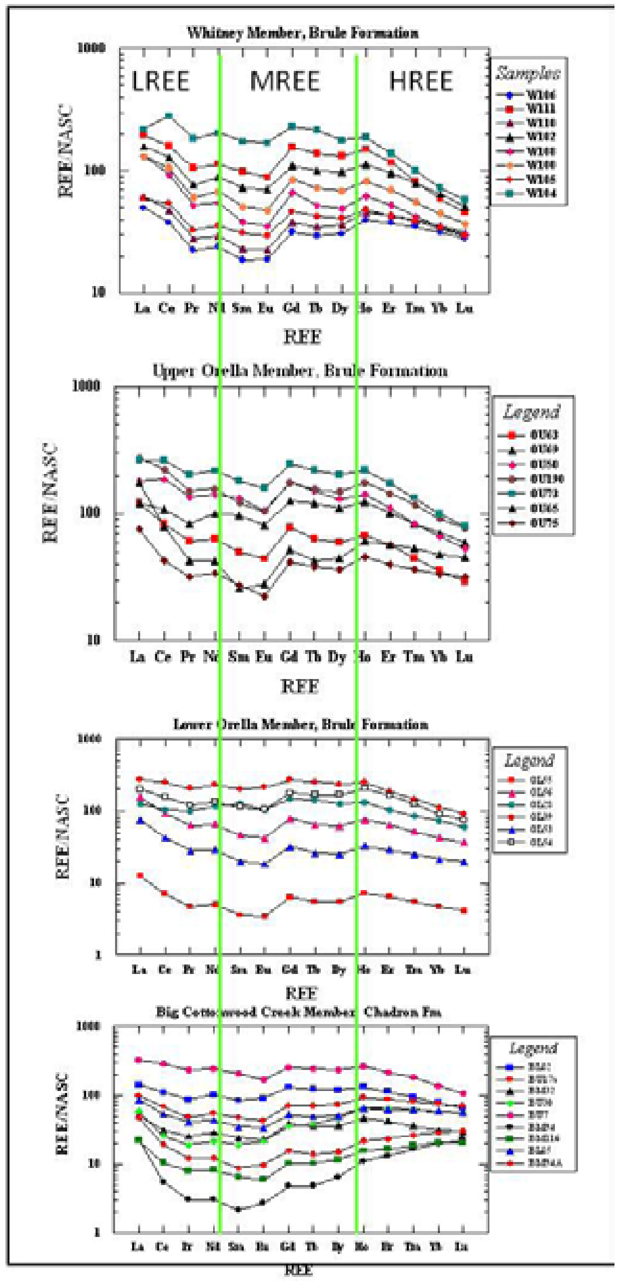

Figure 2. Stratigraphic variability of light, middle, and heavy REE signatures in bones from Toadstool Geologic Park. Modified from Grandstaff and Terry (2009).

ACKNOWLEDGEMENTS

This research has been funded by grants and cooperative agreements from the National Park Service, U.S. Forest Service, and Bureau of Land Management. We thank Richard Ash of the University of Maryland for ICP-MS analyses, and Barbara Beasley, Dale Hanson, Brent Breithaupt, and Rachel Benton for permitting and logistical support.

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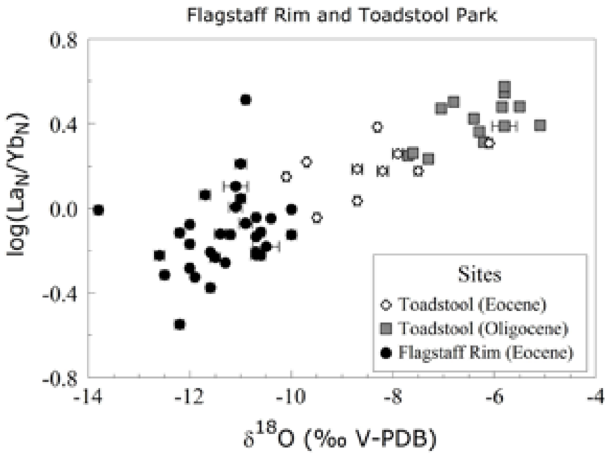

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ORAL PRESENTATION

GEOCHEMICAL FINGERPRINTING OF FOSSIL VERTEBRATES AS A POSSIBLE DETERRENT TO POACHING: SUGGESTED GUIDELINES FOR ESTABLISHMENT OF A GEOCHEMICAL REFERENCE DATABASE

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ABSTRACT—Unless a fossil poacher is caught "in the act" or confesses to a theft, establishing the provenance of a particular fossil bone to its original location on federal property is a challenge. For the past decade, numerous federal land management agencies (BLM, NPS, USFS) have partnered with the Department of Earth and Environmental Science at Temple University to investigate the utility of chemically fingerprinting vertebrate fossils as a means to establish provenance (Figure 1).

The concept of chemically fingerprinting fossil bone is based upon our understanding of the fossilization process. Upon death and burial, bone material, a very fine grained carbonate-substituted bioapatite or dahllite ($Ca5(PO4,CO3)3(O,OH)$) reacts with groundwater and recrystallizes into more stable francolite ($Ca5(PO4,CO3)3(F)$) during which it incorporates rare earth elements (REE), fluoride, distinctive ∂13C and ∂18O isotopes, and uranium (e.g., Metzger et al., 2004; Grandstaff and Terry, 2009). The proportions of these newly incorporated elements create a distinct chemical fingerprint that changes as a function of environmental conditions (e.g., oxidizing vs. reducing and acidic vs. alkaline) and the type and composition of sediment that buried the bone (e.g. sand vs. clay). These signatures are analyzed using inductively coupled-mass spectrometry (ICP-MS) and results are plotted using statistical software (Figure 2).

In order to establish a reference database of geochemical fingerprints for a particular land management unit, a

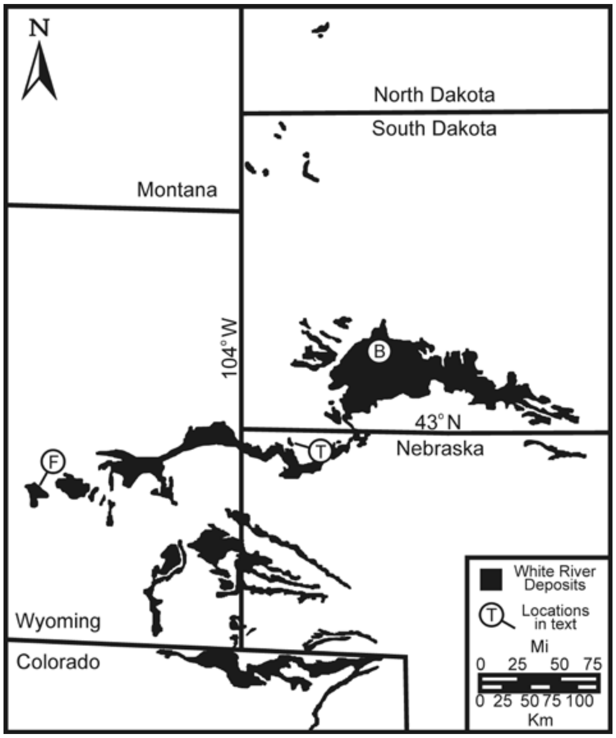

Figure 1. Outcrop map of the White River Badlands showing study sites and government affiliations. B = Badlands National Park, F = Flagstaff Rim (BLM), and T = Toadstool Geologic Park (USFS).

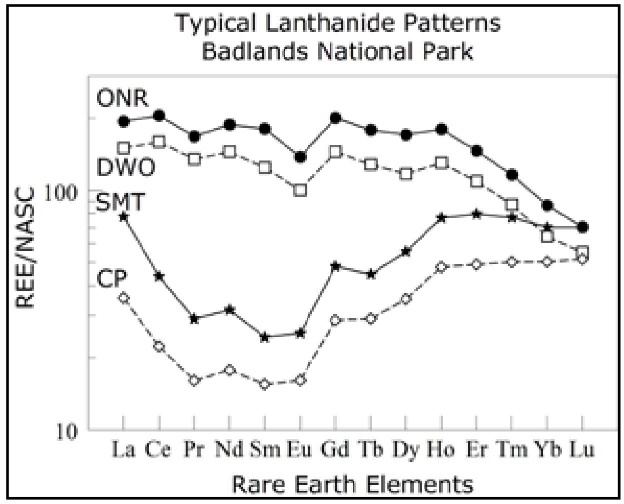

Figure 2. Representative rare earth element signatures from vertebrate fossils in Badlands National Park. See Cerruti et al. (this volume).

background survey of the geology and paleontology is required (e.g. Benton et al., 2007, 2009). The more detailed the survey, the better the database will be. Within any given set of fossiliferous strata, the concentration of fossil remains will vary as a function of rock type, which is the direct result of dominant paleoenvironmental processes at the time the sediments were deposited (Figure 3). By default, different paleoenvironments will promote different geochemical signatures in the fossil bone. Surveying the general distribution of fossils as a function of the geology provides a framework upon which to understand the potential geochemical variability within associated fossils, as well as the areal distribution of the fossil resource and potential sites of poaching activity.

Suggested Guidelines: Unless a fossil fragment can be physically reattached to other pieces of fossil bone still in the rock, establishing the provenance of a bone will require a combination of observations and analyses. At the most basic level, fossil bones will commonly be encrusted with variable amounts of sedimentary matrix. With an understanding of the geology for any given fossiliferous area, it may be possible to narrow down the stratigraphic interval from which the fossil was removed. This is especially true if the fossil in question can be identified, as certain ones will be restricted to particular intervals of the geologic record or geographic locations. In addition, the fossils themselves may have particular colors which relate to specific stratigraphic intervals or locations, or encrustations of secondary minerals that grew either on or in the fossil. Sediments on the bone can be further analyzed for composition (x-ray diffraction, x-ray fluorescence, or thin sectioning) to aid in the determination of provenance.

For defined concentrations of fossil bone (e.g. bone beds) which are commonly targeted by poachers, proactively "fingerprinting" the geochemical signatures of the fossils provides a means to directly establish provenance. In order to do this, certain criteria must be met in order to enhance the fidelity of the fingerprinting method.

1. Understand the taphonomy of any given bone accumulation. What was the environment of deposition (e.g. lake, floodplain, river channel)? Is there any evidence of time averaging? Answers to these questions will be critical when interpreting the geochemical signatures for any given bone bed.
2. Collect a thumbnail-sized fragment of bone. Cortical bone is preferred as it retains the highest "fingerprint to bone" ratio. Make sure to accurately log the stratigraphic position of the sample (Figure 3). Numerous bones should be analyzed for each site in order to document chemical variability.
3. Only 0.1g of bone material is needed for ICP-MS analyses. The remainder of the fossil fragment should be accessioned into a museum database to establish a reference library. These samples can be analyzed with additional techniques, or reanalyzed as needed.
4. Use statistical and graphical software packages to interpret chemical signatures, such as overall patterns and ratios of particular REE and TE (Figure 2).

Our current dataset spans four different regions within the White River Sequence of strata of South Dakota, Nebraska, and Wyoming (Grandstaff and Terry, 2009; Terry

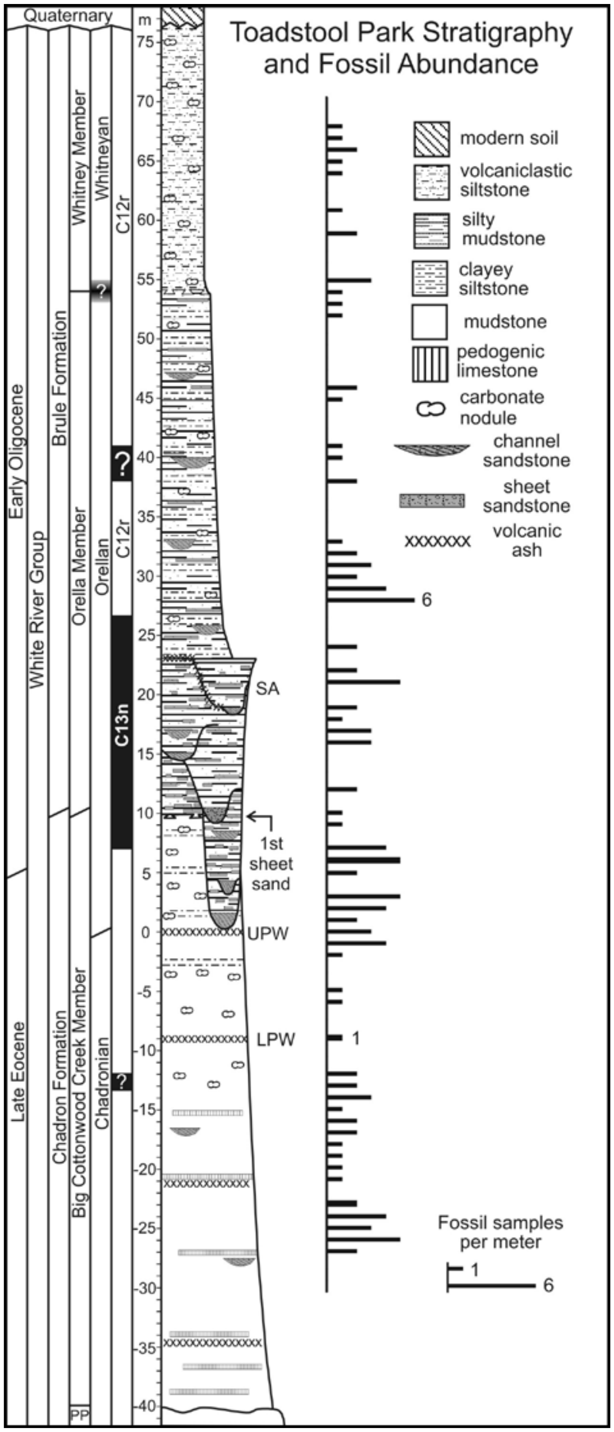

Figure 3. Measured section showing fossil concentrations. See Figure 1 for location. Modified from Grandstaff and Terry (2009).

et al., 2009; Lukens et al., 2010; Cerruti et al., this volume). Although these strata are genetically related, the geological differences between these four regions, and even within particular regions, can be discriminated using REE fingerprinting (Figure 4).

In an effort to reduce costs and to make this chemi-

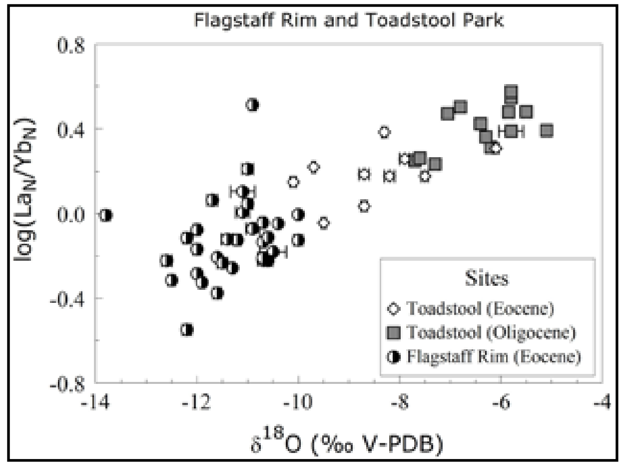

Figure 4. Comparison of rare earth element and isotope geochemical data in vertebrate fossils from Flagstaff Rim, WY and Toadstool Geologic Park, NE. See Figure 1 for locations.

cal fingerprinting method easily accessible to individual resource management specialists, we are currently investigating the fidelity of nondestructive X-ray fluorescence (XRF) techniques to rapidly measure chemical fingerprints of fossil bone in the field (see Lalor et al., this volume).

ACKNOWLEDGEMENTS

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ORAL PRESENTATION

*SMASHED RODENTS, FALSE PREPRINTS, AND THE BBC: THE PALEONTOLOGY OF MISSISSIPPI NATIONAL RIVER AND RECREACTION AREA, MINNESOTA

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ABSTRACT—Mississippi National River and Recreation Area (MISS or MNRRA), which follows the Mississippi River through the Twin Cities metro area of Minnesota, is a little-known paleontological gem of the National Park Service (NPS). The Ordovician rocks exposed in the bluffs of the river host a great diversity of marine invertebrate fossils which have received notice since the 1820s. MISS has a particularly outstanding Late Ordovician record, unsurpassed in the NPS: approximately 455 million years ago, the shallow equatorial sea covering southeastern Minnesota supported abundant corals, bryozoans, brachiopods, bivalves, nautiloids, snails, annelids, trilobites, ostracodes, crinoids, graptolites, conodonts, and other forms. The type specimens of at least 113 to as many as 360 taxa were found at sites within the boundaries of the NPS river corridor. Several notable fossil sites are located in MISS, including rare fossil localities in the St. Peter Sandstone. The Quaternary sediments that blanket the area are also productive, yielding remains of mammoths and giant beavers.

POSTER PRESENTATION

+*DANCING THROUGH DANTE'S TRACKSITE FROM THE GROUND AND AIR: THE USE OF AERIAL DATA COLLECTION AND PHOTOGRAMMETRY TO RECORD A DINOSAUR TRACKSITE IN ELK BASIN, WYOMING

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ABSTRACT—A track-bearing horizon occurs in the Upper Cretaceous Meeteetse Formation on the western limb of Elk Basin Anticline. Outcrops of the Meeteetse Formation occur in an arcuate belt approximately 12 km long offset by regional faulting. Dante's Tracksite is located approximately 31 kilometers north of Powell, Wyoming on public lands administered by the BLM. This is the first reported dinosaur tracksite from the Meeteetse Formation of Wyoming, and the first reported tracksite in Elk Basin, Wyoming. Since its discovery in 2000, nearly 300 dinosaur footprints have been documented in a well-indurated, heavily bioturbated, fine-grained sandstone. Tracks are preserved as natural depressions (true tracks and undertracks) in concave epirelief and natural casts in concave hyporelief. The tracks are formed as compressive and infill features in a key bed at the top of the Meeteetse Formation. Invertebrate traces associated with the dinosaur footprints include possible sea anemone resting traces (Bergaueria sp.), suggesting a near shore marginal marine environment with anastomosing channels, mudflats, lagoons, and tidal flats. Track morphologies consist of two distinct types of tridactyl prints, those with theropod and

those with ornithopod affinities. Extensive close-range photogrammetry was conducted during the summer of 2003 using a 35-mm tripod-based camera and low level photography from an aerial camera blimp system. Using aerial means to construct a photogrammetric mosaic of the dinosaur tracks provides a view of the tracksite possible in no other manner. The use of aerial photogrammetry allows for the accurate capture of spatial relationships of paleontological elements. Photogrammetry was used to measure the x, y and z components of the tracks. This form of study provides insights into the sedimentological conditions prevalent at the time of deposition of the tracks, as well as allowing accurate measurement of the tracks. This tracksite provides evidence for a group of dinosaurs moving through the vicinity of what is now Elk Basin in the Late Cretaceous during deposition of the Meeteetse Formation. The combination of the sedimentology and interpretation of the ichnofacies gives additional insight into the paleoecological conditions during the Campanian of northwestern Wyoming.

POSTER PRESENTATION

+CSI BIG HORN BASIN: FORENSIC MINERALOGY USING EOCENE MAMMAL BONE FRAGMENTS FROM THE WILLWOOD FORMATION, NORTHWESTERN WYOMING, A NEW TOOL FOR RESOURCE MANAGEMENT?

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ABSTRACT—Eocene mammal bone fragments (Set A) came into the possession of United States Department of the Interior, Bureau of Land Management (BLM) Law Enforcement in the summer of 2011, as a result of an investigation. Locality information for these unidentifiable fragments was not available, but a locality on federally managed lands where they might have come from, was suspected as their point of origin. Reconnaissance was made by BLM Law Enforcement along with the National Minerals Testing Laboratory (NMTL) to the suspect locality, where a second set (Set B) of Eocene mammal fragments was collected from an outcrop of the Willwood Formation. It was hypothesized that the geochemistry of the bones might be identical if both sets of fragments came from the same outcrop. The BLM National Minerals Testing Laboratory conducted an X-ray analysis of the fragments to test that hypothesis. Two bone fragments were randomly selected from both Set A and Set B for these tests. The four specimens were analyzed for mineralogical composition using a Rigaku Mini-Flex X-Ray Diffractometer. Bone fragments were prepared for X-ray diffraction using standard laboratory methods. A gram of sample is all that is needed. Bones were hand pulverized in a piston assembly and further pulverized using a diamonite mortar and pestle. The resulting powder was then mounted for X-ray diffraction. Results of the X-ray diffraction patterns were analyzed using JADE-9 software and the X-ray diffraction patterns were overlain for comparison. The four resulting X-ray patterns were 99% identical and it was concluded that there was a strong indication that the bone fragments came from the same locality. When the evidence was presented to the parties of interest in the investigation, it was disclosed to Law Enforcement that Set A had been taken from the same locality as Set B on federally managed lands. As a result of this experiment, it is concluded that X-ray diffraction may be a useful tool in identifying a fossil locality given only fossil fragments, if the results of X-ray diffraction maintain consistency when testing over multiple sets of samples. This preliminary study suggests that additional mineralogical testing using X-ray diffraction should be conducted on fossil fragments from other known localities to determine if the results from this preliminary study are consistently repeatable. If so, then this method will be helpful in determining the site location for fossils with limited provenience information, as well as enhance the BLM's and other land management agencies ability to manage paleontological resources on public lands for future generations.

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ARTICLE

FOSSIL CYCAD NATIONAL MONUMENT: A HISTORY FROM DISCOVERY TO DEAUTHORIZATION

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ABSTRACT—Through the power provided in the Antiquities Act (1906), on October 21, 1922, President Warren G. Harding created Fossil Cycad National Monument in the Black Hills of South Dakota. Scientists recognized that the fossil locality preserved a significant exposure of a Cretaceous cycadeoid forest. Hundreds of fossilized cycad specimens, one of the world's greatest concentrations, were exposed at the surface of the 320 acre site during the late nineteenth and early twentieth centuries. This rare paleontological landscape would soon experience rapid and permanent change. Years of negligent management at the monument resulted in irreparable impacts on the finite and scientifically significant paleobotanical resources. Fossils exposed on the monument's surface disappeared faster than erosion could expose other specimens from beneath. The loss of the exposed petrified plant remains eventually left the site devoid of fossils and ultimately without a purpose to justify its existence as a unit of the National Park Service. On September 1, 1957, the United States Congress voted to deauthorize Fossil Cycad National Monument.

INTRODUCTION

At the turn of the twentieth century there was a growing awareness relative to American antiquities and our natural and cultural heritage. In 1906, Congress passed into law the Antiquities Act as a means to protect some of America's cultural and scientific resources. The Antiquities Act granted the President of the United States the direct authority to designate areas of significant scientific or scenic values as national monuments.

In 1916, the National Park Service was established under the Organic Act with the mission "to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." Originally the National Park Service was established to administer areas designated as national parks, monuments, and reservations. Today, the National Park System administers a wide array of natural, cultural, and historical areas, seashores, scenic riverways, recreation areas, and a variety of other federal land designations.

In 1922, President Warren G. Harding established Fossil Cycad National Monument as a unit of the National Park Service through the authority provided in the Antiquities Act (Fig. 1). Hence, the monument and its resources were entitled to the same levels of protection and management provided through the National Park Service Organic Act. In the case of Fossil Cycad National Monument, the intent was specifically stated in the Presidential Proclamation of October 21, 1922, "rich Mesozoic deposits of fossil cycads and other examples of paleobotany, which are of great scientific interest and value; … it appears that the public interest would be promoted by reserving these deposits as a national monument".

Fossil Cycad National Monument was located in north-central Fall River County, southwestern South Dakota, about 18 km (11 miles) west-southwest of the town of Hot Springs. The site was within the southeastern Black Hills, adjacent to a section of the Black Hills National Forest. The monument originally consisted of 129 ha (320 acres), and was administered through Wind Cave National Park.

The namesake for the monument, Fossil Cycad, is actually a scientific misnomer. The primary fossil plants preserved at the site are the 'cycad-like' cycadeoids, also known as bennettitales to paleobotanists. This confusing nomenclature in no way diminishes the scientific importance of these extremely well-preserved plants which shared the Cretaceous world with dinosaurs and other prehistoric animals and plants. The preservation of the 'Minnekahta cycads' yields morphological details and reproductive structures that had not been documented in fossil cycadeoids from anywhere else around the world. These fossils enabled researchers to more fully understand an otherwise unknown portion of the fossil record.

In recognition of the scientific value of the 'Minnekahta cycad' locality, the monument's proclamation included the following language: "Warning is hereby expressly given to all unauthorized persons not to appropriate, injure, destroy or remove any of the fossils of this monument". Despite this resource protection language in the proclamation, the monument's primary resource was completely removed from the surface in a 'blink of the eye' in geologic time.

A cooperative effort between the National Park Service and the Bureau of Land Management, is ensuring that the history, archives and photographs associated with Fossil Cycad National Monument are preserved. The lesson learned from the history of this almost forgotten monument may help to increase awareness about the fragility of non-renewable paleontological resources. 'Lost—But Not Forgotten' is the legacy we strive for Fossil Cycad National Monument.

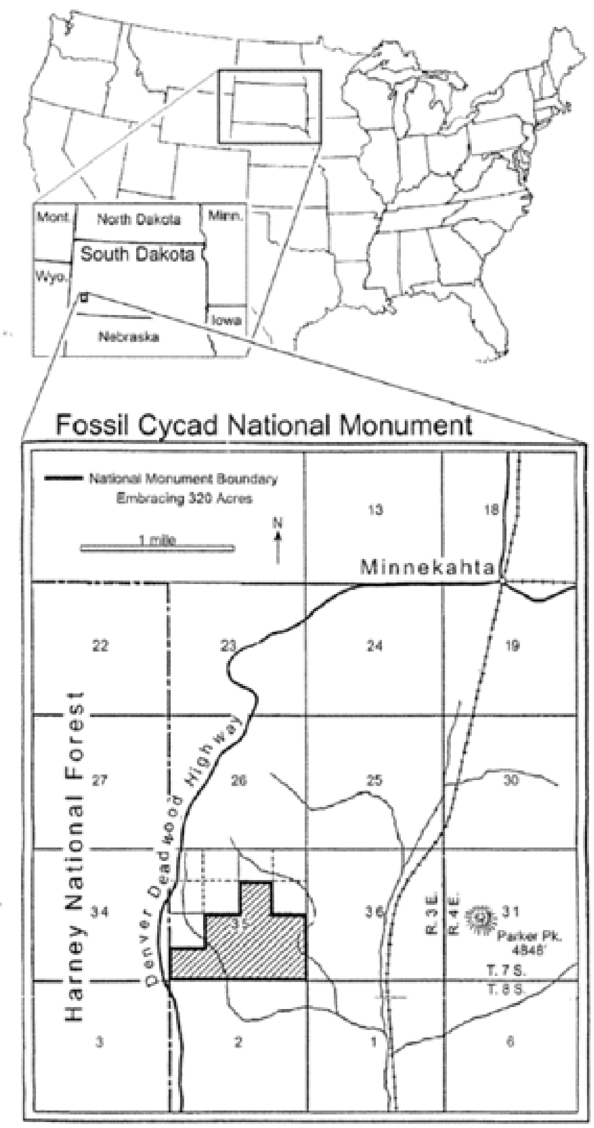

FIGURE 1. Map of Fossil Cycad National Monument, South Dakota.

DISCOVERY AND EARLY COLLECTIONS OF FOSSIL CYCADS

The early accounts involving the discovery of fossil cycadeoids in the Black Hills of the Dakota Territory remain largely unsubstantiated. Vague references to encounters with cycad fossils are associated with George Armstrong Custer's Black Hills Expedition (1874) and the Newton–Jenney Party's scientific expedition sponsored by the U.S. Geological Survey (1875).

By about 1890, around the time when South Dakota achieved statehood, local ranchers near Minnekahta and residents in the town of Hot Springs were discovering the fossil cycads. Some individuals began collecting the cycad fossils to offer for sale as curios they referred to as 'petrified pineapples'.

While visiting Hot Springs, South Dakota, in 1892, University of Iowa professor Thomas H. Macbride purchased a cycadeoid specimen from a curio shop in Minnekahta. This specimen would be designated the holotype specimen for Bennettites dacotensis Macbride (1893a, 1893b). Macbride learned that two ranchers named Arnold and Payne, who homesteaded near Minnekahta, were knowledgeable about the fossil cycad localities on and near their ranch. Macbride planned to return to the Black Hills to explore the fossil localities and collect specimens for the University of Iowa, Museum of Natural History.

During 1893 Macbride returned to South Dakota to visit the fossil cycad localities and make collections (Fig. 2). Macbride was accompanied by Samuel Calvin, Iowa's State Geologist and Chair of the Geology Department at the University of Iowa. Calvin was invited to help evaluate the geology of the cycad-bearing strata and help to determine the stratigraphic position and geologic age of the cycad beds. Macbride and Calvin traveled to the Payne and Arnold 'Horse Ranch' (Fig. 3) which was situated within the cycad locality at the base of Parker's Peak. One exposure of fossil cycads, referred to 'Macbride's Lot', was located behind Arnold's house (Ward's notes, 30 November 1898).

Macbride collected 40–50 specimens of cycadeoids from the Minnekahta locality, accumulating one of the most important collections of these fossil plants in the world. This was the beginning of many years of collecting from this area by scientists such as L. F. Ward (USGS) and O. C. Marsh and G. R. Wieland of Yale University. In October 1893, Macbride published the first paper on the fossil cycadeoids from South Dakota (McBride, 1893a, b) and in December presented along with Professor Calvin a series of papers on this subject before the Iowa Academy of Sciences. Macbride and Calvin's work helped bring scientific attention to one of the most important fossil plant localities in the country. A few of Macbride's cycad specimens were sold or donated to other scientists in the U.S. and internationally. One of the cycadeoid specimens was shipped to William Carruthers at the British Museum as a gift from Macbride in 1894.

LESTER WARD—SMITHSONIAN

In 1892, F. H. Cole of Hot Springs, South Dakota learned about the fossil cycad beds near Minnekahta from local ranchers. Cole sent photographs of the cycad fossils to Smithsonian paleobotanist Lester F. Ward (Fig. 4) which were received in Washington, D.C. in February 1893 (Ward, 1894). Ward wrote back to Cole requesting him to send one specimen back to the Smithsonian for examination. Ward was impressed with the cycadeoid specimen sent by Cole and he purchased a total of six specimens, which arrived in May of 1893. Of these six specimens, four represented new species and were designated as holotypes. In September of that same year, Ward traveled to the Minnekahta fossil locality, joined by Professor W. P. Jenney and his wife who were then in Deadwood. Ward met H. F. Cole in Hot Springs. Cole was unsuccessful

FIGURE 2. Thomas Macbride, seated on a petrified log near the Minnekahta cycad beds, was the first scientist to recognize the significance of this fossil locality (Calvin Photographic Collection, Department of Earth and Environmental Sciences, University of Iowa).

FIGURE 3. Group photo at the Payne and Arnold "Horse Ranch", Minnekahta, South Dakota, with cycadeoid fossil in foreground, c. 1893. Photo No. 1917. (Calvin Photographic Collection, Department of Earth and Environmental Sciences, University of Iowa).

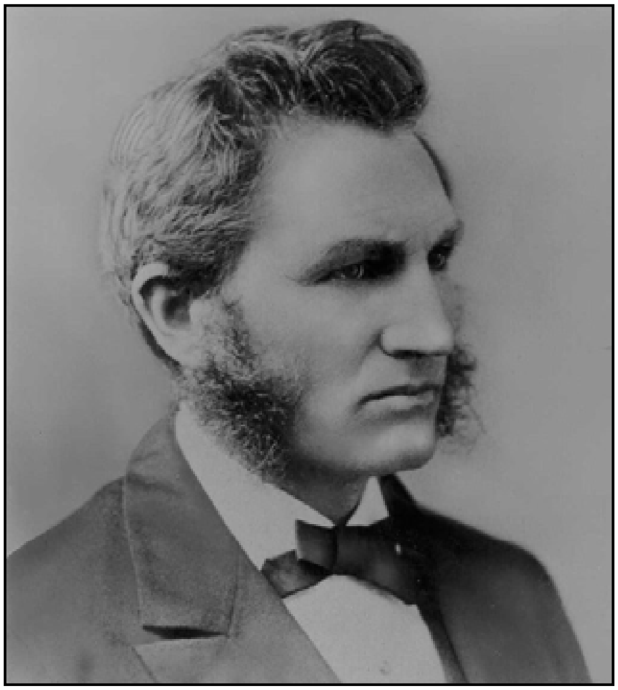

FIGURE 4. Smithsonian paleobotanist Lester Ward (Smithsonian photo).

FIGURE 5. Yale University paleobotanist George R. Wieland (Yale University photo).

in guiding Ward and the others to the fossil cycad locality, and so Mr. Payne from whom Cole had secured the original specimens was located, and he guided the group directly to the fossil locality.

By 1896, Professor O. C. Marsh of Yale had developed interest in the Minnekahta cycads and wished to secure a collection for Yale. Marsh contacted Ward in 1896 and gained useful information as to the "best means of securing them, including the names and addresses of dealers who had them for sale" (Ward, 1899). During the next few years Marsh obtained a collection of 126 cycad trunks from a South Dakota collector named H. F. Wells. Marsh invited Ward to come to New Haven during March and again in June of 1898 to study, photograph, and describe the specimens in the Yale collection. Ward would describe the Yale and Smithsonian collections in two publications (Ward, 1898, 1899).

Ward commented in later years that during "both of my visits to the Black Hills in 1893 and 1895 I saw large numbers of fossil cycads at various places, mostly in the hands of dealers, who held them for sale…" (Ward, 1899). Ward further stated that a number of local ranchers collected fragmentary cycad specimens and offered them for sale. One resident of the town of Hot Springs, named Homer Moore, was a self-proclaimed (fossil) 'dealer'.

GEORGE R. WIELAND

In 1897, a young paleontology student at Yale named George Reber Wieland (Fig. 5) began a life-long interest in fossil cycadeoids. While assisting O. C. Marsh, Professor of Paleontology at Yale University, Wieland traveled to South Dakota and met Ward. Through the encouragement of Ward and Marsh, Wieland's scientific interest in the Minnekahta cycads grew and he changed his focus from vertebrate paleontology to paleobotany. Wieland returned to Yale and the Peabody Museum and continued to study the cycadeoids. He later had two volumes titled American Fossil Cycads published by the Carnegie Institution of Washington (Wieland, 1906, 1916). In a 1900 letter from Ward to Professor John M. Coulter at the University of Chicago, Ward describes how he had strongly impressed upon Marsh the need that the study of these cycads "be taken up at Yale… [and] it ought to be a young man fully equipped in the study of modern botany" (Ward, 31 October 1900). Marsh had been impressed by the work and enthusiasm of a young assistant (G. R. Wieland) who had been helping him with some vertebrate paleontology projects, and so redirected him towards studying cycads. Ward was not aware of Marsh's decision to put young George Wieland to the task, and in the same 1900 letter expressed some apprehension as to the qualifications of Wieland, concerns that would later be proved unfounded.

Wieland's early research reevaluated Macbride's specimens which are figured in Wieland's American Fossil Cycads treatise (Wieland 1906, 1916). Wieland noted uncertainty over the taxonomic status of several specimens because Macbride refused to section the *C. dacotensis* holotype.

FIGURE 6. George Wieland supervises CCC during an excavation at Fossil Cycad National Monument in 1935 (NPS photo).

In 1920, Wieland applied to obtain the fossil cycad-rich land under the Extended Homestead Act "in order that the cycads might not fall into unworthy hands" (Hot Springs Star, 1938). Two years later, he offered to return the land to the federal government, so that a national monument could be established to further protect the petrified plants.

The 320-acre site, located in the Lakota Formation (previously referred to by some as the Dakota Sandstone), contained immense quantities of the fossilized cycadeoids. "The area is probably one of the most interesting fossil plant localities and is known amongst scientific men the world over," wrote E. C. Finney to President Warren G. Harding before the establishment of the monument (Finney, 18 October 1922). Many of the fossil cycad specimens exhibited branching features that were not previously observed. The fossil cycads held the promise of helping to explain the origin of flowering plants.

ESTABLISHMENT OF FOSSIL CYCAD NATIONAL MONUMENT

With Wieland's offer to give the homesteaded land back to the government for the creation of a monument, the government sought insight from scientists. Charles D. Walcott of the U. S. Geological Survey and the Smithsonian Institution was asked to visit the site and assess its value.

Without visiting the locality, Walcott concluded that although there were reports that all surficial cycads had been removed, "in the future, more specimens will be exposed by erosion, and at that time it would be well for the area to be under the jurisdiction of the Government" (Walcott, 15 April 1922).

After reviewing the scientific reports, the Department of Interior endorsed the establishment of a monument to protect the fossil cycad locality. On June 30, 1920, President Woodrow Wilson issued Executive Order 3297 withdrawing the specified land for examination as a national monument.

President Warren G. Harding signed a proclamation on October 21, 1922, establishing the site as Fossil Cycad National Monument: "Whereas, there are located in section thirty-five, township seven south, range three east of Black Hills Meridian, South Dakota, rich Mesozoic deposits of fossil cycads and other characteristic examples of paleobotany, which are of great scientific interest and value " (Presidential Proclamation 1641).

ADMINISTRATION OF FOSSIL CYCAD

Although the responsibility for the care and management of Fossil Cycad National Monument was assigned to the Superintendent of Wind Cave National Park, the day-to-day surveillance of monument was entrusted to local ranchers. There were only sporadic and brief visits to the site by the National Park Service during the 1920s and references to Fossil Cycad do not appear in any of the superintendent's annual reports until 1933. There was no dedicated staff or development of facilities at the monument.

The first official visit to the monument was conducted in 1929 by Roger Toll, the Superintendent at Yellowstone National Park. Toll served during the off-season as the National Park Service Director's field assistant to visit and evaluate some of the undeveloped or proposed parks and monuments in the western states. Under the direction of Horace Albright, the NPS Director, Toll conducted a site visit to Fossil Cycad National Monument on October 20, 1929 (nearly seven years to the day the monument was proclaimed). Toll met with rancher D. H. Knight, who accompanied him on his visit to the monument. Toll's November 20, 1929 site report to the Director Albright stated

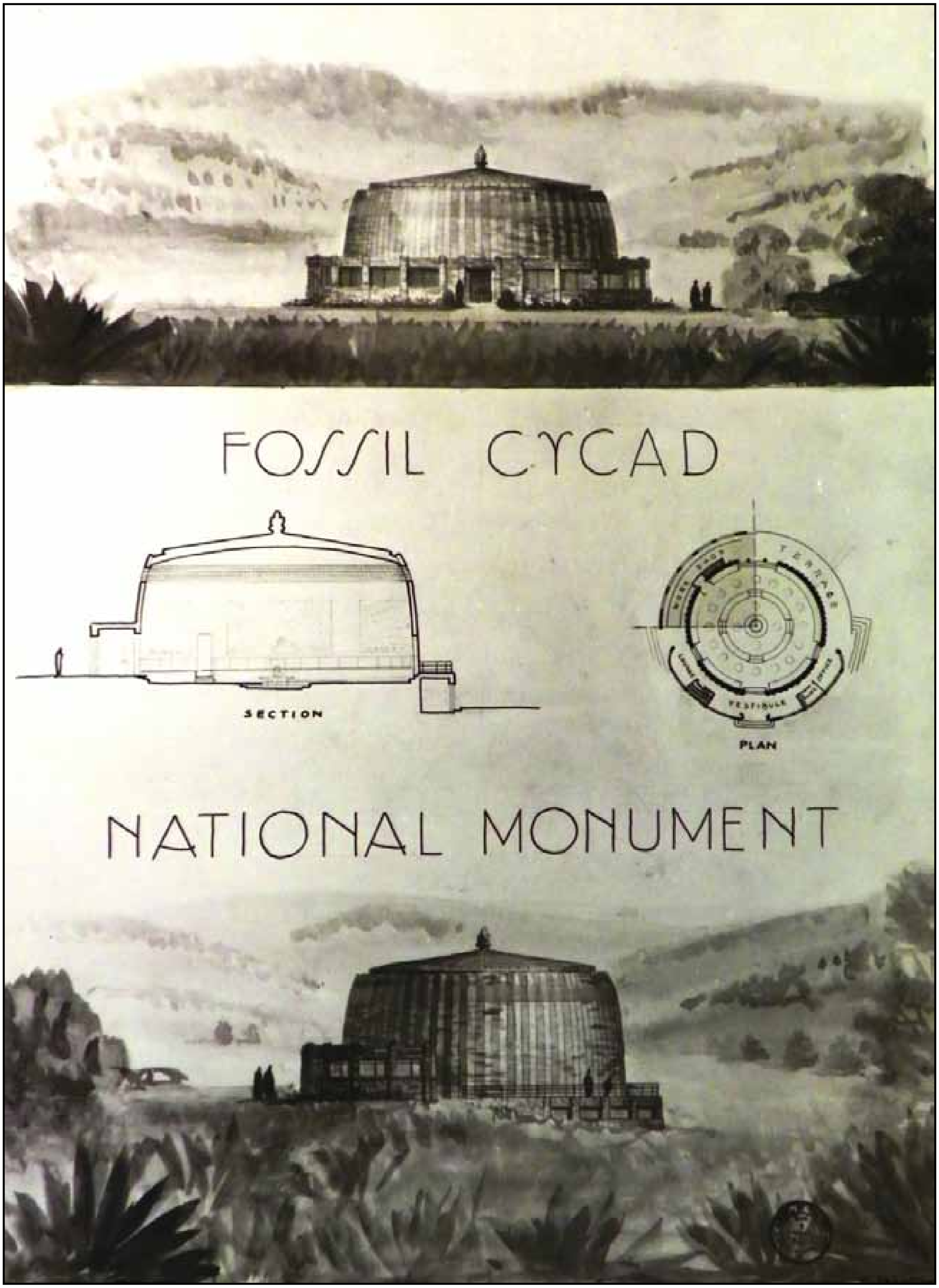

FIGURE 7. Architectural concept drawings for a visitor center at Fossil Cycad National Monument (NPS photo).

"all available specimens have been picked up, and there is nothing left that is of interest to visitors."

Toll's report poignantly concluded, "The present reputation of the national parks and monuments, as places worthy of a considerable journey, is well worth maintaining. So far as I can find out, the Fossil Cycad National Monument has nothing to protect, and perhaps no bed of fossils. If it has no value, present or future, it is a liability, not an asset, to the rest of the system. Unless Professor Wieland, or someone, can furnish information indicating some purpose to be served by the area, it would seem to be desirable to discontinue it as a national monument."

CCC AND FOCY EXCAVATION

Research on the land resumed in October 1935, when Wieland and a crew of thirteen Civilian Conservation Corps workers opened six to eight excavation pits, according to the superintendent of Wind Cave National Park Edward D. Freeland (Fig. 6). In addition to Wieland, Carroll H. Wegemann (acting chief geologist), Roy A. Wilson, National Park Service representative, and Earl A. Trager, Chief of the Naturalist Division of the Park Service were present. Wieland reported that the excavation was a brilliant success with over a ton of uneroded specimens collected. Freeland stated that the excavation had "unquestionably proven that numerous cycads still remain on the monument and excellent specimens have been found." The excavated material was moved and stored at Wind Cave National Park.

Development of the monument was not seriously discussed until around 1936, when Wieland started pressing the issue. The Park Service felt that for any development to proceed, written reports indicating the value of this site were needed. Regional Geologist Carrol Wegemann mapped the stratigraphy of the monument (Wegemann, 1936). He concluded that the cycad sand, which was six to eight feet thick, was either of the Dakota or possibly Morrison Formation. He commented that the lack of good exposures around the monument limited the view of the stratigraphic section. He also reported that the cycads occurred in stream deposits.

Trager met with Wieland at the Geological Society of America convention in New York during December 1935 with the purpose of pressuring Wieland to write up his report. Wieland indicated that his 'price' for continuing work was a black granite museum on the site to house the cycad collection (Trager, 19 February 1936). The value of the monument was already being questioned. In 1929, Acting Director of the National Park Service Arno B. Cammerer wrote to J. Volney Lewis and discussed the validity of the monument: "It was considered worth conserving at the time, and the situation surely cannot have changed. It is similar to Dinosaur [National Monument], where there is nothing on the surface to show its scientific importance, but nevertheless it is there" (Cammerer, 11 December 1929).

A letter reached Wieland in February 1936 first indicating that a proposal for abandonment had been suggested for the monument, sending Wieland into a frenzy of letter-writing to officials of the Park Service and congressmen. In the spring of 1936, following the success of the excavations during the previous fall, Wieland began to promote the need for further field work in the early summer (Wieland, 9 April 1936). His efforts at this failed due to cuts in the federal budget. Wieland's persistence eventually resulted in a visit between he and Secretary Ickes in Washington, D.C. Perhaps sensing a slowing of enthusiasm for the development of the monument, Wieland engaged in aggressive letter-writing to members of Congress during the early summer of 1936 and eventually traveled to Washington, D.C. to personally discuss the matter with Secretary Ickes. Wieland was disappointed to learn from Bryant and Ickes "that no immediate action be taken toward a development program at the Fossil Cycad National Monument" (Bryant, 15 July 1936). Wieland was advised to seek private funding to support development of the monument.

A dispute between Wieland and Wegemann started in 1935 when Wegemann accused Wieland of stealing fossils collected during the November 1935 excavation. Wegemann stated that Wieland had removed all of the original surficial specimens and taken them to Yale University before donating the land to the government. Wieland later in 1939 apparently admitted to Trager that over 1,000 specimens were removed from Minnekahta prior to the acquisition by the National Park Service (Trager, 18 March 1939). This feud escalated when Wegemann shut down the 1935 excavation at Fossil Cycad. The issue culminated when Superintendent Freeland defended Wieland and at the same time criticized Wegemann. Ironically, Wieland would later accuse Freeland of trimming the collection excavated during 1935, which was for a time stored at Wind Cave before being sent on to Yale. Freeland stated "Wegemann has an unfortunate manner with other people, and he has been tactless enough to offend Dr. Wieland, by continual rudeness." (Freeland, 18 November 35). At that point Wegemann engaged in direct communication with Harold C. Bryant, the Assistant Director of the National Park Service, regarding Fossil Cycad without the permission of Superintendent Freeland. In a letter to Wegemann, Bryant wrote that "Doctor Wilson has resigned and Doctor Wieland feels that your treatment of him was discourteous." Bryant also mentioned that Wegemann "should first have communicated with Mr. Freeland so that orders for stopping the work of excavation could have been given by him" (Bryant, 22 November 1935).

The lack of surficial in situ specimens emerged as an obstacle when Wieland insisted on the construction of a visitor center at the monument. Wieland's persistence resulted in the Director of the Park Service recommending the development of a display about fossil cycads at the Wind Cave visitor center. Wieland's response to this idea was negative. He wrote repeatedly on the value of an in situ display:

"Fossil Cycad Monument more than all others of its

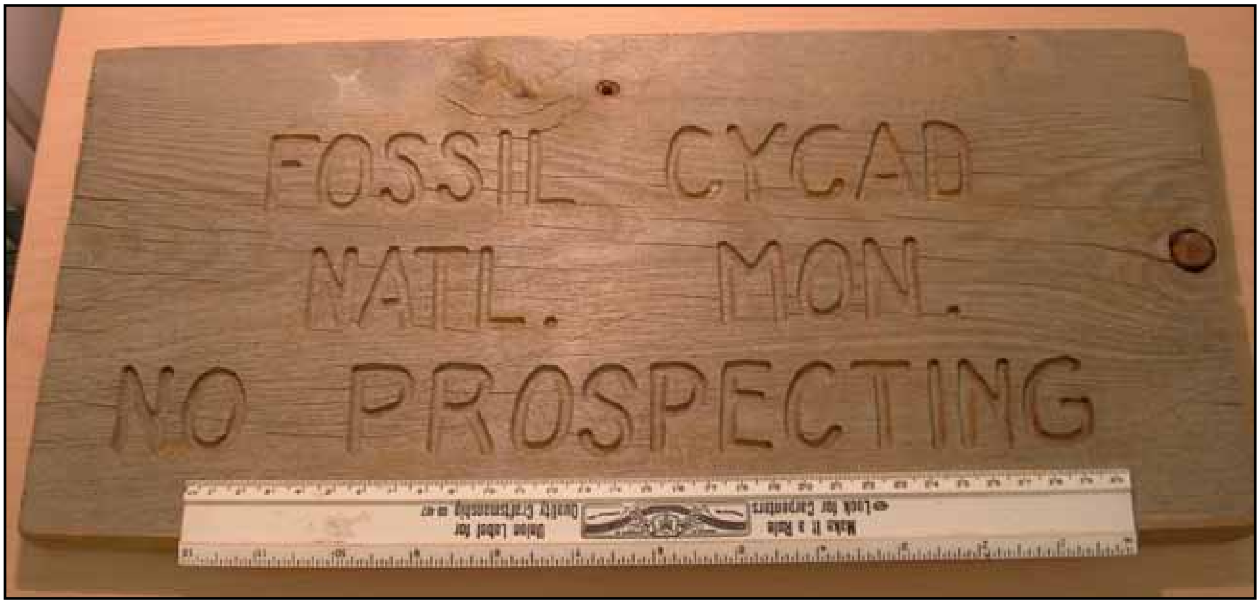

FIGURE 8. Original wooden sign from Fossil Cycad National Monument (NPS photo).

series is as we now see dependent on an absolutely in situ development and display. Without this it can mean but little, as a mere blurred shadow, all but lost again in the shuffle of time" (Wieland, 1937).

The desire to have a cycad display at Wind Cave by Freeland and Wieland's almost obsessive objection to it resulted in many years of conflict between the two men. Wieland, known for his colorful language in letters, referred to Freeland and Wind Cave as "Black Hills Patriots", "Hill billies", "Black Hills gravy train", and "Windy Cave" while Freeland was reprimanded on at least one occasion by Bryant for apparently making disparaging remarks about Wieland to the press.

In order to expedite the creation of a visitor center, Wieland asked architecture students at Yale to submit proposals for a building design. These draft plans were sent to the Department of the Interior for review (Fig. 7). The response from Washington was that the cost for construction of a building at the Minnekahta site was too expensive. In addition to the construction of the visitor center and the building maintenance, there would be a need to build roads into the monument. There was also the fact that the distinct value of Fossil Cycad National Monument eluded many people in the government:

"Developments of additional areas cannot be undertaken unless their justification is unimpeachable and their future maintenance is assured. The Fossil Cycad National Monument does not satisfy either of these requirements. It is realized that the area is of outstanding paleobotanical interest. But it is also realized that the subject of fossil cycads does not have a broad appeal and, therefore, extensive development of the monument would benefit only a limited group of people. This is particularly true since the area does not possess other outstanding attractions. The scenery is neither impressive nor is it unusual; the geological interest, other than its paleobotanic relations, is not phenomenal; the area is too small for wildlife preservation; the terrain does not lend itself well to recreational development, and there is little historic interest" (Slattery, 23 July 1937).

Wieland would reply the next day by telegram to Slattery that "a viewpoint of Fossil Cycad National Monument is utterly inadmissible to tie up with windy cave is a plan with too much bat dung to it" (Wieland, 24 July 1937).

Wieland's insistence continued. His next step was to urge senators and congressmen to contact the Secretary of the Interior regarding the developmental plans for Fossil Cycad National Monument. When these supplications failed, Wieland asked the senators and congressmen from South Dakota and Connecticut to introduce an appropriations bill that would provide funding for a visitor center at Fossil Cycad. The Department of the Interior contended that they did not have the funds to develop the monument, nor did they have a strong enough reason to seek funds:

"Naturally, the development of any exhibit of this type is dependent upon an allotment of funds and these funds can be obtained only if the proposal justified the expense and those making the allotment are convinced that the exhibit is equal to, or better than, many others now waiting development in the various national parks and monuments" (Slattery, 28 May 1937).

The constant rebuffs at development took their toll on Wieland. On August 27, 1937, in a letter to Demaray, Wieland writes "that your department has shown little practical understanding of FOSSIL CYCAD" and "You have stood my good plans off for fifteen years". Even with all this, Wieland would continue for another 15 years until his death to push for development of the Fossil Cy-

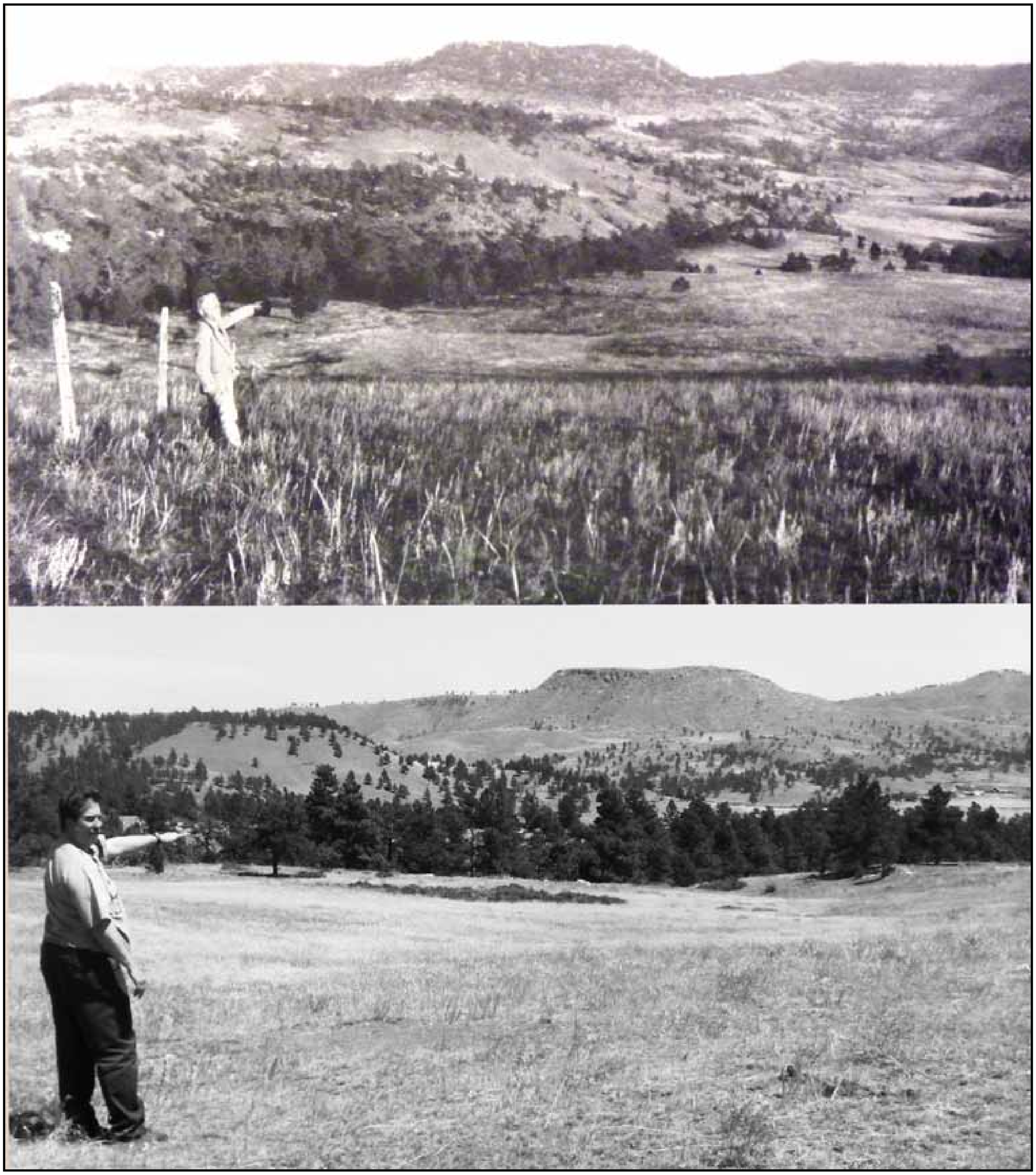

FIGURE 9. Historic and modern photos looking east towards the area once administered as Fossil Cycad National Monument with Parker's Peak in the distance (NPS photo).

cad National Monument and the realization of his dream (Wieland. 1944).

THE LOST SPECIMEN

In 1933, just before the opening of the 'Century of Progress' Exposition at the World's Fair in Chicago, the National Park Service Director's Office wrote to Wind Cave requesting a specimen of fossil cycad to be used in a display at the Fair.

Wind Cave did not have a specimen and contacted Mr. W. E. Parks of Lincoln, Nebraska. Parks agreed to loan his cycad specimen to be placed on display at the Chicago World's Fair. The National Park Service later lost the fossilized cycad specimen loaned by Parks. Mr. Parks requested that the National Park Service either replace the specimen or provide some compensation for the lost specimen.

The National Park Service effectively avoided the issue for years. Since a receipt of property was never produced at the time the specimen was received on loan, Parks' persistent claims regarding the lost specimen did not receive appropriate attention. Parks' requests for $75 as compensation for the lost specimen were challenged by the Regional Naturalist, who recommended that only $50 compensation be paid instead of the $75 requested.

In a letter dated October 5, 1945, Mr. Trager, Regional Chief Naturalist described the lost specimen as, "a crushed cycad stump about 6 or 7 inches wide by 10 or 12 inches long. It was a very poor specimen and consequently was not exhibited at Chicago" (Trager, 5 October 1945). Because of a misunderstanding, this specimen was thought to be worthless and discarded.

Wieland suggested to Parks and the National Park Service that a specimen could be made available to replace the lost specimen. In June 1946, National Park Service staff traveled to Fossil Cycad National Monument to see if they could find a cycad to replace Parks' lost specimen. A replacement specimen could not be located.

The Interior Solicitor presented his opinion in a memo dated July 16, 1946:

"Unless settlement can be made under the act of December 28, 1922 (42 Stat 1066, 31 US Code Sec 215) the only financial relief for Mr. Parks would be by Act of Congress on a Bill for his relief." (Interior Solicitor, 16 July 1946).

On January 27, 1947, the Solicitor wrote "We realize that the settlement of Mr. Park's claim has been unduly drawn out. As yet, however, no logical solution has presented itself. A monetary settlement is not possible now since the statutory limitation of one year from presenting the claim has passed long since." (Interior Solicitor, 27 January 1947).

Parks responded to the National Park Service in a letter dated April 5, 1947, "From the past it looks as if I am a victim of government red tape" (Parks, 5 April 1947). By the fall of 1947, Parks decided that his only option was to write to his congressman (Parks, 28 October 1947).

On July 6, 1949, H.R. 3010 "A Bill for the Relief of Walter E. Parks" was passed by the House of Representatives. The Bill awarded Parks a settlement of $125.

DEAUTHORIZATION OF THE MONUMENT

By the early 1950s, the principal advocates for Fossil Cycad National Monument, George Wieland and South Dakota Senator Peter Norbeck, had died. "The National Park Service thinks Fossil Cycad National Monument is a white elephant and wants to get it off its paper", according to Secretary Will G. Robinson of the South Dakota Historical Society (Robinson, 18 January 55). Representative E. Y. Berry from South Dakota introduced legislation in January 1955 to abolish Fossil Cycad National Monument. The bill was introduced at the request of the National Park Service.

Robinson suggested that the site be transferred to the South Dakota Historical Society with the intent to preserve the fossil locality from any exploitation by private individuals. Robinson traveled to Fossil Cycad National Monument on May 28, 1956 with the Superintendent of Wind Cave. There was no evidence of fossil cycad material on the surface during their visit.

According to James Bump, a professor at the South Dakota School of Mines, there are other cycads found in the Black Hills. Bump indicated, though, that other than a few specimens in the collections at his institution, Wieland apparently took all the cycads from the monument and set them up in a museum at Yale.

During the 84th Congress, Senate Bill 1161 was introduced to abolish Fossil Cycad National Monument as a unit of the National Park Service. The bill was supported by the Department of Interior and the National Parks Association. The bill was signed into law on August 1, 1956 and became effective September 1, 1957. On December 6, 1957, Assistant Secretary of Interior Royce A. Hardy issued Public Order 1562 to carry out the directive of the public law. The land was turned over to the Bureau of Land Management.

Ironically, George Wieland played a role in both the creation and abolishment of Fossil Cycad National Monument.

POST-MONUMENT HISTORY

Between 1957 and 1998, the Bureau of Land Management (BLM) has maintained the 320 acre site previously designated as Fossil Cycad National Monument within the South Dakota Resource Area. In 1980, construction within a 300 foot highway right-of-way occurred within the boundaries of the revoked monument. During construction activities, fossil cycad material was unearthed.

In 1997, the BLM published an environmental assessment (EA) that analyzed the Fossil Cycad area relative to meeting the Area of Critical Environmental Concern (ACEC) criteria. The ACEC designation highlights areas where special management attention is needed to protect and prevent irreparable damage to resources. Members of the public nominated the Fossil Cycad area for ACEC designation.

The Draft Amendment to the South Dakota Resource Management Plan prepared by the BLM states that "BLM management objectives should involve the long-term conservation of the area's geologic, and paleontologic values for future generations to study and enjoy." The preferred alternative (Alternative C) indicates the following determinations: 1) retaining the area in public ownership would help make the scientific information available to the public; 2) restricting activity would help protect the area; 3) by allowing rights-of-way, important scientific information may be uncovered during surface disturbance; and 4) this information would be recovered by the BLM and made available to the scientific community.

Fossil Cycad National Monument was never officially open to the public and never had a visitor center or public programs. According to paleontologist Theodore White, "No present areas of the National Park Service contain fossil cycads. Therefore it could be concluded that the area should have been retained in the system based on its merits in relation to the thematic evaluation." The legislation abolishing the monument contains the following statement: "That if any excavations on such lands for the recovery of fissionable materials or any other minerals should be undertaken, such fossils remains discovered shall become property of the Federal government" (S. 1161).

PRESERVING THE MEMORY OF FOSSIL CYCAD NATIONAL MONUMENT

In an effort to preserve the history of the forgotten fossil locality and abolished national monument, the senior author began to compile the archives, records, photographs and other information related to Fossil Cycad National Monument beginning in 1991 (Santucci and Hughes, 1998). The lessons learned through the history of the monument clearly illustrate the challenges associated with the management and protection of non-renewable paleontological resources. Archives associated with Fossil Cycad National Monument continue to be discovered, helping to further understand the events which resulted in the loss of a National Park Service unit.

During 2011, two original wooden routed signs from Fossil Cycad National Monument were discovered beneath other items at the Museum of Geology, South Dakota School of Mines & Technology (Fig. 8). One of these signs was donated to the National Park Service by Sally Shelton and is now curated into the collections at the Harpers Ferry Center in West Virginia. The signs represent one of the few tangible remains of the monument from the period it was administered by the National Park Service.

During 2012, National Park Service staff developed the first digital geologic map for the area previously administered as Fossil Cycad National Monument (Connors and O'Meara, 2012). This map was based upon the preliminary geologic map of the southwest part of the Minnekahta Quadrangle, Fall River County, South Dakota (Wilmarth and Smith, 1957).

In 2012, the authors of this article began to scan and organize the thousands of documents, photos and other archives associated with Fossil Cycad National Monument into a web-based database. This information is being shared with the Bureau of Land Management, the National Archives and Records Administration, several academic institutions, and the media. Through this effort the hope is to preserve the important story involving the loss of a significant fossil locality and the abolishment of a unit of the National Park Service, and to increase awareness about the fragility of non-renewable paleontological resources. Perhaps the lessons learned may be used to deter visitors to places like Petrified Forest National Park from engaging in souvenir hunting of petrified wood. Ultimately, this effort will ensure that the legacy of Fossil Cycad National Monument is 'Lost—But Not Forgotten' (Fig. 9).

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It is with pleasure that we thank a number of individuals that provided interest, input and support to this publication. B. MacIntosh (NPS Historian) and D. Nathanson (NPS Library Harpers Ferry Center) helped pull together forgotten archives related to Fossil Cycad National Monument. C. and B. Longenecker helped to ensure that every stone was unturned in our efforts to uncover the scattered information related to Fossil Cycad. We also thank L. Klise (Yale Peabody Museum of Natural History); W. Massa (Yale University Libraries); T. Adrian (University of Iowa Museum of Natural History); T. Jorstad, S. Lesser, S. Jarbo, and M. Miller (Smithsonian National Museum of Natural History); S. Shelton (South Dakota School of Mines & Technology); J. Schwarz (National Archives); and G. Liggett, B. Breithaupt, T. Baca, and historian J. Moon (BLM) for providing information and suggestions. Additional thanks to T. Connors and R. Horrocks from the National Park Service for their help in understanding the history and geology of Fossil Cycad National Monument. Finally, B. Higgins' (NPS—Geologic Resources Division) enthusiasm and interest in the Fossil Cycad story has inspired us to develop this manuscript.

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ARTICLE

WAS CHARLES H. STERNBERG THE PROFESSIONAL ANCESTOR OF THE MODERN COMMERCIAL FOSSIL COLLECTOR?

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INTRODUCTION

Charles H. Sternberg (1850–1943) (Fig. 1) was the patriarch of a family which for two generations was involved in collecting and selling fossils to wholly or partially financially support themselves. Sternberg began his collecting career in the early years of the 'dinosaur rush' of the nineteenth century, at times collecting for both Edward D. Cope and O. C. Marsh, as well as for various institutions. His three sons continued with an interest in paleontology, and all his sons ended up being employed with government or academic institutions (Rogers, 1991). Sternberg-collected fossils, whether collected by the father or the second generation, can be seen in almost every major museum in North America and Europe.

Sternberg's name and career are often invoked by modern-day commercial collectors to make the claim that they are simply carrying on in Sternberg's legacy, that their collecting activities are little different in scope than his and that they similarly contribute to the science of paleontology. The November 19, 2013 public auction at Bonhams in New York is one example of recent commercial activity involving fossils. According to the auction catalogue of fossils specimens for sale, 35 lots had estimated values over $10,000. Thirty-seven percent of those lots (13) had values over $100,000; 9% (3) had values over $500,000; and the two headlining specimens were valued at $1.8 and $7 million respectively (Anonymous, 2013). This summary does not include specimens that were pulled from the sale.

Those asking prices are considerable sums of money, and are not inconsistent with other recent fossil sales. Can modern commercial collectors claim that their activities are essentially no different than the work that Sternberg did? If Sternberg was the ancestral commercial dealer, what did his dealings look like compared with those of today? The goal of this paper is to explore the economics of commercial fossil collecting during Sternberg's time and compare that with these high-dollar sales of dinosaurs and other fossils today. Are modern collectors following Sternberg's lead, at least as far as how much he earned when fossil collecting compared to the market prices sought today?

CASE STUDY

The actions and events of Sternberg's collecting activities in the San Juan Basin of New Mexico in 1921 have been well documented (Hunt et al., 1992), and will serve as an historic case study. Whereas Sternberg did sell individual fossils, often fully prepared and mounted for display, he more often worked under contract for a benefactor for a collecting season. Under those arrangements he was paid a sum, out of which he covered his expenses and retained some amount of income for himself. All the material discovered during the contract period was shipped to the individual, or more often institution, paying the contract. In this regard his operation is in direct contrast to most of the modern commercial collectors who first find fossils, and then work to sell them piecemeal.

FIGURE 1. Charles H. Sternberg. Photograph from the Forsyth Library, Fort Hays State University, Hays, Kansas.

In 1921 Sternberg was under contract with the University of Uppsala, Sweden, and took his direction from

Dr. Carl Wiman. It was agreed that the university would pay $2,500 for the season's work and get all fossils. Immediately, we can see that Sternberg's arrangement was comparable to a contract worker being employed for a period of time, and not comparable to a vendor selling a commodity. At the end of the season, Sternberg delivered to the university an itemized list of 113 specimens, some of them being individual fossils, but they also included specimens like dinosaur and crocodile skulls, about 60 turtle skeletons, and several partial dinosaur skeletons. So how does the amount of money he was paid in 1921 compare to modern monetary values?

As any economist would tell you, this is not as simple a question as it might seem on the surface. When comparing the value of monetary amounts in different time periods (1921 compared to 2014) there are many different ways to view those values, and depending upon the metric and assumptions used, the amounts can vary widely. Also, costs of different goods and services are not constant, so what might cost $500 (in modern value) in 1921 may only cost $10 due to improvements and efficiencies of advancing technologies. For these reasons a purely straight across-the-board comparison cannot be made. All of the figures given in the discussion come from the calculators at MeasuringWorth.com (Williamson, 2014), and I acknowledge Samuel Williamson for guidance; however, all mistakes in interpretation are mine. The last year that site has modern data is 2012, so all modern figures given in the discussion are in terms of 2012 dollars.

PAYMENT AS SALARY

If we examine Sternberg's 1921 contract as if it were a salary, we might compare it to current purchasing power based upon the Consumer Price Index, which is a measure of the cost of goods and services over time. In this view, $2,500 in 1921 would purchase about $32,100 worth of material (real cost) in 2012. Another value we could compare it to is a statement of value. This value is a measure of purchasing power. Over time we purchase more consumables due to a higher standard of living, and the prices of those consumables increase due to inflation. So, $2,500 in 1921 could be valued today as being able to purchase $79,700 (real value).

However, we must remember that the money paid to Sternberg was both salary and operational expenses, from which he had to buy supplies and hire wagons, horses, and laborers. Throughout the season, Sternberg wrote to Dr. Wiman about sending the money from the contract as apparently Sternberg fronted the money for the season in anticipation of Wiman paying. In letters dating at least from July, 1921 until he was finally paid sometime after November, 1921, Sternberg complained to his benefactor about lacking the funds.

On July 30, 1921 Sternberg wrote to Wiman and asked for the money in a post script:

"PS I am depending on the money being sent to Glendale National Bank Calif. The first of August, to meet my expenses here they are heavy." (All quotes taken from Sternberg letters are printed in Hunt et al. [1992]).

By September 4, 1921 Sternberg's tone became more urgent:

"The thing that worries me is that I have received no notice from the Glendale National Bank that the $2500 has been received. It is very serious as I depended on that money to continue my work until the end of my contract and I do not want to lose any time going to town as I will have to in order to cable you asking where the money is. It is a serious thing to be out of money here among strangers."

Despite these pleas, Sternberg continued work and reported his discoveries to Wiman. Late in the field season Sternberg discovered a nearly complete ceratopsian skeleton, articulated but lacking a head. Perhaps hoping to play upon any guilt Wiman might have about the delay in transferring the money, Sternberg suggested that this specimen was worth a bit of extra money to compensate for the extra time he took to collect it. He wrote on November 14, 1921:

"Taking up this specimen and travelling by my Fords [sic] truck will take me to the end of December. You will realize as I found it [the ceratopsian skeleton] during contract time I cannot keep it myself. Farther that when I started taking it up I had to finish. This of course greatly injured me financially. For that reason I cabled you and you freeded [sic] yourself by saying 'no more money.' Unless I receive $622 ½ in addition to the $2500 I will have worked 5 months for the bare expenses of my expedition. But under the circumstances I am forced to send the skeleton to you. I have sold skeletons no better for $2000."

This reply indicates that Sternberg had already asked for extra money and that Wiman had replied no. Hunt et al. (1992) speculated, and I also think it likely, that Wiman did not take Sternberg up on sending extra money, although he was apparently eventually paid the original contract price and the specimens shipped to Sweden.

There are several telling bits of information in this correspondence that provide evidence of Sternberg's sense of honor, and the commercial value that he placed upon his work and the fossils. If we are to fully believe Sternberg, the expedition cost him more than the $2500 agreed upon, leaving no room for his profit, and he even suggested a rather specific price of $622.50 to make him whole.

There is no way of knowing how much money over his overhead Sternberg made, or if he did lose money. For the sake of argument, if we assumed that Sternberg exaggerated his financial situation to Wiman, and in fact could pocket $500 as profit (extremely unlikely), than that amount of money adjusted to today would be $6,410 using the Consumer Price Index (historic standard of living), $15,900 under the statement of value index (contemporary standard of living), or $37,700 using an economic status index that measured the relative 'prestige value' using per-capita Gross Domestic Product (GDP).

PAYMENT AS COMMODITY

It is clear in the given case study that Sternberg was not selling the fossils he collected as a commodity, but that he collected under contract. However, we can gain some insight into the commercial value of fossils as commodities at that time from the correspondence. Sternberg noted that the ceratopsian skeleton that he collected was in itself worth $2,000, although this is likely an exaggerated value. What is the modern monetary equivalent to that 1921 estimate of value?

To estimate the modern value of a commodity we can again turn to the Consumer Price Index, which gives an indication of how much an item would cost in today's dollars (real price). Another valuation indicates how 'affordable' that amount would be to an average person by taking into account wages over time (income labor value). Again using the calculators at measuringworth.com those numbers for a $2,000 dinosaur skeleton in today's money are $25,700 (real price) and $112,000 respectively (labor value). We know that Sternberg was paid $2,500 for all the fossils he collected; including the one he suggested was worth $2,000. However, for the price of $2,500 the total lot of specimens, all 113, shipped for the modern values of $32,100 (real price) or $141,000 (labor value).

PAYMENT AS A PROJECT

Another potential way to evaluate what Sternberg was paid in 1921 for the collection of the dinosaur material is to view it from the standpoint of the university that hired him to carry out the project, in this case the expedition and collection of fossils. In other words, the decision was made that this use of $2,500 was an appropriate and affordable project as they could have chosen to spend that money another way. For example, labor costs in Sweden were generally lower than in the United States, so the $2,500 could have purchased overall more labor at home (Bureau of Labor Statistics, 1927), and might have been used to cover a lecturer at the university, for example, rather than buying fossils. As with the other evaluation methodologies there are several different approaches to this.

Using a Historic Opportunity Cost index compares the cost relative to the GDP Deflator. The GDP Deflator is an index that represents the 'average price' of all goods and services produced in the economy, with changes in the Deflator being a broad measure of inflation. It is generally preferred to use Consumer Price Index for projects of a person, but is included here for discussion. The $2,500 paid for this project in 1921 calculates to be a modern project value of $25,600.

DISCUSSION

How profitable was the life of a fossil hunter in 1921? These data suggest that if we generously grant Sternberg a net profit for his time in the field after expenses, he may have made $6,410 to $15,900 (in 2012 dollars) for five months of work. Assuming he could do that all 12 months (which he could not due to weather) his annual modern income at least for that year could be approximated as $15,384 to $38,160. In 1921, Sternberg was not a young man at 71 years of age, so he was not at his prime, however there is no reason to think that this range of income was not generally typical for him. At the highest estimate of $38,160 annually Sternberg earned more than the modern poverty rate for a two-person household (him and his wife) of $15,510 (Federal Register, 2014), but again it is very unlikely that he was able to net that much for the summer's work. The lower estimate of $15,384 puts him just below the poverty line.

If he had been able to sell the fossils he collected individually, his 'prize' specimen of the season, with his likely inflated estimate of worth of $2,000 in 1921, he might have been able to sell for somewhere between $25,700 and $112,000 in modern dollars.

Looking at the season from the point of view of the university that hired him it seems to have cost them about $25,600 (in 2012 dollars) for a season's work to mount the expedition, pay their labor and expenses, and bring in a sizeable collection of fossils. This seems like a reasonable approximation of what many museums who conduct field collecting trips might anticipate their costs to be. At least it is not wildly out of line.

In the Bonhams sale of November 19, 2013, 35 lots had estimated values over $10,000. Of those, more than a third had values over $100,000, and 9% were valued over $500,000. The two headlining specimens, a full Tyrannosaurus rex mount and the "Montana Dueling Dinosaurs", had asking prices of 3.6 to 14 times over $500,000. (It should be noted that most of these high-dollar specimens did not sell that day). In his 'wildest' estimate, Sternberg's ceratopsian dinosaur had a modern value of $112,000, but was really much closer in value to the real price of $25,700.

It is understood that the exercise undertaken here involves a lot of room for interpretation. The specimens at auction could be argued to have been especially commercially valuable, whereas those collected in 1921 by Sternberg might not be directly comparable. This is not a large data set of historic sales. It may not be without merit that economics was once called "the dismal science" by historian Thomas Carlyle. It might be an impossible task to attempt an analysis like this, at least when done by a paleontologist. However, I think some conclusions can be drawn.

First, Sternberg did get paid to collect fossils, but that meant he was a commercial fossil collector, not a commercial fossil dealer. He was often paid for his labor and expenses on contract, and not for the specimens themselves. Even when he attempted to convince Wiman that he should get paid more because of the quality and expense involved in collecting the ceratopsian partial skeleton, he knew that the specimen already belonged to the university because that was his contract.

Why did Sternberg not push harder to make the case that he should get more money? Clearly if he really felt that the single specimen could be sold for the price he gave he might have tried harder to work a different deal. Honor is certainly one reason—Sternberg knew the terms of the contract he entered. However, no doubt the market at the time also played a large role. Universities and museums were the only ones buying fossils, period. There was no larger market demand for fossils as decorative or novelty items such as there exist today.

To illustrate that point we turn to the unrelated case of Earl Douglass. In 1913, in a clever attempt to secure rights to the public lands that would one day become Dinosaur National Monument in Utah, Douglass filed a mining claim on the land to gain exclusive rights for the Carnegie Museum to collect there. The claim was denied by the Department of the Interior (DOI) and Douglass appealed that decision. The DOI has the authority to adjudicate appeals and grant a final decision in cases like this. The claim was ultimately denied on the grounds that fossil bones could not be classed as a "mineral product in trade or commerce, nor does it [dinosaur bones] possess economic value for use in trade, manufacture, the sciences, or in the mechanical or ornamental arts;..." (Department of the Interior, 1916:326). At least in 1915, the DOI could find no commercial value in dinosaur bones. That finding might surprise a modern reader who has seen dinosaurs sold for millions. Sternberg did not have a wide supply of eager buyers.

Lastly, Sternberg was very clear about his own motives. He was driven by the love of the fossils and the contribution that he felt he was making to science. In a December 6, 1919 letter to Dr. Wiman he wrote:

"Every dollar I receive goes back into the expenses of my field and laboratory work...So I feel with you I can look back upon my life with gratitude to God that He has chosen me, a small insignificant crippled man to add to His glory, by adding to human knowledge the wonderful story of his [sic] buried dead. With that sentiment I have been able to endure contempt, lack of support and a thousand other things that irritate a man, who works among a people so wrapped up in the pursuit of the Almighty Dollar, they can see nothing else. But enough of my self. Let my works stand as an enduring monument to my devotion to science."

To compare most modern commercial fossil collectors and the modern market for fossils to the time and the man of Charles H. Sternberg is just plain wrong, and is a disservice to his memory. The professional phylogeny from Sternberg is more properly traced to museum and university employees who have, like Sternberg, found a way to make a modest living by doing what they love, collecting and preserving fossils for the good of us all. His actions and words show that Sternberg was far more similar to those academic collectors than to the modern version of those selling fossils. While commercial fossil collectors of today may share some similarities, some plesiomorphic traits if you will, with Sternberg, theirs is a much different business in a very different world. In 1921 Sternberg sold 113 specimens, including a 7.5 foot ceratopsian skull; a partial ceratopsian skeleton; other dinosaur vertebrae, jaws, teeth, femora, and numerous sundry other parts; partial crocodile skull; and close to 60 turtle skeletons. If we assume their worth was equal to the highest modern value calculated in these exercises, the claim might be made they were all combined worth $141,000 in modern terms. It looks like in 1921, $100,000 bought a lot more than one can get today.

Critics might point out that today there is more of a market demand, and that it is demand that drives prices up to their current levels, and it is all just the action of the free market. The point is granted. But Sternberg collected before these present market conditions, worked on slim margins with limited market demand, and yet he toiled on, with a true deep passion for science. He was not inspired by potential astronomical financial gains seen in modern times. For these reasons modern commercial fossil collectors should relinquish any claim of professional phylogeny with Charles H. Sternberg, or any of his clan.

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ARTICLE

FOSSIL POINT (LAKE CLARK NATIONAL PARK & PRESERVE): ALASKA'S "JURASSIC PARK" FOR MIDDLE JURASSIC INVERTEBRATE FOSSILS

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ABSTRACT—The Fossil Point area on the south side of Tuxedni Bay is situated within Lake Clark National Park & Preserve in south-central Alaska. This aptly named topographic feature contains one of the most productive marine invertebrate fossil sites known in Alaska. Two formations, the Fitz Creek Siltstone and overlying Cynthia Falls Sandstone, both elements of the Tuxedni Group, are present in exposures at Fossil Point. The rich and well preserved invertebrate fauna was recognized during the nineteenth century when the area was previously part of Russian America. Eichwald (1871) provided some of the first descriptions and illustrations of Jurassic fauna from from Fossil Point and elsewhere in Alaska. The inoceramid bivalves described by him are now assigned to the genus *Retroceramus* (Blodgett, 2012). Four inoceramid species were established by Eichwald, and there has been considerable debate subsequently by paleontologists as to the validity of these species or whether or not they merely represent ecological variants belonging to one or two species. The Middle and Upper Jurassic fauna exposed in Tuxedni Bay indicate a major global climatic cooling event. The Middle Jurassic Tuxedni Group and overlying Chinitna Formation faunas represent warmer water (probably subtropical to warm temperate) compared to the succeeding fauna of the Upper Jurassic Naknek Formation representing cool water (probably cool temperate) typified by a boreal fauna consisting predominantly of the bivalve *Buchia*. Recommended future work would include producing a measured section and obtaining detailed biostratigraphic collections for the purpose of better documenting the fauna, establishing the morphological variability of the component species and describing the remaining accompanying invertebrate taxa that have not been documented to date. Hence, Fossil Point provides an excellent laboratory to study dramatic climatic change within the middle part of the Mesozoic.

INTRODUCTION

Fossil Point is a prominent headland located along the south side of Tuxedni Bay on the west side of Cook Inlet, south-central Alaska (Figs. 1). The Middle Jurassic strata exposed at Fossil Point (Fig. 2) have long been known for their extremely prolific fossil invertebrate marine fauna. Knowledge concerning the cornucopia of fossil materials available here extends back to the final days of Russian America, in what is today Alaska. A significant fossil collection was made by the Russian mining engineer Peter Doroschin and sent to the Russian capital at St. Petersburg, where they were ultimately studied and described by Eichwald (1871) (Fig. 3). Eduard von Eichwald (1795–1876) described many important Jurassic fossils from Alaska. His material was collected when Alaska was still part of the Russian Empire. Eichwald was one of Russia's early and preeminent paleontologists. He was of German ancestry and was born in present-day Latvia, but spent much of his later career in St. Petersburg. Most of his scientific articles were written in German, but appeared in various Russian publications.

Fossil Point has long been known to Cook Inlet fishermen who would fish in Tuxedni Bay. Extensive fossil collecting has taken place at Fossil Point by private fossil collectors (Rock, 1980), and fossil specimens from Fossil Point are on display in various businesses in the cities of Homer and Anchorage. The most common megafossils found at Fossil Point belong to the widespread plexus of early inoceramid bivalves which are characteristic of Alaska's Middle Jurassic strata, both in southern Alaska as well as the Arctic Coastal Plain (Imlay, 1955, 1965). These early members of the family Inoceramidae were formerly referred to the genus *Inoceramus*, but more recently have been transferred to a separate new genus *Retroceramus*, established by Z. V. Koshelkina based on her studies of Middle Jurassic Siberian faunas. Among the earliest named species of the genus were four species established by Eichwald (1871) from the area of Tuxedni Bay on the west side of Cook Inlet (see Figures 4–8 for examples). These four species (all originally assigned to the genus *Inoceramus*) are: *Retroceramus porrectus* (Eichwald, 1871) (Fig. 4); *R. ambiguus* (Eichwald, 1871) (Fig. 5); *R. eximius* (Eichwald, 1871) (Fig. 6); and *R. lucife*r (Eichwald, 1871) (Fig. 7).

As noted above, Eichwald's Alaskan inoceramid specimens were collected in and around Tuxedni Bay on the west side of Cook Inlet. They are especially common at the aptly named Fossil Point along its south shore, where they are the most easily recognizable fossils found in exposures at the locality (Fig. 2). The inoceramids from Fossil Point and Tuxedni Bay are referenced in several publications, including Dall (1896), Hyatt (1896), Stanton and Martin (1905), Martin and Katz (1912), Martin (1926), Moffit (1927), Detterman (1963), and Detterman and Hartsock (1966). Similar inoceramids are found in coeval strata of the Iniskin Peninsula south of Tuxedni Bay (Blodgett and Tainter, 2013). Ralph W. Imlay (1908–1989) is regarded as the foremost expert on Alaska's Jurassic fossils and

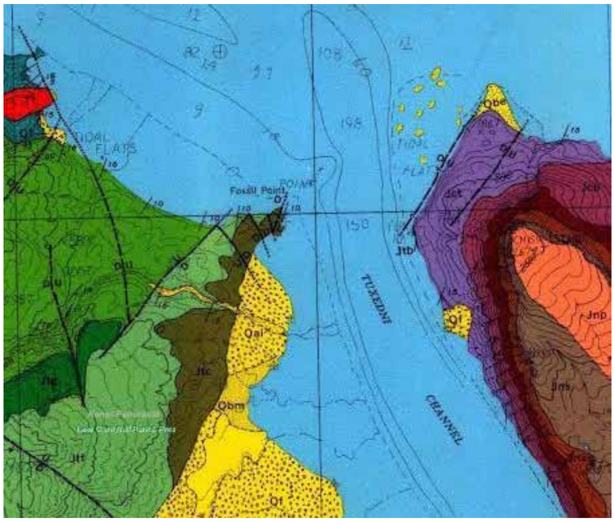

FIGURE 1. Geological map of part of the western side of Cook Inlet showing Fossil Point, Tuxedni Bay, and Chisik Island (modified from Magoon et al., 1976). The strata at Fossil Point are assigned to the Cynthia Falls Sandstone of the Tuxedni Group (shown in brown), to the west of which are adjacent to outcroppings of the Fitz Creek Siltstone (shown in light-green color) of the Tuxedni Group.

recognized only two of Eichwald's species as being taxonomically valid, with the remaining two being regarded as merely synonyms or variants. However, Russian paleontologists have regarded these four species as all being viable for biostratigraphic and taxonomic studies. In light of their great prominence in faunas of the Middle Jurassic, it seems timely for a renewed effort to systematically collect these forms from throughout the stratigraphic section exposed at Tuxedni Bay in order to better chronicle their variability, taxonomic validity, and stratigraphic significance. A direct comparison to the original specimens used by Eichwald is obvious, and not a daunting task, as this material is deposited in St. Petersburg, Russia.

STRATIGRAPHIC SUCCESSION AT FOSSIL POINT

Two lithostratigraphic formations are exposed at Fossil Point, the Fitz Creek Siltstone and overlying Cynthia Falls Sandstone (Fig. 1). Both units are considered to be of middle Bajocian (early Middle Jurassic) age and are recognized to be distinct formations within the Tuxedni Group. Figure 9 shows the stratigraphic succession within the Tuxedni Group and their relationship with the underlying Talkeetna Formation and overlying Chinitna Formation.

FITZ CREEK SILTSTONE OF TUXEDNI GROUP (MIDDLE BAJOCIAN)

The Fitz Creek Siltstone was named by Detterman (1963), replacing the informal terms "lower siltstone member of the Tuxedni Formation" of Kirschner and Minard (1949) and the "siltstone member of the Tuxedni Formation" of Imlay (1953). The formation was named for Fitz Creek, the principal stream on the Iniskin Peninsula to the south of Tuxedni Bay. The type section is located along Tonnie Creek on the Iniskin Peninsula. Detterman and Hartsock (1966) stated that the sections of this formation ranged in thickness from 198 to 380 m (650 to 1,280 ft), with the type section being 332 m (1,090 ft) thick. The contact with the underlying Gaikema Sandstone was stated by these authors as conformable in all sections. The contact with the overlying Cynthia Falls Sandstone was noted to be sharp and usually conformable in most areas, with the exception of the area just north of Hickerson Lake where the contact is locally unconformable. The formation crops out on both the Iniskin Peninsula and to north as far as the south shore of Tuxedni Bay, where it terminates at Fossil Point. Detterman in Poulton et al. (1992) describes the formation as thin-bedded dark gray siltstone with limestone concretions, minor thin sandstone, with a thickness ranging from 150 to 390 m (492 to 1,279 ft).

Fauna

The marine invertebrate fauna (Table 1) of the Fitz Creek Siltstone has long been noted as being abundantly fossiliferous and it has by far the most diverse fossils of all the formations which comprise the Tuxedni Group. For the first time in the stratigraphic record, ammonites play a more prominent role in the fauna than bivalves, which dominated the underlying Red Glacier Formation and Gaikema Sandstone. This difference was attributed by Detterman and Hartsock (1966) to the different environments indicated by the dominance of siltstone in the lower units, as opposed to sandstone in the overlying Fitz Creek and Cynthia Falls.

Detterman and Hartsock (1966) noted that the most common bivalves in the formation are *Inoceramus* (=*Retroceramus* in this instance) and *Pleuromya*. The *Retroceramus* found in the Fitz Creek is *R. ambiguus* (Eichwald), which is different than the common retroceramids founds in the older beds. They also commented that the *Pleuromya* is a smooth type, in contrast to the coarsely ribbed forms found in the older beds of the Tuxedni Group. Other abundant but less common bivalves are *Trigonia*, *Parallelodon*, *Pecten*, *Camptonectes*, and *Astarte*. Descriptions of ammonites from the Fitz Creek Siltstone are found in Imlay (1964).

Age

The Fitz Creek ammonite fauna is correlative with the *Otoites sauzei* and *Stephanoceras humphriesianum* zones of northwestern Europe. Imlay (1964) and Detterman and Hartsock (1966) both indicate a middle Bajocian age for the Fitz Creek ammonite fauna. Imlay (1982, 1984) also gave a middle Bajocian age for this formation.

Biogeographic affinities

As noted previously Imlay (1964) considered the middle Bajocian faunas of the Tuxedni Group to have their closest affinities (generically and specifically) with coeval

FIGURE 2. Various views of Fossil Point. **A**, Aerial view from the northeast; **B**, More distant aerial view from north-northeast; **C**, Closer aerial view from northeast.; **D**, Historical photo taken by C. W. Purington in 1896 of the prominent headland at Fossil Point (compare with modern view in right-center of Fig. 2C). This same photo appears as Plate LVIII in Dall (1896). Figures 3A–3C courtesy of Richard G. Stanley, U.S. Geological Survey, Menlo Park, California.

faunas known from other parts of the Pacific coast from Alaska to California, rather than with those of the same age known from the western interior of Canada and the U.S.

CYNTHIA FALLS SANDSTONE OF TUXEDNI GROUP (LATE MIDDLE BAJOCIAN)

The unit was first recognized as the Cynthia Falls Member of the Tuxedni Formation by Kellum (1945) and was later raised to formational status by Detterman (1963) within his Tuxedni Group which he concurrently raised from formation to group status. The Cynthia Falls Sandstone was considered by Detterman to be 180 to 210 m (600 to 700 ft) thick. The type section was designated as being on Tonnie Creek, and was named after Cynthia Falls, a prominent waterfall on Hardy Creek on the Iniskin Peninsula. The formation consists mainly of massive to thick bedded coarse-grained greenish-gray graywacke-type sandstone, interbedded with lesser, thick layers of pebble-cobble conglomerate and arenaceous siltstone (Detterman, 1963). Graded bedding was also noted as being present in the sandstone (Detterman and Hartsock, 1966). Detterman in Poulton et al. (1992) described the unit as being composed of medium to thick bedded greenish gray sandstone with few conglomerate beds, containing very few fossils, and indicated its thickness to be ca. 200 m (660 ft.). The contacts were also stated by Detterman (1963) to be conformable with the underlying and overlying formations. However, Detterman and Hartsock (1966) noted that the lower contact with the Fitz Creek Siltstone is conformable and sharp except near Hickerson Lake, where a slight angularity was said to exist. In addition, they indicated that the upper contact with the overlying Twist Creek Siltstone is conformable throughout most of its areal extent. The exception to this occurs in an area in the southwestern Iniskin Peninsula, where the Twist Creek is removed, and the Bowser Formation unconformably overlies the Cynthia Falls Sandstone. The areal extent of the Cynthia Falls Sandstone starts at the southern terminus near the southwestern edge of the Iniskin Peninsula, proceeding NNE and terminating at the its northernmost exposure at Fossil Point on the south shore of Tuxedni Bay.

Fauna

The fossil fauna from the Cynthia Falls Sandstone (Table 1) is limited in diversity, being somewhat devoid of molluscan remains. The ammonites *Chondroceras* and *Stephanoceras* suggest correlation with the European standard ammonite zone of *Stephanoceras humphriesianum* (Imlay, 1964:B14; Detterman and Hartsock, 1966). The few bivalves found in the formation included faunal elements suggesting links with the underlying Fitz Creek Siltstone. Ammonites from this formation were described in Imlay (1964), who noted that few ammonites were found


GEOGNOSTISCH-PALAEONTOLOGISCHE

BEMERKUNGEN

ÜBER DIE

HALBINSEL MANGISCHLAK

UND DIE

ALEUTISCHEN INSELN

VON

Dr. Eduard von Eichwald.

St. PETERSBURG.

Buchdruckerei der Kaiserlichen Akademie der Wissenschaften.

1871.

FIGURE 3. Cover of Eichwald's 1871 classic paper in which the first taxonomic descriptions of marine invertebrates from Fossil Point were made.

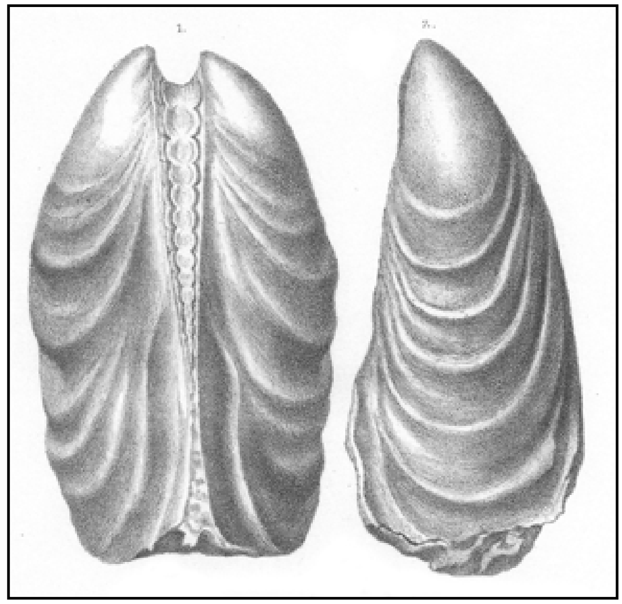

FIGURE 4. *Retroceramus porrectus* (Eichwald, 1871) (originally named *Inoceramus porrectus*). Eichwald (187:191) reported this species from the entrance to Tuxedni Bay ("Einfahrt in die Bucht Tukusitnu"), corresponding to the exposures directly at Fossil Point on the south side of the bay.

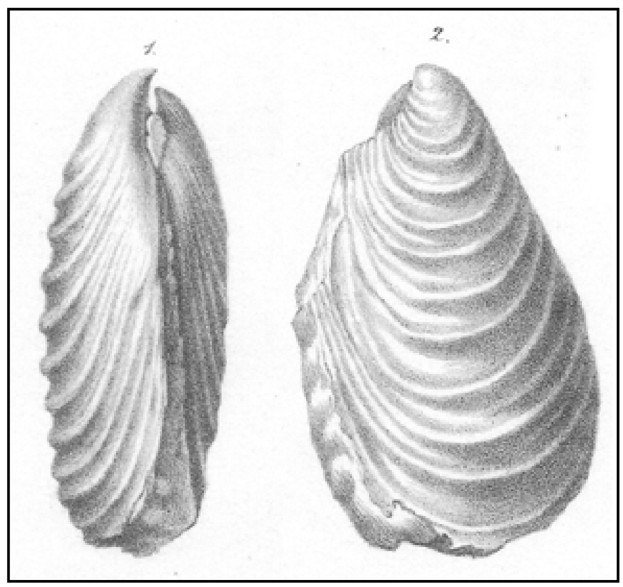

FIGURE 5. *Retroceramus ambiguus* (Eichwald, 1871) (originally named *Inoceramus ambiguus*).

in the formation, but the genera and species present are identical with those in the underlying Fitz Creek Siltstone, indicating a similar age.

Age

The Cynthia Falls Sandstone has been cited as being of late middle Bajocian age (Imlay, 1982; Imlay, 1984).

PALEOCLIMATIC IMPLICATIONS OF SOUTHERN ALASKAN MIDDLE AND UPPER JURASSIC INVERTEBRATE FAUNAS

Imlay (1965) in his presidential address to the Paleontological Society gave considerable discussion to the prominence of inoceramid (most now placed in the genus *Retroceramus*) bivalves in Middle Jurassic faunas of Alaska, standing in stark contrast to their total absence from Upper Jurassic faunas of Alaska! Inoceramids also disappear at the same time from faunas of the Canadian Arctic Islands and Northeast Russia (Kolyma region), and in all the above-mentioned regions appear to ecologically be replaced by bivalves belong to the genus *Buchia*. This absence coincides with a marked reduction in overall faunal diversity in the same regions, most likely indicating a major interval of global cooling (resulting in a heightened global climatic gradient) at this time. These areas were situated at that time very close to the North Pole. Inoceramids abruptly reappear in great abundance in southern Alaska during the latter part of the Early Cretaceous in the Herendeen Formation (Hauterivian–Barremian) on the

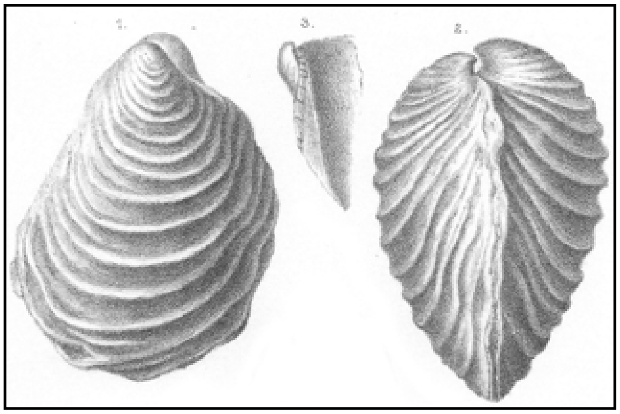

FIGURE 6. *Retroceramus eximius* (Eichwald, 1871) (originally *Inoceramus eximius*).

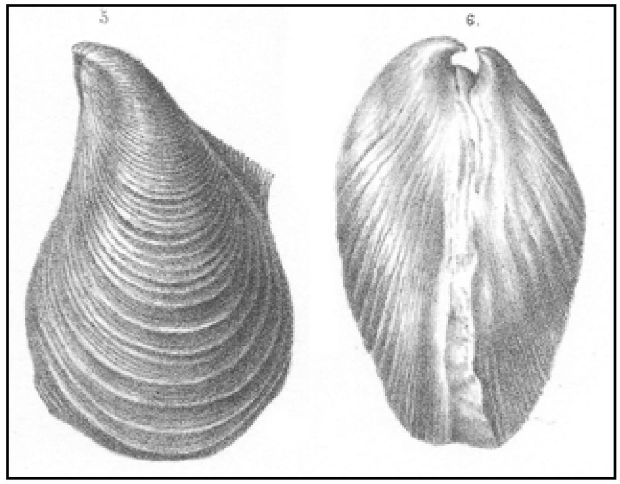

FIGURE 7. *Retroceramus lucifer* (Eichwald, 1871) (originally *Inoceramus lucifer*).

FIGURE 8. A *Retroceramus* specimen collected by Minerals Management Service (now Bureau of Ocean Energy Management - BOEM) geologists from Fossil Point at Tuxedni Bay. This specimen is now deposited at the Geologic Materials Center (GMC) in Eagle River, Alaska. Photograph by Jean A. Riordan and Robert B. Blodgett.

Alaska Peninsula and its lateral equivalent, the Nelchina Formation in the southern Talkeetna Mountains. This seems to coincide with a significant climatic warming event when marine faunas of these regions become more diverse.

Another bivalve group which almost completely disappears in the Upper Jurassic of Alaska is the trigoniid bivalves. One the last species reported from the Jurassic occurs in the Callovian (uppermost Middle Jurassic) strata of the Chinitna Formation on Chisik Island in Tuxendi Bay, immediately east of Fossil Point (Fig.11).

PALEONTOLOGICAL RESOURCE MANAGEMENT AND PROTECTION

Fossil Point is administered by the National Park Service (NPS) within Lake Clark National Park and Preserve. Lake Clark National Monument was first established in 1978. The monument was reauthorized Lake Clark National Park and Preserve through the Alaska National Interests Lands Conservation Act (ANILCA) in 1980.

The management of the paleontological resources at Fossil Point presents a number of challenges. As a coastal fossil locality, Fossil Point is subjected to a variety of natural processes including sea currents, tides, storms and long-term changes in sea level. Additionally, this well-known fossil locality appears to have been visited by private fossil collectors and hobbyists for many years (Rock, 1980). There are anecdotal references and a few private fossil collections which designated specimens from Fossil Point, Alaska. These references appear to have occurred principally in the past prior to NPS administration of Fossil Point. There is evidence that suggests that some unauthorized fossil collecting has been undertaken at Fossil Point after Lake Clark National Monument was established as a unit of the NPS in 1978.

According to NPS laws, regulations and policies, the collection of fossils in parks without a permit is prohibited. These regulations and policies associated with paleontological resources apply on federally owned lands and waters, on lands and waters that are administered by the NPS pursuant to a written instrument or over which the NPS holds a less-than fee interest, and in waters subject to the jurisdiction of the U.S. up to the mean high water line, regardless of the ownership of the submerged lands (Brunner et al., 2010).

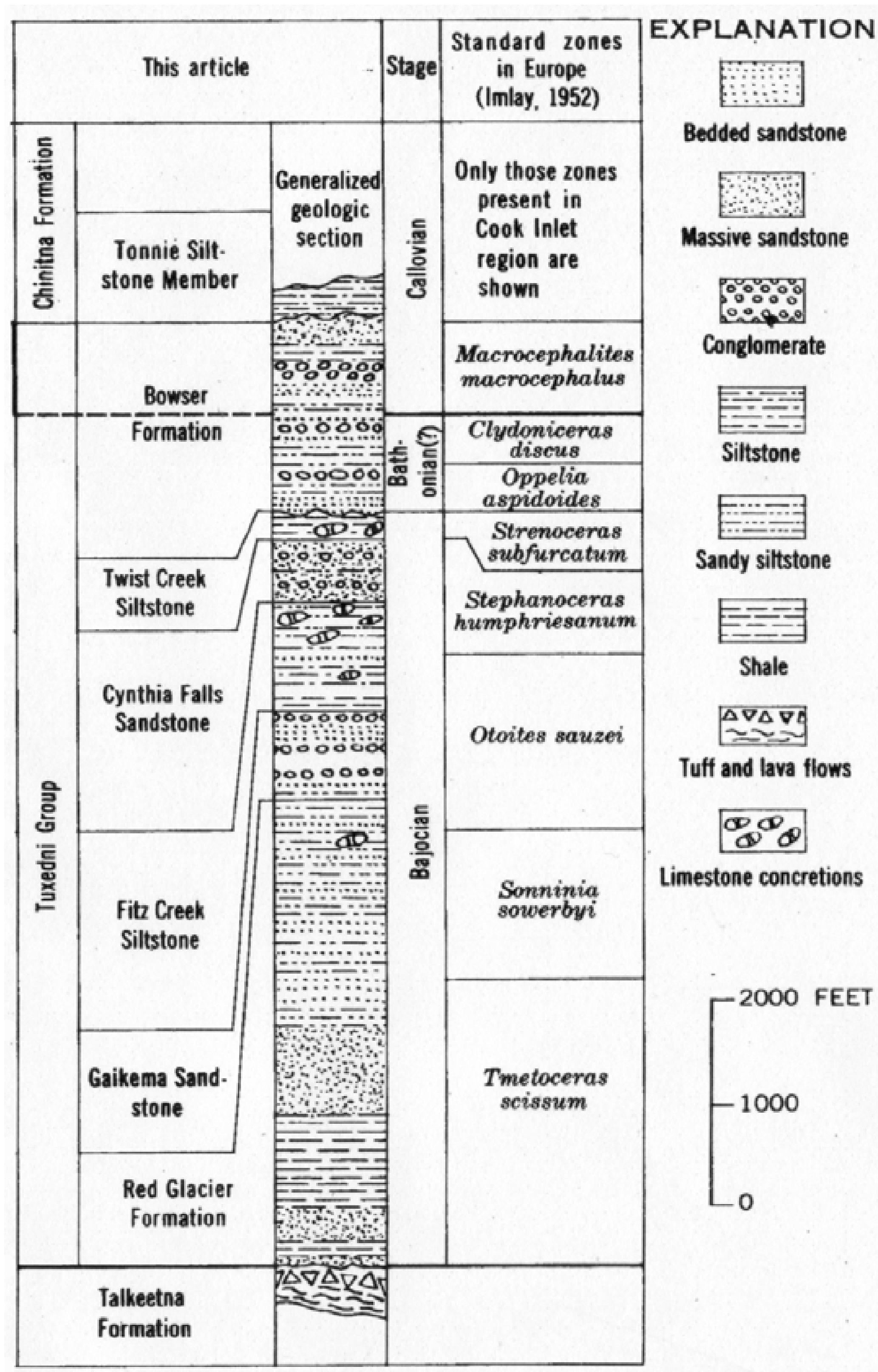

FIGURE 9. Stratigraphic nomenclature of the Tuxedni Group in Cook Inlet region, Alaska (from Detterman, 1963).

TABLE 1. Taxa identified in the Fitz Creek and Cynthia Falls formations. Compiled from Imlay (1964) and Detterman and Hartsock (1966).

TAXON	FITZ CREEK FORMATION	CYNTHIA FALLS FORMATION
BRACHIOPODA		
Rhynchonellid brachiopods	X	X
. Brachiopoda indet.	X	
GASTROPODA indet.	X	
BIVALVIA		
Grammatodon sp.	X	X
Cucullaea sp.	X	
Parallelodon sp.	X	
Pinna sp.	X	
Retroceramus ambiguus (Eichwald)	X	
Retroceramus sp	X	X
Oxytoma sp.	X	
Pteria sp.	X	
Ostrea sp.	X	
Trigonia sp.	X	
Pecten sp.	X	
Camptonectes sp.	X	
Lima sp.	X	
Pleuromya sp.	X	
Goniomya sp.	X	
Pholadomya sp.	X	
Astarte sp.	X	
Lucina sp.	X	
Plagiostoma sp.	X	
Mytilus sp.		X
AMMONOIDEA		
Phylloceras sp.	X	
Macrophylloceras sp. indet.	X	
Macrophylloceras sp. undet. A	X	
Macrophylloceras sp. undet. B	X	
Calliphylloceras sp.	X	
Holcophylloceras costasparsum Imlay	X	
Holcophylloceras cf. H. costisparsum Imlay	X	
Holcophylloceras sp. juv.	X	
Sonninia tuxedniensis Imlay	X	
Sonninia cf. S. tuxedniensis Imlay	X	
Strigoceras cf. S. languidum Buckman	X	
Lissoceras bakeri Imlay		X
Lissoceras sp.	X	
Oppelia stantoni Imlay	X	
Chondroceras defonti (McLearn)	X	X
Chondroceras cf. C. defonti (McLearn)	X	
Chondroceras allani (McLearn)	X	X
Chondroceras cf. C. allani (McLearn)	X	
Chondroceras cf. C. oblatum (Whiteaves)		X
Chondroceras sp.	X	X
Normannites sp.	X	X
Normannites (Itinsaites) crickmayi (McLearn)	X	X
Normannites (Itinsaites) cf. N. (I.) crickmayi (McLearn)	X	X
Normannites (Itinsaites) itinsae (McLearn)	X	
Normannites (Itinsaites) cf. N. (I.) itinsae (McLearn)	X	
Normannites (Itinsaites) variabilis Imlay	X	
Normannites (Itinsaites) cf. N. (I.) variabilis Imlay	X	
Stephanoceras sp.	X	X
Stephanoceras (Skirroceras) kirschneri Imlay	X	
Stephanoceras? sp.	X	
Stemmatoceras cf. S. palliseri (McLearn)	X	
Stemmatoceras tuxedniese Imlay	X	
Stemmatoceras ursinum Imlay	X	
Stemmatoceras sp. juv.	X	
Teloceras itinsae (McLearn)	X	
Teloceras. aff. T. itinsae (McLearn)	X	
Zemistephanus richardsoni (Whiteaves)	X	
Zemistephanus cf. Z. richardsoni (Whiteaves)	X	
Zemistephanus carlottensis (Whiteaves)	X	X
Zemistephanus? sp.	X	
Ammonoidea indet.		X
BELEMNOIDEA indet.	X	

In order to more fully assess the natural and anthropogenic impacts to the paleontological resources at Fossil Point, the establishment and implementation of a monitoring strategy at the locality is warranted using best practices (see Santucci and Koch, 2003; Santucci et al., 2009). An initial assessment of the fossil locality should include a consideration of the wide range of factors that may influence the condition and stability of the area. The initial assessment will represent the baseline information from which a monitoring protocol could be established for Fossil Point. Paleontological resource monitoring at Fossil Point will provide data and information that will enhance the management and protection of a world renowned fossil locality.

CONCLUSIONS

The early Middle Jurassic strata exposed at Fossil Point provides some of the earliest named and illustrated

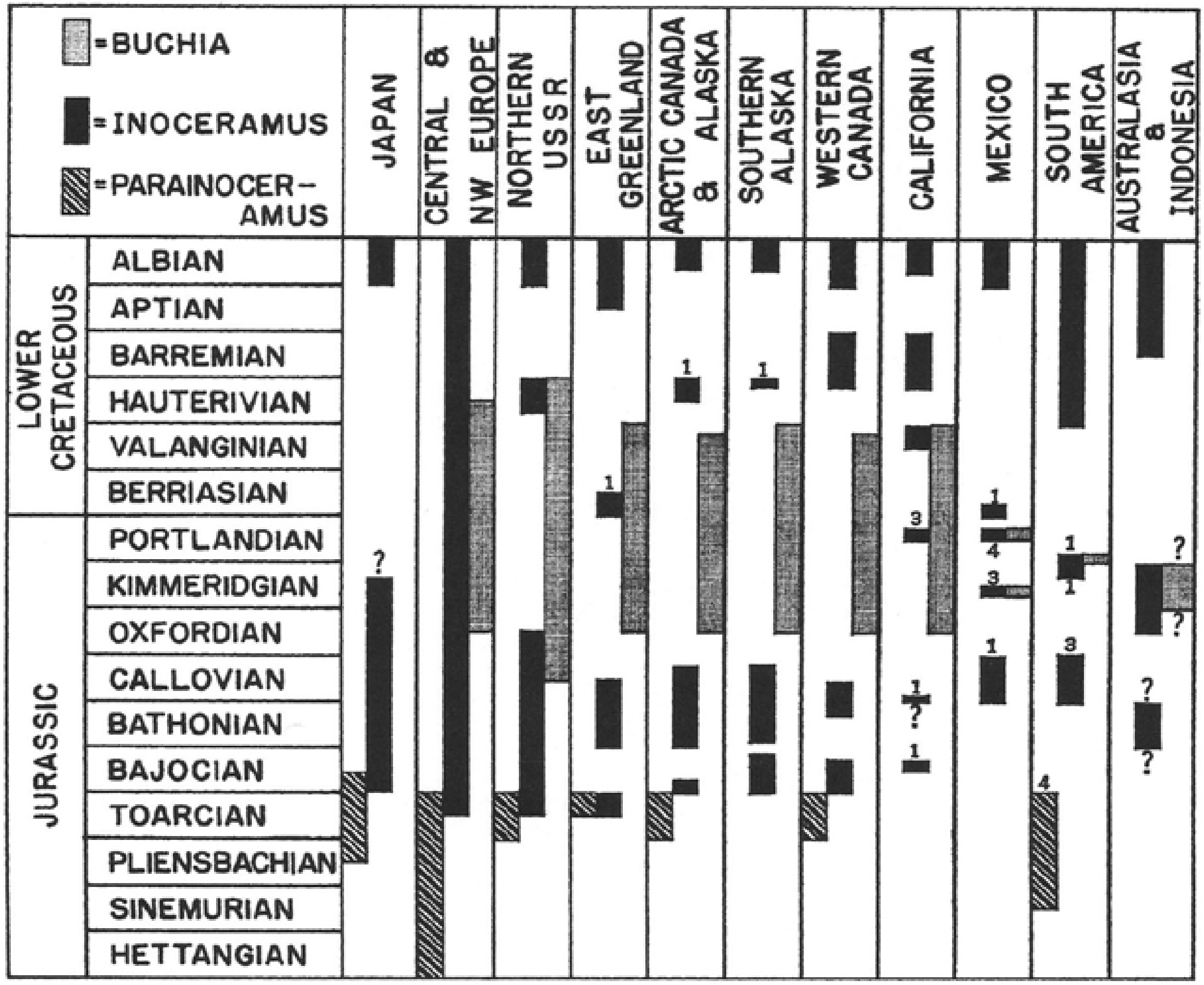

FIGURE 10. Diagram from Imlay (1965) showing the stratigraphic distribution of selected invertebrate groups during the Jurassic and Lower Cretaceous. The inoceramid bivalves (shown in black; also including the genus *Retroceramus*) are conspicuously absent from the Upper Jurassic (Oxfordian–Portlandian) and lower Lower Cretaceous (Berriasian–Valanginian) of both southern Alaska and arctic Canada/arctic Alaska.

fossils from this time interval in western North America. Despite the naming and illustration of the beautiful large inoceramid (*Retroceramus*) bivalve species represented here (Figs. 4–8), most of the accompanying fauna remains undocumented either in illustration or description. This report illustrates the need to undertake a comprehensive study of the invertebrate species present at Fossil Point. Such an undertaking would enable the development of complete faunal lists and photo documentation for each species, plus some formal taxonomic studies including the paleoflora and potential vertebrate fossils. One primary objective will be a review of the inoceramids described to date to determine their proper stratigraphic order, ecological associations, variability and taxonomic validity. As the original Alaskan inoceramid types utilized by Eichwald are now deposited in St. Petersburg, Russia, a direct comparison to the originals is obvious, and a close working relationship with Russian specialists or even a visit to the host museum for their study may be in order.

ACKNOWLEDGEMENTS

We extend our thanks to R. G. Stanley, U.S. Geological Survey, Menlo Park, California, for his helpful discussion related to the geology of Fossil Point and the Tuxedni Bay area and kindly sharing his photographs from Fossil Point. Additional thanks is given to S. Prien of the ARLIS Interlibrary Loan office, Alaska Resources Library & Information Services (ARLIS), Anchorage, Alaska, for her assistance in obtaining hard-to-find paleontological references pertinent to our work on the Middle Jurassic fauna at Fossil Point. We also extend our appreciation to the National Park Service staff in Alaska, Guy Adema, Linda Stromquist and Jeff Shearer, for their support of paleontological resource stewardship in the Alaska parks.

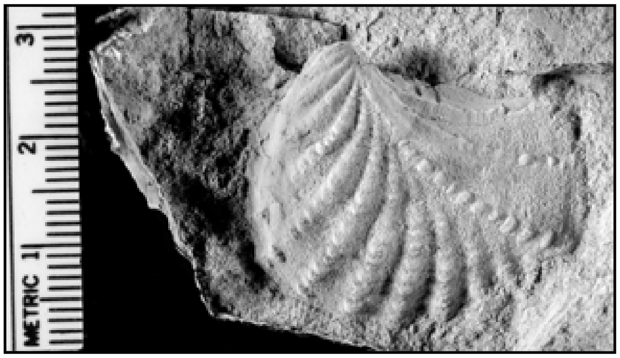

FIGURE 11. A trigoniid bivalve from the uppermost Middle Jurassic (Callovian) Chinitna Formation on Chisik Island, Tuxedni Bay, Cook Inlet region, south-central Alaska.

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ARTICLE

SMASHED RODENTS, FALSE PREPRINTS, AND THE BBC: THE PALEONTOLOGY OF MISSISSIPPI NATIONAL RIVER AND RECREATION AREA, MINNESOTA

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ABSTRACT—Mississippi National River and Recreation Area (MISS or MNRRA), following the Mississippi River through the Twin Cities metro area of Minnesota, is a little known paleontological gem of the National Park Service (NPS). The Ordovician rocks exposed in the bluffs of the river host a great diversity of marine invertebrate fossils which have received notice since the 1820s. MISS has a particularly outstanding Late Ordovician record, unsurpassed in the NPS: approximately 455 million years ago, the shallow equatorial sea covering southeastern Minnesota supported abundant corals, bryozoans, brachiopods, bivalves, nautiloids, snails, annelids, trilobites, ostracodes, crinoids, graptolites, conodonts, and other forms. The type specimens of at least 113 to as many as 360 taxa were found at sites within the boundaries of the NPS river corridor. Several notable fossil sites are located in MISS, including rare fossil localities in the St. Peter Sandstone. The Quaternary sediments that blanket the area are also productive, yielding remains of mammoths and giant beavers.

INTRODUCTION

Mississippi National River and Recreation Area (MISS or MNRRA) was established November 18, 1988 and encompasses 116 km (72 miles) of the Mississippi River and surrounding lands in east-central Minnesota, in the Twin Cities of Minneapolis and St. Paul and the surrounding metro area (Fig. 1). MISS is host to a variety of natural and cultural resources, including areas of scenic beauty, geologically and biologically significant areas, archeological sites from the past several thousand years, and locations that illustrate frontier history and the growth and development of the metro. Unlike many NPS units, very little of the land within its boundaries is owned by the NPS (only 0.25 of 218 km2 [62.42 of 53,775 acres]). Instead, it is a 'partnership park' that works in concert with numerous city, county, state, business, educational, and private entities.

One of the less-publicized facets of MISS is its paleontology. The river corridor contains a phenomenal record of Late Ordovician life, the best to date known from any NPS unit. It also has Early and Middle Ordovician fossils, which are uncommon in the NPS, and Quaternary material, including one of the best specimens of the extinct giant beaver *Castoroides ohioensis*. A combination of the natural geography of the area and human developments limit the great majority of bedrock outcrops of the Twin Cities metro to the river corridor, particularly the river bluffs from Nicollet Island to Dayton's Bluff and to a lesser extent from Newport to Hastings (see for example the distribution of outcrops in Mossler, 2013). These factors grant MISS a near monopoly on this aspect of the Twin Cities, and make the NPS river corridor the natural place to begin any examination of the rocks and fossils of the metro. Fossils have been reported from sites within MISS since the 1820s, and even today a cursory examination of some of the Upper Ordovician rocks is usually sufficient to reveal abundant fossils. Some localities stand out against this productive background: MISS includes in its boundaries three rare fossil sites in the St. Peter Sandstone, microfossil sites in the Glenwood Formation and Decorah Shale, and two widely published localities in the Decorah Shale. Beyond scientific value, MISS also offers unique opportunities to observe fossils in an urban setting.

HISTORICAL BACKGROUND

Fossils have been reported from the river corridor since at least 1824, with brief descriptions provided by several authors (Keating, 1824; Featherstonhaugh, 1836; Nicollet, 1843; Owen, 1852a). The systematic study of Minnesota's geology began in earnest in the 1870s with the Geological and Natural History Survey of Minnesota under Newton Horace Winchell. Winchell employed several specialists to describe the state's fossils, the most prolific being Edward Oscar Ulrich. Winchell and his team wrote a number of paleontological publications, culminating in volume 3 of The Geology of Minnesota, an exhaustive monograph published in two parts (Lesquereux et al., 1895; Ulrich et al., 1897). In a miniature of the contemporaneous 'Bone Wars', Winchell, who taught at the University of Minnesota (UMN) until 1890, and C. H. Hall, the head of the Department of Geology and Mineralogy, developed a personal enmity. At one point, Hall had his student Frederick W. Sardeson rush a description of some brachiopods ahead of the planned monograph because they would be used in an upcoming publication of Hall's. In retaliation, Winchell had Ulrich extract a description of brachiopods as a new paper and used false preprints to poach priority (Weiss, 1997).

Since the 1890s, the study of paleontology in Minnesota has not been as contentious, but has still been productive. A number of researchers associated with the UMN, including Sardeson, Clinton R. Stauffer, and Robert Sloan, have made important contributions, and the Science Museum of Minnesota (SMM) has issued several publications, primarily on Quaternary material. Notable publications include Sardeson (1916), Stauffer and Thiel (1941), Stauffer (1945), Powell (1948), Erickson (1962), Sloan (1987a, 2005), and Sloan et al. (2005).

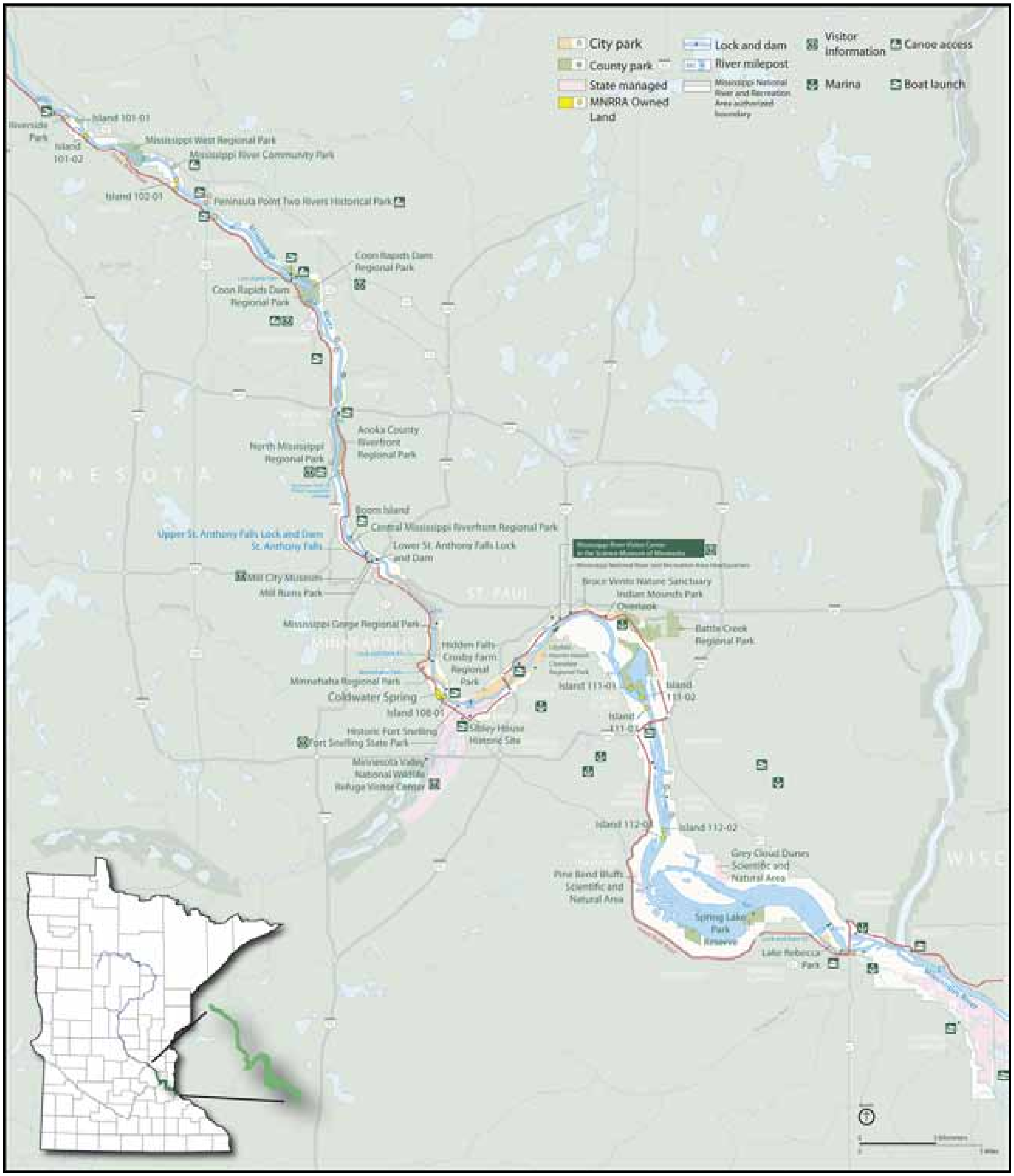

FIGURE 1. Map of Mississippi National River and Recreation Area (NPS).

GEOLOGIC BACKGROUND

The geologic history of MISS and the Twin Cities metro is that of a quiet craton interior. The most recent major tectonic event is the great Midcontinent Rift, which nearly split North America roughly 1.1 billion years ago. Its course in the vicinity roughly traces the modern St. Croix River valley to the east, and it generated folds and faults that form the structural framework beneath the metro. Much of the metro is within the Twin Cities Basin, a product of this ancient structural heritage (Mossler, 1972, 2008; Ojakangas, 2009).

The formations that are exposed within MISS pertain to two great sea level cycles: the Upper Cambrian and Lower Ordovician rocks are part of the Sauk Sequence, and the Middle and Upper Ordovician rocks are part of the Tippecanoe Sequence, with a substantial unconformity

Formation	Age	Fossils Within MISS
Quaternary sediments	late Pleistocene-Holocene	Hidden Falls: giant beaver (latest Pleistocene or earliest Holocene) and associated remains of freshwater clams, freshwater snails, snakes, shrews, modern beavers, rabbits, and bats, uncertain age; Other vertebrates: isolated mammoth remains from Coon Creek, Hastings, and St. Paul; St. Anthony Falls: postglacial freshwater snails in fluvial sand and Quaternary snails in drift (modern?)
Prosser Formation (only as riprap in Hastings)	Late Ordovician	Brachiopods, bivalves, and unidentified shelly fossils
Cummingsville Formation	Late Ordovician	The receptaculitid Fisherites
Decorah Shale	Late Ordovician	Chitinozoans, receptaculitids, sponges, tabulate and rugose corals, conulatans, bryozoans, brachiopods, cornulitids, monoplacophorans, bivalves, nautiloid cephalopods, snails, segmented worms, trilobites, ostracodes, stylophorans, crinoids, cystoids, edrioasteroids (Platteville?), conodonts, graptolites, invertebrate burrows, and possibly rostroconchs and scenellids
Platteville Formation	Late Ordovician	Green algae, sponges, rugose corals, conulatans, bryozoans, brachiopods, monoplacophorans, hyoliths, bivalves, nautiloids, snails, trilobites, ostracodes, sea stars, crinoids, cystoids, graptolites, conodonts, enigmatic invertebrates (‘*Chaetetes lycoperdon*’), invertebrate burrows, unspecified fossils, and possibly scenellids and rostroconchs
Glenwood Formation	Late Ordovician	Bryozoans, brachiopods, bivalves, snails, segmented worms, trilobites, ostracodes, crinoids, conodonts, invertebrate burrows, bioturbation, and unspecified micro- and macrofossils
St. Peter Sandstone	Middle–Late Ordovician	Bryozoans, brachiopods, monoplacophorans, bivalves, nautiloid cephalopods, snails, unidentified invertebrate fossils, invertebrate burrows, and bioturbation
Prairie du Chien Group (Shakopee Formation over Oneota Dolomite)	Early Ordovician	Snails, stromatolites, unspecified fossils, and possibly bivalves
Jordan Sandstone	Late Cambrian	None to date

TABLE 1. Concise tabulation of MISS stratigraphy and fossils.

between the two groups. Due to its location near the center of the craton, Minnesota records the seas at their greatest extents, so deposition is relatively truncated compared to other areas, with several unconformities (Mossler, 2008). During the early Paleozoic, Minnesota was several degrees south of the equator and rotated clockwise on the order of 90° (Ojakangas, 2009). Marine deposition was divided by the Transcontinental Arch and other highs, separating the seas over northwestern and southeastern Minnesota (Mossler, 2008). Volcanoes, associated with the Taconic Orogeny and located offshore of what is now the southeastern United States, occasionally spewed vast amounts of ash (Emerson et al., 2004; Herrmann et al., 2010), represented today in MISS by bentonite layers that can be as thick as 7 cm (3 in) (Dokken, 1987). One such event resulted in a local mass extinction (Sloan et al., 2005).

The Tippecanoe Sea retreated from the metro area sometime after about 450 Ma. Following this, there is no record of deposition in MISS and the central metro until the onset of glaciation in the Pleistocene; there are reports of buried Cretaceous rocks in the outer metro, but none near MISS (Mossler, 2013). Multiple glacial episodes redrew the geography of the region, dropping thick drift sequences, creating vast meltwater lakes, and forcing drainage to move; the Twin Cities metro is laced by deeply buried former channels of the Mississippi–Minnesota–St. Croix drainage system (Wright, 1972; Ojakangas, 2009).

FORMATIONS

Bedrock outcrops within MISS are limited to a handful of units. In ascending order, they are the Jordan Sandstone (Upper Cambrian), the Oneota Dolomite and Shakopee Formation of the Prairie du Chien Group (Lower Ordovician), the St. Peter Sandstone (Middle–Upper Ordovician), the Glenwood Formation, the Platteville Formation, the Decorah Shale, and the Cummingsville Formation (Upper Ordovician) (Fig. 2). Older rocks illustrated on maps are buried by glacial drift and fluvial sediment (Mossler and Tipping, 2000; Mossler, 2008, 2013). The formations represent various depositional conditions in a shallow marine setting near a coast. All of the Ordovician units and the Quaternary sediments are fossiliferous within MISS (Table 1).

Jordan Sandstone (Upper Cambrian)

The Jordan Sandstone is the oldest unit exposed within MISS, and the only Cambrian unit that is visible at the surface. It can be seen along the Mississippi River just north of Hastings near Lock & Dam 2 (Mossler, 2006a,

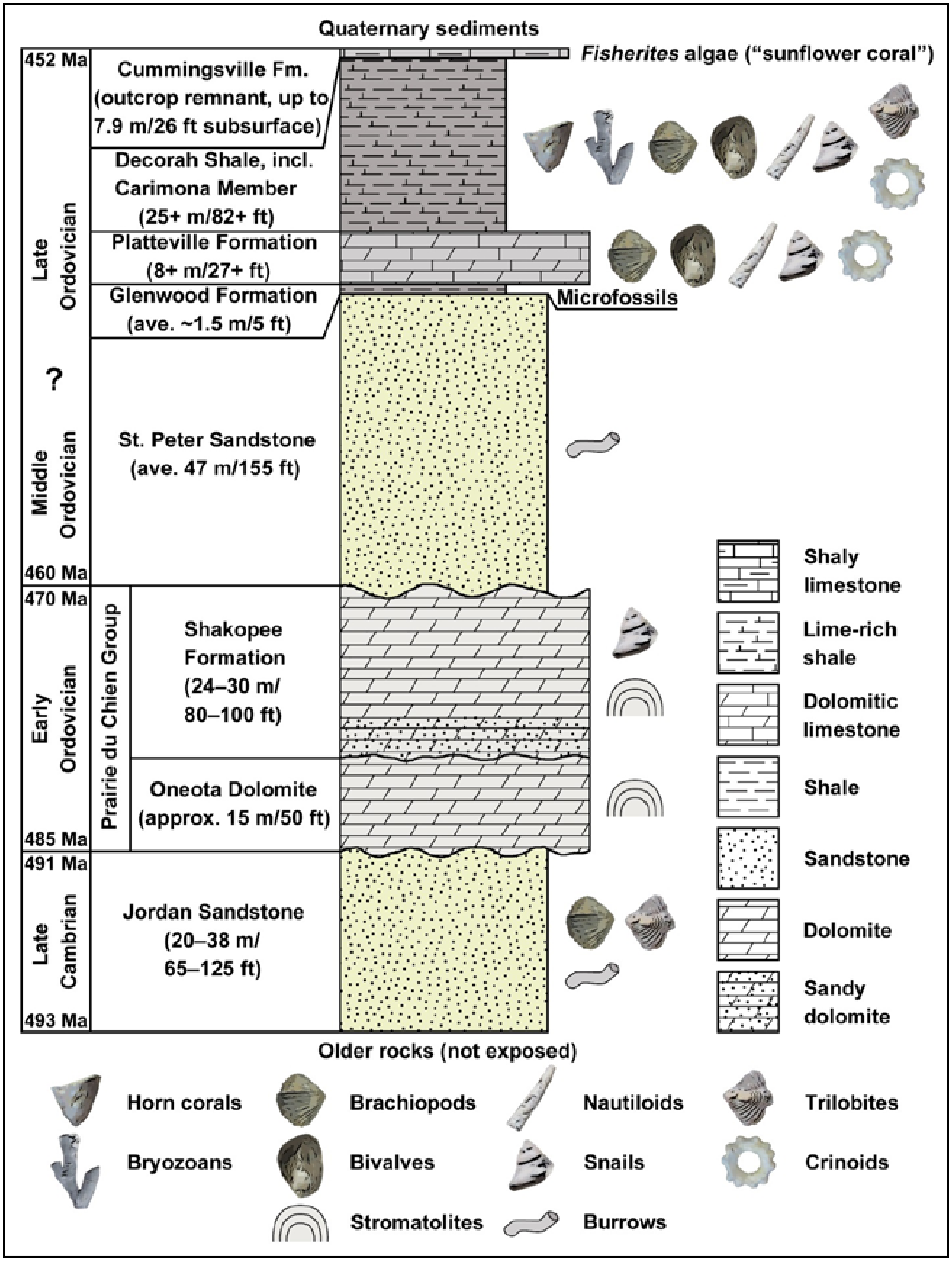

FIGURE 2. Schematic stratigraphic column of MISS area bedrock formations, with common fossils (not all are known from MISS yet). Thicknesses and lithologies after Mossler and Tipping (2000) and Mossler (2008, 2013). Dates are for the approximate ages of the rocks, not the geologic periods. Lithologic patterns and symbols for trace fossils taken from the Federal Geographic Data Committee's standards.

2006b), where it appears orange because of iron staining; when unaltered, it is usually light gray (Mossler, 2013). Fossils are rare in this formation and have not yet been reported from MISS. Typical fossils found elsewhere include brachiopods, trilobites, conodonts, and invertebrate burrows (Mossler, 2008).

Prairie du Chien Group (Lower Ordovician)

The Prairie du Chien Group includes two Lower Ordovician units: the Oneota Dolomite and overlying Shakopee Formation. Both are bluff-forming resistant grayish formations, but the Oneota Dolomite is dominantly dolomite and the Shakopee Formation varies from dolomite to sandy dolomite to sandstone (Mossler, 2008). Outcrops flank the Mississippi River in the southeastern third of MISS, from about Newport to Hastings (Mossler, 2013), and there are good road cut exposures along U.S. Route 10 north of Hastings. Most fossils in these formations are stromatolites and other microbial structures, and it is thought that the paleoenvironmental conditions were harsh to living things (Webers, 1972a).

Fossils are uncommon in the Prairie du Chien Group within MISS. Shumard (1852) made note of snail beds north of Grey Cloud Island and south of the present location of Lock & Dam 2, and an un-published field trip guide (Kain, 1973) reported a stromatolite north of Lock & Dam 2. The U.S. 10 road cuts include small stromatolites as well as rare molds and casts of snails and possible bivalve casts. Additional inspection of the rocks will probably reveal more microbial structures.

St. Peter Sandstone (Middle–Upper Ordovician)

The light-colored St. Peter Sandstone is one of the most prominent formations of the Twin Cities, forming the lower part of the bluffs in the central part of MISS (Fig. 3). It is well-known informally for its extreme softness: there is practically no cement, so it is easily inscribed and readily forms caves. It has several other notable characteristics: it is almost pure quartz (99%), with uniform grain size; it appears to lack sedimentary structures; and it forms an almost literal sheet, covering 575,000 km2 (225,000 miles2) while averaging only 30 m (100 ft) thick (Webers, 1972b). Recent interpretations combine eolian and marine processes to explain it, such as continental sand sheets reworked by a rising sea (Dott et al., 1986) or sand transported by wind into shallow marine settings (Mazzullo and Ehrlich, 1987).

Unsurprisingly, this formation is not a hotbed of fossils, but three fossil localities are known from MISS, at Dayton's Bluff, Highwood, and South St. Paul (Sardeson, 1892, 1896; Sloan, 1987b). These sites have produced casts and molds of bryozoans, brachiopods, monoplacophorans, bivalves, nautiloids, and snails (Sloan, 1987b). They are notable as some of the few body fossils described from the formation over the entire multistate region where it is present. Burrows have also been reported from sites within MISS (Mazzullo and Ehrlich, 1987).

Glenwood Formation (Upper Ordovician)

The Glenwood Formation is a thin (typically about 1 m [3–5 ft] thick in the metro; Mossler, 2013) recessive shaly formation. Often the lower part is sandy like the underlying St. Peter Sandstone. The best places to see it within MISS are where both the St. Peter Sandstone and overlying Platteville Formation are clearly exposed. In such places, the Glenwood Formation is a gray to brown unit in a notch between the two. One excellent site is the viewing area adjacent to Lock & Dam 1 (Fig. 3).

The Glenwood Formation has few described macrofossils, but investigations within MISS have yielded abundant microfossils as well as a few macroscopic specimens. Stauffer (1933, 1935a) described scolecodont elements and conodonts from samples obtained near the Washington Avenue Bridge, and a thin zone in the formation here contains bryozoans, brachiopods, snails, trilobites, ostracodes, crinoids, and burrows (Johnson, 1988). A few other localities in the river corridor have yielded lesser quantities of similar fossils (Stauffer and Thiel, 1941; Cooper, 1956; Johnson, 1988; Sloan, 2005).

Platteville Formation (Upper Ordovician)

The Platteville Formation is a hard gray formation mostly composed of limestone and dolomite, with some shaly limestone. It is very visible in the Twin Cities, where it forms the cap of the Mississippi River bluffs (Fig. 3) and supports waterfalls such as Minnehaha Falls. It can be a hazardous formation to investigate because it forms steep walls that project over the softer underlying rocks and can shed large blocks. The Platteville Formation might be the most extensively studied formation in southeastern Minnesota, due to its abundant fossils, notable lithological variations (it has several members), and convenient access from the University of Minnesota (Sloan, 1972). Within MISS, it is exposed "more or less continuously" from St. Anthony Falls to the Robert Street Bridge (Schwartz, 1936:50), and also on Dayton's Bluff.

Fossils in this formation are often concentrated in patches or thin beds (Mossler, 1985, 2008), and dolomitization in the Twin Cities Basin has destroyed many fossils and has caused others to be replaced by dolomite (Mossler, 1985). However, it is no exaggeration to state that any outcrop is almost guaranteed to yield fossils, in the author's experience typically molds and casts of brachiopods, bivalves, and snails. Bryozoans, nautiloids, trilobites, large ostracodes, crinoids, and trace fossils are also encountered with some regularity within MISS, and an inspection of the literature and the collections of the SMM and UMN reveals a number of rarer components of the MISS biota, such as green algae, corals, conulatans, hyoliths, sea stars, cystoids, conodonts, and graptolites. Fossils are easiest to see on blocks that have fallen from outcrops. Notable published localities in MISS include Fort Snelling (Keating, 1824; Featherstonhaugh, 1836), St. Anthony Falls (Featherstonhaugh, 1836; Shumard, 1852; Herrick, 1877), the Minneapolis campus of the UMN (Winchell, 1877;

FIGURE 3. Three of the important formations of MISS: off-white St. Peter Sandstone beneath the Glenwood Formation (the thin recessive grayish and brownish layers about halfway up the exposure) and capping Platteville Formation at Lock & Dam 1

Stauffer, 1935a; Stauffer and Thiel, 1941), Lock & Dam 1 (Stauffer and Thiel, 1941), and Shadow Falls (Sloan, 1987c, 2005; Sloan et al., 2005). However, because of the sheer abundance of fossils and the extensive outcrops within MISS, it is somewhat misleading to speak of discrete localities.

Decorah Shale (Upper Ordovician)

The Decorah Shale is a soft green-gray shale with some thin beds of limestone. Both lithologies are abundantly fossiliferous. In particular, limestone fragments are often hashes of shells, bryozoan fragments, crinoid columnals, and other small fossils. Within MISS, the Decorah Shale is present on the east side of the Mississippi gorge in St. Paul, in isolated areas on the west side of the gorge, and on the south side of the river between Fort Snelling and central St. Paul, but it rarely crops out because of its recessive nature and the thick blanket of glacial drift in many areas (Mossler, 2013). The only place in the river corridor with good outcrops is the Brickyard on the south side of the river. This area preserves the thickest known section of the formation, at 27.2 m (89.2 ft) (Sloan et al., 2005; not including a thin interval recently transferred from the underlying Platteville Formation by Mossler, 2008). Near the base of the formation is the Deicke K-bentonite (Mossler, 2008), recently dated to 454.59 ± 0.56 Ma (Renne et al., 2010).

The Decorah Shale is the best formation for finding fossils in southeastern Minnesota (Mossler and Benson, 2006). The fossils are easy to extract and represent the most diverse assemblage for any of the Ordovician units in the state (Mossler, 2008), with practically all Ordovician phyla at their greatest abundance and diversity (Webers, 1972a). Reports of fossils in MISS have come from the Brickyard, Shadow Falls, beneath Northrop Auditorium (Stauffer, 1930, 1933, 1935b), and the area around the Ford Plant, Ford Bridge, and Lock & Dam 1 (Stauffer, 1925, 1933, 1935b; Stauffer and Thiel, 1941). By far the best locality is the Brickyard, with Shadow Falls a distant second. These sites have produced fossils of chitinozoans (Stauffer, 1933), receptaculitids and other algae (pers. obs., SMM collections), sponges, rugose and tabulate corals (Adamson, 1993; Sloan, 2005), conulatans, cornulitids (UMN collections), bryozoans (Karklins, 1969), brachiopods (Rice, 1987), monoplacophorans (UMN collections), bivalves, nautiloids, snails (Stauffer and Thiel, 1941), annelids (Stauffer, 1933), trilobites (Sloan, 2005), ostracodes (Swain et al., 1961; Swain and Cornell, 1987), crinoids (Brower and Veinus, 1978), cystoids (UMN collections), edrioasteroids (Bather, 1915), stylophorans (SMM collections), conodonts (Stauffer, 1935b; Sweet, 1987), graptolites (Stauffer, 1930), and burrows and other traces (Stauffer and Thiel, 1941) (Fig. 4). The most common fossils are from bryozoans, brachiopods, and crinoids, sometimes known informally as the 'BBC'. These three groups are ubiquitous both loose and in slabs. Snails, trilobites, nautiloids, and trace fossils are also common.

The Brickyard, the former operations of the Twin City Brick Company, has long been known as a prolific fossil site. It became the property of St. Paul in 1983, and in 1984 a permit system was established for fossil collecting (Rice, 1987). The fossils and geology of the site have been discussed in a number of publications (Stauffer and Thiel, 1941; Swain et al., 1961; Karklins, 1969; Brower and Veinus, 1978; Rice, 1987; Swain and Cornell, 1987; Sweet, 1987; Adamson, 1993; Sloan, 2005; Sloan et al., 2005), and it is regarded as the best fossil site in the Twin Cities. Unfortunately, the combination of unsupported limestone beds within recessive shale in steep quarry cuts, loose overlying Quaternary sediment, ample precipitation, and a robust freeze-thaw cycle results in the occasional rock fall or slide. One such accident killed two fourth-grade students and injured two others May 22, 2013, and the site was closed indefinitely (Baran and Nelson, 2013; Gilbert, 2013). Shadow Falls is part of a small park at the west end of Summit Avenue in St. Paul. This locality is much smaller than the Brickyard, but includes good exposures of the underlying formations. It has been used for educational purposes since the 1890s (Scott, 1899). A number of publications discuss the Decorah Shale and other aspects of this site (Winchell, 1877; Ulrich, 1886; Mazzullo and Ehrlich, 1980; Dokken, 1987; Rice, 1987; Sloan et al., 1987a, 1987b, 2005; Johnson, 1988; Kolata et al., 1996; Sloan, 2005).

Cummingsville Formation (Upper Ordovician)

The Decorah Shale is capped in a few areas near the Brickyard by thin remnants of the Cummingsville Formation, a limestone formation with some shale beds (Mossler, 2013). It is fossiliferous within MISS, but the literature can be confusing because it was not designated until relatively recently (Weiss, 1955) and its historical equivalents tended to take part of the upper Decorah Shale (compare Schwartz, 1936 and Stauffer and Thiel, 1933, 1941 to Sloan, 1987d or Mossler, 2008). This is exacerbated because the contact between the two formations is arbitrary and time-transgressive (Mossler, 2008). Fossils of the receptaculitid ('sunflower coral') Fisherites oweni have been found in this formation at the Brickyard (Sloan, 2005).

Quaternary Sediments (Pleistocene–Holocene)

The Quaternary sediments of MISS record a variety of processes and settings including rivers, lakes, wetlands, caves, eolian settings on former lake beds, and talus beneath bluffs, but the dominant contributors were glaciers. Fossils are uncommon within MISS. The best specimen is an example of the giant beaver *Castoroides ohioensis* (Fig. 5), recovered from Hidden Falls Park during a Works Progress Administration construction project in 1938. The specimen was found crushed beneath a fallen ledge of the Platteville Formation; it appears that the animal took shelter beneath the ledge, which then collapsed on it. The fossil is one of the most complete, albeit damaged, examples of this species (Powell, 1948; Erickson, 1962). Radiocarbon dating gives an age of 10,320 ± 250 radiocarbon years before present (Erickson, 1967). The site also yielded shells of freshwater clams and snails and bones of snakes, shrews, normal sized beavers, rabbits, and bats. The invertebrate fossils may represent animals that lived in the area before Hidden Falls Creek cut through, or prey animals brought for consumption to the talus pile left by the limestone block, and the vertebrate remains probably belong to animals that lived in open spaces in the talus (Powell, 1948). Other Quaternary fossils from MISS include isolated mammoth remains from Coon Creek, Hastings, and St. Paul (Stauffer 1945), and freshwater snails found above the glacial drift at and near St. Anthony Falls (Owen, 1852b; Shumard, 1852). Floral and faunal remains are also common at archeological sites within MISS, including specimens of angiosperms, clams, snails, fish, turtles, birds, and mammals (Taylor, 1955; Johnson and Taylor, 1956).

MUSEUMS AND TYPES

The bulk of the fossils from MISS in museum collections are at the UMN (Minneapolis) and the SMM (St. Paul). Smaller but notable collections can be found at: the National Museum of Natural History (Washington, D.C.), which holds a number of 19th century types; the Natural History Museum of Los Angeles County (Los Angeles, CA); and the Peabody Museum of Natural History (New Haven, CT). Several other institutions have a handful of specimens, and it is likely that there are other small collections due to the ease of acquiring material and prolific collector Sardeson's practice of occasionally selling or trading fossils.

One of the notable aspects of MISS paleontology is the large number of species named from fossils found within its boundaries (at least 113) or potentially within its boundaries (at least 247). Among them are chitinozoans, green algae, sponges, corals, conulatans, bryozoans, brachiopods, monoplacophorans, rostroconchs, scenellids, bivalves, nautiloids, snails, annelids, trilobites, ostracodes, crinoids, edrioasteroids, conodonts, and trace fossils. The majority of the species confirmed from MISS were named during the 20th century, whereas almost all of the unconfirmed species were named during the 19th century. With the exception of Sardeson's St. Peter Sandstone finds and a crinoid described by Ulrich (1886), provenance information for 19th century fossils is limited to city. Thus, although many of the forms described in the 19th century were probably found within MISS simply based on

FIGURE 4. A selection of common Decorah Shale fossils from MISS. Top row, left to right: branching bryozoan, discoidal bryozoan and branching bryozoan, flat branching bryozoan, two small brachiopods, one larger complete brachiopod, and one valve of a larger brachiopod. Bottom row: partial nautiloid in rock, small nautiloid fragment, bellerophont snail, two smaller snails, fragments of trilobites in a chip of rock, three loose crinoid columnals and a short section of stalk, and two connected horn corals.

outcrop distribution, we cannot be certain in any specific case. The numbers are almost certainly inflated by splitting and other subjective factors (Bretsky and Bretsky, 1975; Eriksson, 1999; Weiss, 2000), but are still impressive. One odd postscript is the complexity of what constitutes type specimens or type series. Many 19th century forms were described from a handful of specimens from multiple localities (occasionally multiple states) without explicit catalog numbers. Later archivists have sometimes reported syntypes as being present at both the UMN (Rice, 1990) and the National Museum of Natural History (Schuchert, 1905), with no indication that a divided type series was intended, for example as sometimes occurred with Florissant material.

CULTURAL RESOURCE CONTEXTS

MISS fossils have been found in several broad cultural contexts. They are commonly present in building or landscaping stone. For example, many pieces of fossiliferous Platteville Formation stone from excavations at the Bishop Whipple Federal Building are used as landscaping stone at Coldwater Spring, the first significant mainland parcel to be owned by the NPS. Fossiliferous building stone is also present in the rock wall next to the stone staircase at Hidden Falls Park, and fossiliferous riprap is in use at Hastings. The riprap was quarried near Cannon Falls in southeastern Minnesota (J. Fitzgerald, Fitzgerald Excavating and Trucking, pers. comm., September 2013), from the Prosser Formation, which overlies the Cummingsville Formation and is otherwise not represented in MISS. Floral and faunal remains are found at a number of archeological sites as noted above, and there are also tools of potentially fossiliferous stone (Fleming and Hager, 2010). Finally, fossil sites like the Brickyard and Shadow Falls are frequently used for education and recreation. Thousands of people in the Twin Cities and elsewhere have collected fossils from the Brickyard on school or scouting field trips, and some of them have gone from this early interest in fossils to careers in the sciences.

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ARTICLE

PRESERVING THE PYGMY MAMMOTH: TWENTY YEARS OF COLLABORATION BETWEEN CHANNEL ISLANDS NATIONAL PARK AND THE MAMMOTH SITE OF HOT SPRINGS, SD, INC.

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ABSTRACT—Channel Islands National Park (CHIS) encompasses five islands off the coast of southern California. Though the park has numerous paleontological deposits, there is currently no paleontologist on staff to manage this resource. In the past, the Park Archaeologist has acted as de facto paleontologist, conducting limited salvage collection and alerting interested scientists to significant finds. Discovery of a nearly complete pygmy mammoth (*Mammuthus exilis*) skeleton in 1994 on Santa Rosa Island spurred the involvement of the Mammoth Site of Hot Springs, SD, Inc. (MSHS). A twenty-year volunteer-based collaboration between MSHS and CHIS has helped to alleviate the resource management gap with regard to proboscidean remains. Since 1994, MSHS has led several salvage trips, performed surveys of Pleistocene mammoth localities, prepared many recovered specimens, and conducted research resulting in numerous publications. The latest excursion culminated with the collection of a *M. exilis* tusk and giant deer mouse (*Peromyscus nesodytes*) tibia from ~80,000 year old sediments exposed in Garañon Canyon, Santa Rosa Island.

INTRODUCTION

Channel Islands National Park (CHIS) includes five islands off the southern California coast: Santa Cruz, Santa Rosa, San Miguel, Anacapa, and Santa Barbara. The Santa Barbara and Anacapa islands were originally designated Channel Islands National Monument in 1938, and other islands were later added to the park. Elephant-like bones were first reported on Santa Rosa Island by a Coast and Geodetic Survey in 1856 (Agenbroad and Morris, 1999), but did not appear in the scientific literature until 1873 (Stearns, 1873). The pygmy mammoth received species designation in 1928, when given the name *Elephas exilis* (Stock and Furlong, 1928), but was later reassigned to *Mammuthus*.

Channel Islands mammoths received only intermittent attention throughout the 20th century. Phil Orr, an archaeologist with the Santa Barbara Museum of Natural History (SBMNH), collected mammoth material while simultaneously conducting significant archaeological research on Santa Rosa Island from the late 1940s through the 1960s (Orr, 1968; Agenbroad, 2002c). As archaeological and paleontological materials often occur in neighboring strata within a typical sea cliff exposure, this facilitated Orr's joint studies.

After Orr, scientific collecting of pygmy mammoth, or any other fossils, largely ceased until Santa Rosa Island was acquired from private ownership by the National Park Service (NPS) in 1987. No substantial collection or excavation of mammoth material was under-taken until 1994, with the discovery of a nearly complete adult male *Mammuthus exilis* skeleton on Santa Rosa Island. This specimen remains the most complete pygmy mammoth ever recovered.

The four northern islands (Anacapa, Santa Cruz, Santa Rosa, and San Miguel; Fig. 1) represent only the highest peaks of what used to be a much larger island named Santarosae (Orr, 1968). During ice ages, significant amounts of water were trapped in glaciers, drastically lowering global sea levels and causing the four islands to unite. At the end of the Pleistocene when glaciers melted and sea level rebounded, an estimated 76% of Santarosae was inundated and the islands assumed their modern shorelines (Agenbroad, 2002a). Pygmy mammoth remains have been found on Santa Rosa, San Miguel and Santa Cruz islands but have not yet been recovered from Anacapa.

The pygmy mammoth was endemic to Santarosae and represents one of the most extreme cases of insular dwarfism in North America. *Mammuthus exilis* evolved from the much larger mainland form, the Columbian mammoth (*Mammuthus columbi*) (Agenbroad, 2002c). Absence of a land bridge between Santarosae and the California mainland during the Pleistocene suggests the mainland mammoths migrated to the island across the Santa Barbara Channel (Fig. 1). Today, the Channel separates CHIS from the mainland by about 19 km at its narrowest point (Tweet et al., 2012), but during ice age sea levels the Santa Barbara Channel was reduced to only 6–9 km wide. Modern elephants have been documented to be capable swimmers, a trait they likely shared by their mammoth relatives, who swam the restricted Channel to reach Santarosae (Wenner and Johnson, 1980).

Columbian mammoths reaching Santarosae had to contend with new ecological pressures, including a restricted habitat range and finite food supply. The large mainland *M. columbi* were unable to access pasturage on steep mountainous terrain. Smaller individuals with lower centers of gravity gained better access to vegetation on steeper slopes of the island, reducing dietary stress and eventually leading to progressively smaller body sizes. This resulted in the evolution of the dwarfed form, *M.*

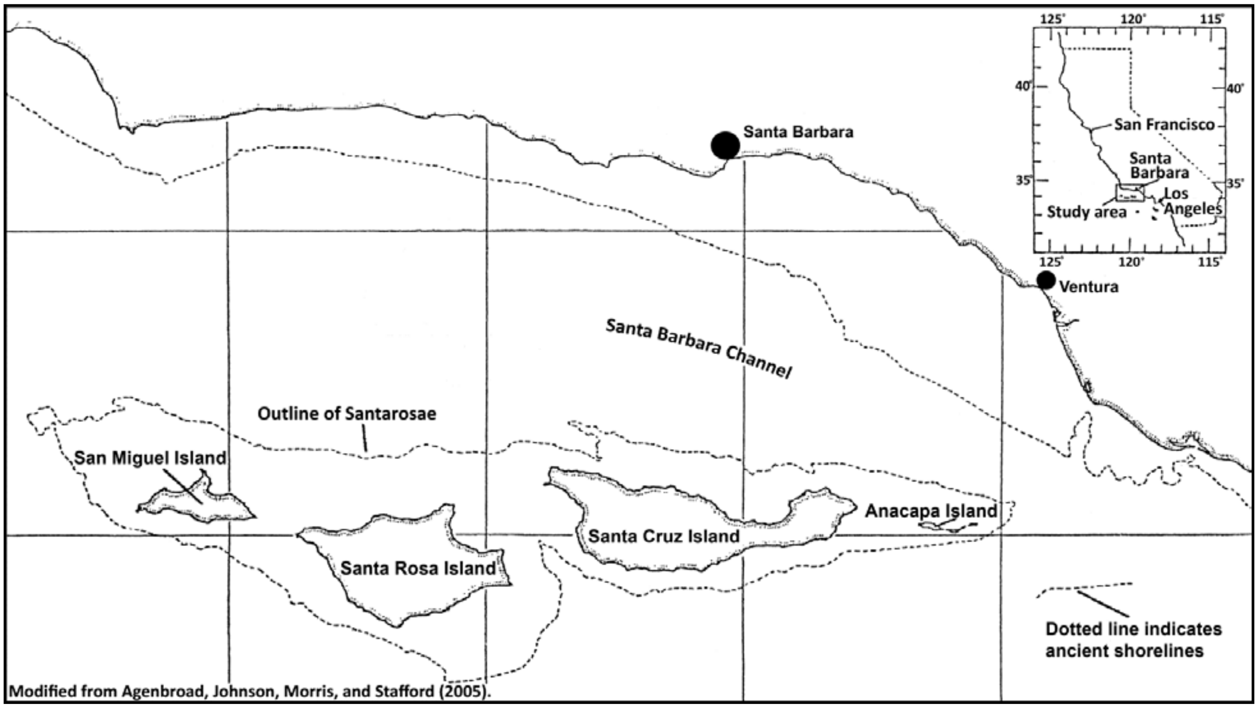

FIGURE 1. Map of the four northern Channel Islands: San Miguel, Santa Rosa, Santa Cruz and Anacapa. The dotted line marks the approximate shoreline of Santarosae during reduced sea level. Modified from Agenbroad et al. 2005.

exilis, which experienced an estimated 46% decrease in stature (Agenbroad et al., 1999) and a 50% decrease in tusk length (Agenbroad, 2002b).

Relative to other North American proboscideans, much of the life and evolutionary history of *M. exilis* remains unknown. The timing and number of ancestral *M. columbi* migrations to Santarosae, the rate of size reduction, the possible contemporaneity of mammoths and humans (Agenbroad et al., 2005), and the potential role of humans in the island mammoths' extinction (Rick et al., 2012) remain largely unresolved. The first step toward answering these questions is to secure the fossils rapidly eroding from Pleistocene alluvium. Since the discovery of the articulated specimen in 1994, the Mammoth Site of Hot Springs, SD (MSHS) has worked with CHIS in an effort to preserve and study its unique island mammoth.

HISTORY OF COLLABORATION

Channel Islands National Park contains diverse fossil assemblages including terrestrial and marine vertebrates, invertebrates, plants, trace fossils, and foraminifera (Tweet et al., 2012); however, there is no paleontologist within the CHIS system to manage the resource. As an alternative, outside scientists have conducted much of the paleontological survey, collection, and research on the Islands with the aid of the Cultural Resource Division. For the past 20 years, MSHS has partnered with CHIS to document, salvage, and preserve fossils of the Channel Islands pygmy mammoth and its ancestral species the Columbian mammoth.

The Mammoth Site is a private non-profit museum in Hot Springs, South Dakota, which houses a large collection of *M. columbi* material. Upon discovery of a suspected *M. exilis* skeleton in July 1994, CHIS contacted MSHS Site Director Larry Agenbroad with an invitation to fly to Santa Rosa Island and evaluate the articulated skeleton. The specimen was confirmed as *Mammuthus*, and recommendation was made that it be collected prior to the winter storm season. The skeleton was located in the steep face of an eroded sand dune deposit and was in danger of erosional destruction (Agenbroad et al., 1999).

A small crew (two MSHS members, a Duke University researcher, and the CHIS Archaeologist) succeeded in exposing, casting and removing the ~90% complete articulated skeleton, which was later dated to 12,840 ± 410 BP (CAMS-24429) (Agenbroad, 1998). It was taken to the mainland (NPS–Ventura) and then to Hot Springs, SD (MSHS) for preparation, molding, and casting. Replicas of the articulated skeleton, as found in situ, were produced for the SBMNH and NPS–Ventura. SBMNH was identified as the NPS paleontological repository due to its ownership of the Orr collection, proximity to the park, and relatively safe seismic location. The 1994 articulated skeleton and all subsequent recovered specimens are housed at SBMNH.

During the spring of 1995, MSHS initiated a pedestrian survey of Santa Rosa Island. Continued survey and collection trips through 2008 documented GPS coordinates of over 380 mammoth localities on Santa Rosa, San Miguel, and Santa Cruz islands (Agenbroad, 2009). The high re-

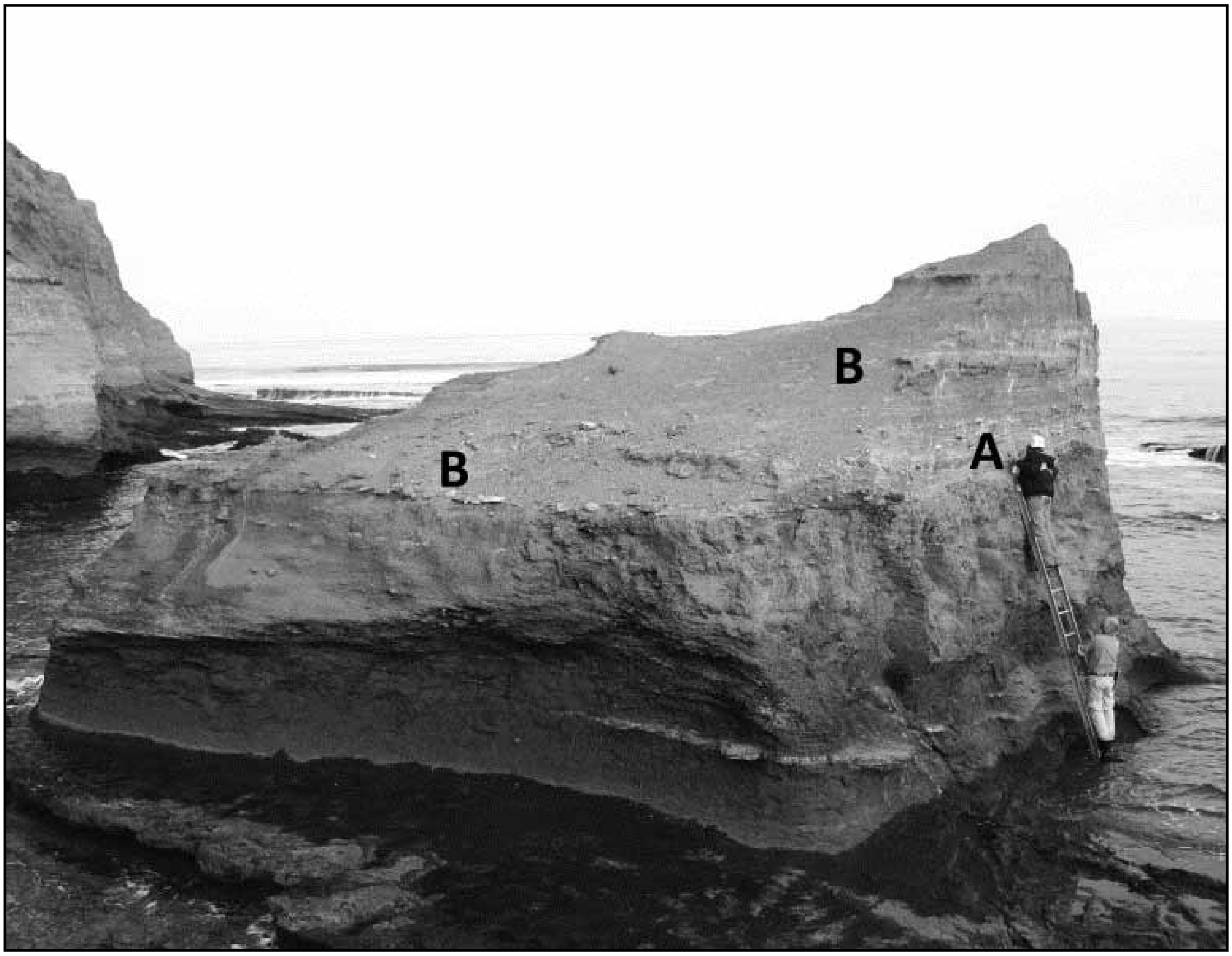

FIGURE 2. The sea stack at the mouth on Garańon Canyon. **A**, approximate location of tusk of *Mammuthus exilis* and tibia of *Peromyscus nesodytes* in Pleistocene alluvium; **B**, approximate locations of two *Chendytes lawi* femora recovered from loose sediments atop the sea stack.

lief and limited infrastructure of the park make routine monitoring of the many fossiliferous localities a difficult and time-consuming task. High erosion rates for Pleistocene alluvium often result in fossil material being exposed and destroyed within a six month period (Agenbroad and Morris, 1999). Soon after the pedestrian survey began, the decision was made to collect only unique specimens, or those specimens in immediate danger of loss by erosion. Since then, the majority of MSHS collecting on the Islands has focused on salvage of eroding material rather than controlled excavation.

Santa Rosa Island provided the majority of material located and/or collected, but San Miguel Island also proved an abundant source of *M. exilis* remains. Santa Cruz Island supplied fewer fossil remains, which were limited to the western end of the island. Much of Santa Cruz Island is of igneous origin, with fewer alluvial deposits that could serve to preserve terrestrial paleontological remains. Anacapa Island has yet to produce any mammoth material.

Columbian mammoth remains appear to be confined to marine terraces on Santa Rosa Island in contrast to remains of pygmy mammoths, which are also encountered towards the center of the islands on steeper terrain. The center of gravity was calculated for *M. exilis* and compared to values from MSHS specimens of *M. columbi*. Results indicate that *M. exilis* was able to negotiate island slopes about 20% steeper than the larger ancestral forms (Agenbroad, 2002b). The ability to traverse Santarosae's steeper terrain allowed *M. exilis* greater access to upland pastures, while *M. columbi* was restricted to the lower grade coastal landscapes. Comparative research between the ancestral and derived forms of the Channel Islands mammoths was facilitated by MSHS's readily available collection of *M. columbi* material.

Specimens recovered during survey and collection trips were cleaned, preserved, and recorded in SBMNH-NPS collections. Expeditions involving MSHS scientists are estimated to have nearly doubled the pygmy mammoth material now in collections at SBMNH (Agenbroad and Morris, 1999). In addition, a large avocational collection of mammoth fossils, called the Woolley Collection, was donated to SBMNH in 1995. The fossils were amassed by Boris Woolley, a member of the ranching family who owned Santa Rosa Island prior to its purchase by the NPS.

The influx of specimens over the past two decades has greatly expanded the osteological collection available to researchers for future study.

A recent NPS report (Tweet et al., 2012) recommends continued support of MSHS work with CHIS. The report encourages park staff to take advantage of opportunities to work with experienced paleontologists in the field. As a result, CHIS rangers will be trained by MSHS staff to better recognize paleontological material, assess the threat of erosion, and make informed decisions about when it is necessary to contact outside paleontologists for further investigation and possible salvage of threatened or vulnerable specimens. Improved training for park personnel increases the chances of recognizing and saving a significant find in remote areas, before erosion takes its toll. In this way CHIS, its paleontological resources, MSHS, and other researchers all benefit from a productive relationship.

NOVEMBER 2013 EXPEDITION

In July 2013, Dan Muhs of USGS alerted Agenbroad (MSHS) to the presence of a nearly complete mammoth tusk eroding from Pleistocene sediments on Santa Rosa Island. The tusk was exposed in a sea stack at the mouth of Garañon Canyon and lay just above the contact of Pleistocene alluvium and the Miocene Rincon Shale Formation (Fig. 2). Proximal and distal ends of the tusk were missing, but the distal tip of the pulp cavity was intact. Muhs (unpubl. data) identified the tusk as *M. exilis* and dated the depositional layer to ~80,000 BP.

The quality of the specimen, and its unique geologic position as documented by Muhs (unpubl. data), made the tusk a high priority target for collection. However, the window for collection was short. Winter storms increase erosive forces of waves in the surf zone, and specimens exposed in sea cliffs have a greater probability of suffering irreparable damage or destruction during the winter season (Santucci and Koch, 2003). MSHS quickly organized a salvage expedition with NPS for early November 2013, prior to the onset of the upcoming winter storm season.

When the team (two MSHS members and the former CHIS Archaeologist) arrived, the tusk was still in good condition, though some exposed surfaces were beginning to spall. All exposed areas were consolidated with McGean PVA B-15 in acetone prior to jacketing and removal. Extraction of this specimen proved a complicated endeavor, confounded by numerous environmental factors including limited work time due to tidal fluctuations, unexpectedly resistant matrix, and limited anchor points for equipment stabilization.

Two additional extinct taxa were recovered from the sea stack locality (Fig.2), identified as *Chendytes lawi*, a flightless goose, and *Peromyscus nesodytes*, the Channel Islands giant deer mouse (P. Collins, pers. comm., 2013). *P. nesodytes* was a late Pleistocene endemic of Santarosae, while *C. lawi* inhabited both the islands and the nearby mainland coast (Guthrie, 1998; Rick et al., 2012). Two *C. lawi* femora were recovered along with isolated remains of *M. exilis* from loose sediments located approximately 0.25–1 m above the contact of Pleistocene alluvium with the Rincon Shale. A single *P. nesodytes* tibia was discovered within the jacketed matrix surrounding pygmy tusk after the tusk was removed.

The earliest presence of *M. exilis* and *P. nesodytes* on the Channel Islands is not well defined. Material from both taxa has been recovered from sediments dated to 200,000 BP by Orr (1968). However, according to Muhs (unpubl. data), Orr's (1968) dates have been deemed unreliable due to the unsuitability of the dated material. The ~80,000 BP year date from Muhs is among the oldest reliable dates now available for *M. exilis* and *P. nesodytes*.

SUMMARY

The collaborative efforts of MSHS and CHIS have been productive, but constant field work is needed to safeguard rapidly eroding paleontological resources. With the exception of the 1994 articulated specimen, most Mammoth Site trips to the island were of short duration and focused on survey and salvage collection. The sporadic nature of this arrangement makes it difficult to support more detailed excavation. Crews are unable to devote time to incomplete specimens or more complicated, time-consuming extractions. Increased training for Park staff, partnership with additional specialist institutions or researchers, or the introduction of a CHIS paleontologist position would go a long way to further improve salvage and research efforts.

The Mammoth Site hopes to maintain its relationship with CHIS into the future, helping to preserve a resource unique to the Channel Islands and to elucidate the evolutionary history of North America's smallest mammoth and the world in which it lived.

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ARTICLE

DESCRIPTION OF AN EARLIEST ORELLAN FAUNA FROM BADLANDS NATIONAL PARK, INTERIOR, SOUTH DAKOTA AND IMPLICATIONS FOR THE STRATIGRAPHIC POSITION OF THE BLOOM BASIN LIMESTONE BED

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ABSTRACT—Three new vertebrate localities are reported from within the Bloom Basin of the North Unit of Badlands National Park, Interior, South Dakota. These sites were discovered during paleontological surveys and monitoring of the park's boundary fence construction activities. This report focuses on a new fauna recovered from one of these localities (BADL-LOC-0293) that is designated the Bloom Basin local fauna. This locality is situated approximately three meters below the Bloom Basin limestone bed, a geographically restricted stratigraphic unit only present within the Bloom Basin. Previous researchers have placed the Bloom Basin limestone bed at the contact between the Chadron and Brule formations. Given the unconformity known to occur between these formations in South Dakota, the recovery of a Chadronian (Late Eocene) fauna was expected from this locality. However, detailed collection and examination of fossils from BADL-LOC-0293 reveals an abundance of specimens referable to the characteristic Orellan taxa *Hypertragulus calcaratus* and *Leptomeryx evansi*. This fauna also includes new records for the taxa A*djidaumo lophatus* and *Brachygaulus*, a biostratigraphic verification for the biochronologically ambiguous taxon *Megaleptictis*, and the possible presence of new leporid and hypertragulid taxa. The Bloom Basin local fauna represents the earliest Orellan local fauna described from the Big Badlands of South Dakota and provides crucial insights into the age and stratigraphic position of the Bloom Basin limestone bed. The results of this study emphasize the vital importance of paleontological monitoring of high impact activities as a tool for discovering significant new localities and faunas and protecting crucial natural resources.

INTRODUCTION

One of the founding principles behind the establishment of the National Park System (NPS) is the protection and preservation of those natural resources contained within the boundaries of all designated land management units. One crucial component of resource management on NPS lands, with regards to paleontological resources, is the combined use of paleontological surveys prior to high impact activities (e.g., road construction, fencing) and paleontological monitoring during those activities. Together, these practices facilitate the identification, documentation, and preservation of significant paleontological specimens and localities that would otherwise be adversely affected. They also provide opportunities to survey infrequently visited areas, expanding knowledge of a management unit's paleontological resources and providing critical information that can be used to evaluate the impacts of future proposed activities, develop resource protection protocols, and guide scientific research by both park employees and external research partners.

For almost a decade, an extensive fencing project has been ongoing at Badlands National Park to upgrade portions of the boundary fence. Physical science technicians directly monitored construction activities in areas of bedrock outcrop and spot checked the sediments excavated during the drilling of postholes in sod-covered areas as part of the plan to mitigate the impact of these activities on the park's paleontological resources. Three new paleontological localities were identified, documented, and added to the park's expansive paleontological locality database since 2012 as a consequence of these monitoring activities. One of these localities (BADL-LOC-0292) is a subsurface locality that produced material from an unidentified species of fish that would not have been discovered by traditional paleontological surveying methods. A second is an extensive vertebrate locality (BADL-LOC-0298) that straddles the fence line and would have been directly impacted by the fencing activities without the use of proper paleontological monitoring.

The third locality (BADL-LOC-0293), which is contained entirely within the park immediately adjacent to the fence line, is situated within the southern edge of the Bloom Basin along the park's northern boundary. This locality preserves a unique and diverse fauna (Table 1), here identified as the Bloom Basin local fauna. Sediments at this locality are exposed in an area eroded below the surface of the surrounding prairie. The top of the local stratigraphic section, which is about three meters above the fossil-bearing layer, is capped by a continuous carbonate layer several centimeters in thickness here identified as the Bloom Basin limestone bed (BBLB sensu Evans and Welzenbach, 1998; Benton and Reardon, 2006), based on comparisons to the type locality situated to the northeast (see Welzenbach, 1992). The thickness of the BBLB varies throughout the Bloom Basin, being thicker in the center of the basin (~1 meter) and thinning towards the margins before the exposures are lost entirely (Welzenbach, 1992; Evans and Welzenbach, 1998). The BBLB is restricted to the Bloom Basin of south-central South Dakota (Welzenbach, 1992; Evans and Welzenbach, 1998); however, similar limestones appear near the contact between the Chadron and Brule formations within South Dakota (Evans and Welzenbach, 1998). The presence of this marker bed at the top of the local section with no overlying strata present ensures that all fossils collected both in situ and on the surface at this locality were preserved in the strata situated immediately below the BBLB and are not displaced from overlying sediments of the Brule Formation.

The BBLB was deposited within a perennial, stratified, freshwater lake (Welzenbach, 1992; Evans and Welzenbach, 1998) and is traditionally positioned by various authors either at the contact between the Chadron Formation and the overlying Brule Formation (e.g., Welzenbach, 1992; Benton and Reardon, 2006), or slightly below this contact within the Chadron Formation (e.g., Evans and Welzenbach, 1998). However, little prior stratigraphic work has been conducted in the Bloom Basin region of the park, with prior authors basing the stratigraphic position and age of the BBLB largely on correlations with carbonate layers observed in other areas of South Dakota and Nebraska (Welzenbach, 1992). Additionally, little paleontological work has been conducted within the Bloom Basin area, making it impossible to assess the age of the BBLB based on its position relative to biochronologically dated faunas. Here we describe the newly discovered Bloom Basin local fauna, assess the biochronologic age of that fauna, and discuss the implications this study has for the age, stratigraphic position, and regional correlation of the BBLB.

Institutional Abbreviations—BADL, Badlands National Park, Interior, South Dakota U.S.A.; CSC, Chadron State College, Chadron, Nebraska U.S.A.; SDSM, South Dakota School of Mines and Technology, Rapid City, South Dakota U.S.A.; UNSM, University of Nebraska State Museum, Lincoln, Nebraska.

Anatomical Abbreviations—Dental characters are designated with uppercase letters for upper dentition and lowercase letters for lower dentition: I/i, incisors; C/c, canines; P/p, premolars; M/m, molars.

MATERIALS AND METHODS

Fossil Collection and Preparation Methods

Most fossils collected from BADL-LOC-0293 were collected as float specimens after being subaerially eroded, though a few specimens (i.e., BADL 63554) were only partially exposed and remained in situ. No quarrying took place at this locality; therefore, all specimens collected were in some way exposed prior to discovery. Float specimens were not prepared, cleaned, or stabilized in the field. Preparation of specimens was conducted at the seasonal fossil preparation lab at Badlands National Park and further work was conducted in the preparation lab in the James E. Martin Paleontology Research Laboratory at South Dakota School of Mines and Technology. Matrix was removed from specimens using two different mechanical preparation methods. A pneumatic airscribe (Paleo Tools© Microjack #1) was used to remove relatively soft matrix in easily accessed areas, while air abrasion was used in more delicate areas and in places where the matrix was well-cemented. Two different powder compounds were used during air abrasion: sodium bicarbonate was used to remove softer matrix, while crushed pumice was used on areas where the matrix was well-cemented and difficult to remove. When needed, specimens were stabilized using two different solutions of Paraloid® B-72 (ethyl methacrylate co-polymer), one dissolved in ethanol (5% weight by weight mixture) and the other dissolved in acetone (10% weight by weight mixture).

Screen Washing of Bulk Sediment for Microfossils

Bulk matrix removed during the excavation of a rhinocerotid skull (BADL 63554) during this study was retained and processed for microvertebrate fossils. These sediments were first soaked in warm water for at least twenty-four hours, then placed in a 0.5 mm mesh sieve and placed under running water to remove the silt and mud fraction of the sediment. The sediment was then placed in a drying rack for another twenty-four hours. Once dry, the sediment was dry sieved on a 0.5 mm mesh sieve, and the remaining matrix was retained and examined under a dissecting microscope. All fossil material noted was removed from the sediment sample and retained for identification. Though processing of this sediment is still ongoing, several important specimens of small rodents and reptiles were recovered (see below).

Dental Terminology

In regards to ruminant dental anatomy, we have elected to use the dental terminology proposed by Bärmann and Rössner (2011). That study standardized ruminant dental terminology in order to circumvent previously proposed, but unsupported homology statements.

SYSTEMATIC PALEONTOLOGY

Class REPTILIA Laurenti, 1768
Order TESTUDINES Batsch, 1788
Family TRIONYCHIDAE Gray, 1825
APALONE Rafinesque, 1832

Trionyx Wagler, 1830 (original description)
Apalone Rafinesque, 1832 (original description)
Platypeltis Fitzinger, 1835 (original description)
Trionyx Cope, 1891:5, plate I, figs. 8-9 (revised diagnosis)
Aspideretes Hay, 1904 (in part) (original description)
Platypeltis Hay, 1908:546, plate 113, figs. 1-3 (revised diagnosis)
Amyda Clark et al., 1967:26 (revised diagnosis)
Aspideretes Harksen and Macdonald, 1969:15 (revised diagnosis)
Apalone Meylan, 1987 (new combination)
Apalone Hutchison, 1996:339, fig. 3 (new combination)

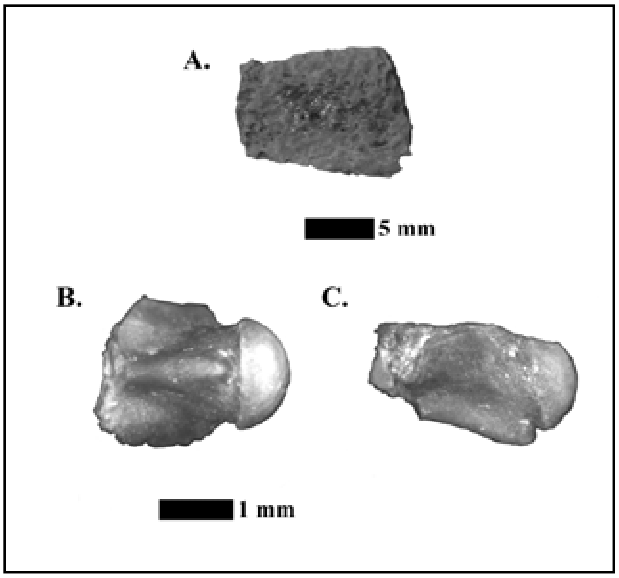

FIGURE 1. Photographs of selected reptiles identified from the Bloom Basin local fauna. **A**, BADL 63556, *Apalone* sp. carapace fragment in dorsal view; **B**, SDSM 63454, *Calamagras angulatus* vertebra in ventral view; **C**, right lateral view of the same.

APALONE sp.
(Fig. 1)

Referred Specimens—BADL 63556, partial costal plate fragment.

Known Occurrences—Cypress Hills Formation, Canada; Chadron Formation, Nebraska, North Dakota, and South Dakota; Brule Formation, North Dakota and South Dakota.

Comments— Recent North American trionychids were traditionally attributed to the genus *Trionyx*, until revisions by Meylan (1987) resurrected the genus Apalone. Two subgenera, *Apalone* and *Platypeltis*, were also recognized, but those taxa cannot be distinguished from each other based on the morphology of the carapace (Hutchison, 1996). The only species of trionychid turtle previously reported from the White River Group is *A. leucopotamica* (Cope, 1891). Though the type material of *A. leucopotamica* is highly fragmentary, Hay (1908) and Hutchison (1996) were able to confirm the validity of this species based on comparisons with more complete referred specimens from Nebraska. While BADL 63556 is too incomplete and weathered to allow referral to the species level, the dorsal sculpturing on the carapace is clear enough to confidently refer this specimen to the taxon *Apalone*.

Order SQUAMATA Oppel, 1881
Family BOOIDAE Gray, 1825
CALAMAGRAS Cope, 1873c

Calamagras Cope, 1873c:15 (original description)
Aphelophis Cope, 1873c:16 (original description)
Calamagras Sullivan and Holman, 1996:364 (new combination)
Calamagras Holman, 2000:59 (revised diagnosis)

CALAMAGRAS ANGULATUS Cope, 1873c
(Fig. 1)

Calamagras angulatus Cope, 1873c:16 (original description)
Ogmophis angulatus Cope, 1874:783 (new combination)
Calamagras angulatus Sullivan and Holman, 1996:364 (new combination)
Calamagras angulatus Holman, 2000:62, fig. 30 (revised diagnosis)

Referred Specimens—BADL 63454, partial trunk vertebra.

Known Occurrences—White River Formation, Colorado; Brule Formation, South Dakota; Gering Formation, Nebraska; Harrison Formation, Nebraska; Monroe Creek Formation, Wyoming.

Comments—BADL 63454 consists of a partial vertebra, only lacking the neural arch, or accessory processes. The morphology of this specimen corresponds with description of the holotype provided by Holman (2000). Specifically, the vertebra is longer than wide in ventral view and a moderately well-developed hemal keel is present on the ventral surface of the centrum that ends slightly anterior to the border of the posterior condyle. The only other record of this species from South Dakota is based on the referral of two trunk vertebrae (SDSM 20189 and 20197) from the Brule Formation at Reva Gap, Harding County, South Dakota (Sullivan and Holman, 1996).

Class AVES Linnaeus, 1758
Order indet.

Referred Specimens—BADL 61905 and 63559, eggshell fragments.

Comments—There has been no study, as of yet, that can determine the taxonomic or parataxonomic status of this specimen without undertaking destructive sampling to examine the microcrystalline structure of the eggshell. Therefore, referral of these specimens is restricted to the clade Aves.

Class MAMMALIA
Order LEPTICTIDA McKenna, 1975
Family LEPTICTIDAE Gill, 1872
MEGALEPTICTIS Meehan and Martin, 2012
MEGALEPTICTIS ALTIDENS Meehan and Martin, 2012
(Fig. 2)

Referred Specimens—BADL 61907, a left maxillary fragment with P4-M2

REPTILIA Laurenti, 1768
- TESTUDINES Batsch, 1788
  - ?TESTUDINIDAE Batsch, 1788
  - TRIONYCHIDAE Gray, 1825
    - *Apalone* sp.
- SQUAMATA Oppel, 1881
  - *Lacertilia* indet.
  - BOIDAE Gray, 1825
    - *Calamagras angulatus* Cope, 1873c

AVES Linnaeus, 1758
- Aves indet.

MAMMALIA Linnaeus, 1758
- LEPTICTIDA McKenna, 1975
  - LEPTICTIDAE Gill, 1872
    - *Megaleptictis altidens* Meehan and Martin, 2012
- CREODONTA Cope, 1875
  - HYAENODONTIDAE Leidy, 1869
    - *Hyaenodon* sp. indet.
- CARNIVORA Bowdich, 1821
  - CANIDAE Flower, 1869
    - *Hesperocyon gregarius* (Cope, 1873c)
  - AMPHYCYONIDAE Haeckel, 1866
    - *Daphoenus* sp.
  - NIMRAVIDAE Cope, 1880
    - *Dinictis* sp.
  - CARNIVORA incertae sedis
    - *Palaeogale sectoria* (Gervais, 1848)
- LAGOMORPHA Brandt, 1855
  - LEPORIDAE Gray, 1821
    - *Megalagus* sp.
    - *Palaeolagus haydeni* Leidy, 1856
    - Leporidae indet.
- RODENTIA Bowdich, 1821
  - ISCHYROMYIDAE Alston, 1876
    - *Ischyromys* sp.
  - APLODONTIDAE Brandt, 1855
    - *cf. Brachygaulus* sp.
  - EUTYPOMYIDAE Miller and Gidley, 1918
    - *Eutypomys cf. thomsoni* Matthew, 1905
  - EOMYIDAE Winge, 1887
    - *Adjidaumo lophatus* Korth, 2012
  - HELISCOMYIDAE Korth, Wahlert, and Emry, 1991
    - Heliscomyidae indet.
- PERISSODACTYLA Owen, 1848
  - RHINOCEROTIDAE Gray, 1821
    - *Subhyracodon* sp.
  - EQUIDAE Gray, 1821
    - *Mesohippus* sp.
- ARTIODACTYLA Owen, 1848
  - ENTELODONTIDAE Lydekker, 1883
    - *Archaeotherium* sp.
  - MERYCOIDODONTIDAE Thorpe, 1923
    - *Merycoidodon culbertsoni* Leidy, 1848
  - HYPERTRAGULIDAE Cope, 1879
    - *Hypertragulus calcaratus* (Cope, 1873b)
    - Hypertragulidae gen. et sp. indet.
  - LEPTOMERYCIDAE Zittel, 1893
    - *Leptomeryx evansi* Leidy, 1853
    - *Leptomeryx* sp.

TABLE 1. Preliminary faunal list for the Bloom Basin local fauna based on specimens collected from locality BADL-LOC-0293.

Known Occurrences—Brule Formation, South Dakota.

Comments—Several diagnostic features of M. altidens are noted in BADL 61907. The P4 through M2 display the following features: presence of well-developed, centrally positioned precingula that bear small cuspules; presence of moderate labial cingula; absence of lingual cingula; and, presence of well-developed postcingula with tall hypocones. The holotype of *M. altidens* was collected in the tan silt-stones of the White River Group in Custer County, South Dakota during an 1894 Kansas University field expedition (Meehan and Martin, 2012). This locality description likely refers to high-altitude White River Group deposits situated in the eastern Black Hills. However, the lack of detailed geographic and stratigraphic data recorded with this specimen prevents confident referral of this specimen to either the Chadron or Brule Formation. Based on the fauna collected in association with the holotype, Meehan and Martin (2012) inferred that the biochronological age of this species was likely Chadronian, but could not completely rule out the possibility that it was Orellan. This uncertainty is the result of a lack of biostratigraphic resolution for these high-altitude faunas preserved in South Dakota. Thus, BADL 61907 serves as the only stratigraphically and biochronologically verified occurrence of this taxon.

Also collected from BADL-LOC-0293 is a moderately preserved leptictid skull and dentaries (BADL 61618). However, the upper and lower dentition on this specimen remain in occlusion and further preparatory work is needed to reveal the taxonomic affinities of that specimen.

Order CREODONTA Cope, 1875
Family HYAENODONTIDAE Leidy, 1869
HYAENODON Laizer and Pariello, 1838

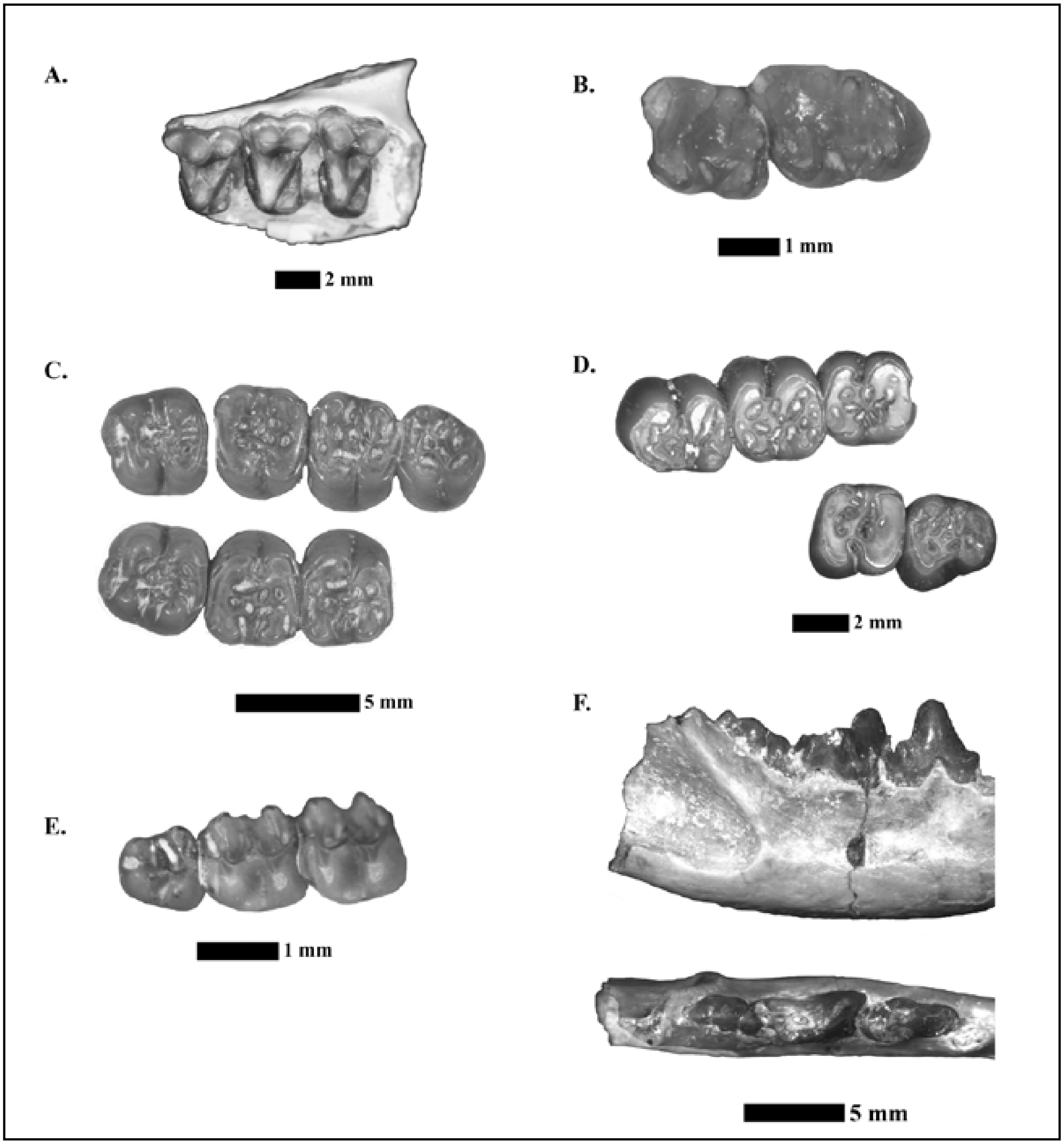

FIGURE 2. Photographs of some significant mammalian fossils from the Bloom Basin local fauna. **A**, BADL 61907, *Megaleptictis altidens* left maxilla fragment with P2 through M2 in ventral view; **B**, crown view of BADL 63453, *cf. Brachygaulus* sp. m2 through m3; **C** crown view of BADL 63460, *Eutypomys cf. thomsoni* maxilla fragments with LM1 through M3 and RP4 though M1; **D**, crown view of BADL 61621, *Eutypomys cf. thomsoni* left m1 through m3 and BADL 61621 right p4 through m1; **E**, crown view of BADL 61615, *Adjidaumo lophatus* p4 through m2; **F**, BADL 63558, *Palaeogale sectoria* dentary fragment with p4 through m2 in labial and dorsal views (edentulous anterior portion cropped from image).

Hyaenodon Laizer and Pariello, 1838 (original description)
Taxotherium Blainville, 1841 (original description)
Hyaenodon Leidy, 1853 (revised diagnosis)
Pseudopterodon Schlosser, 1887 (original description)
Neohyaenodon Thorpe, 1922b:278, Figs. 1-2 (original description)
Hyaenodon (Protohyaenodon) Stock, 1933:435 (original description)
Hyaenodon Scott and Jepsen, 1936 (new combination)

Hyaenodon Van Valen, 1967:268 (new combination)
Hyaenodon (Neohyaenodon) Mellett, 1977 (new combination)
Hyaenodon (Protohyaenodon) Mellett, 1977 (new combination)
Hyaenodon Gunnell, 1998:98 (revised diagnosis)

HYAENODON sp.

Referred Specimens—BADL 61619, edentulous skull and mandible.

Known Occurrences—*Hyaenodon* is one of the most cosmopolitan carnivorous mammals with Middle Eocene to Oligocene occurrences in North America and Eurasia, along with a few occurrences in Africa.

Comments—This specimen is represented by the edentulous skull and mandible of a very young individual. The alveoli in this specimen are not mediolaterally angled, as would be expressed by the carnassial set of a carnivoran; rather, the alveoli are anteroposteriorly oriented, which is typical of the posterior-most carnassial teeth in creodonts. This specimen was found in close association with scattered cranial and dental remains of a larger, presumably adult specimen of *Hyaenodon*, but that specimen was considered too fragmentary and weathered to collect.

Order CARNIVORA Bowdich, 1821
Family CANIDAE Flower, 1869
HESPEROCYON Scott, 1890

Amphicyon Leidy, 1856:90
Canis Cope, 1873b:3
Galecynus Cope, 1881:177
Cynodictis Scott and Osborn, 1887:152
Hesperocyon Scott, 1890:37
"*Pseudocynodictis*" Schlosser, 1902:164
Nothocyon Matthew, 1924:fig. 28
Hesperocyon Green, 1952:124
Nanodelphys? Russell, 1972:7
cf. Hyaenodon? Russell, 1972:47
Hesperocyon Wang, 1994:24. Wang and Tedford, 1996:435 (new combination)

HESPEROCYON GREGARIUS (Cope, 1873b)

Amphicyon? gracilis Leidy, 1856:90 nom. preoc. (original description)
Canis gregarius Cope, 1873b:3 (original description)
Canis lippincottianus Cope, 1873c:9 (referred specimen only)
Galecynus gregarius Cope, 1881:177 (new combination)
Cynodictis gracilis Scott and Osborn, 1887:152 (new combination)
Hesperocyon gregarius Scott, 1890:37. Green, 1952:124. Russell, 1972:53 (in part) (new combination)
Cynodictis gregarius Scott, 1898:400 (new combination)
Nothocyon gregarius Matthew, 1924:fig. 28 (new combination)
Pseudocynodictis gregarius Schlosser, 1902:50. Scott and Jepsen, 1936:101. Galbreath, 1953:75. (new combination)
Cynodictis paterculus Matthew, 1903:209 (new combination)
Cynodictis lippincottianus Lambe, 1908:61 (new combination)
Amphicyon angustidens Thorpe, 1922c:425 Fig. 1 (new combination)
Cynodictis paterculus Thorpe, 1922c:428 (new combination)
Pseudocynodictis angustidens (=*lippincottianus*) Hough, 1948:590 (new combination)
Pseudocynodictis nr. paterculus Galbreath, 1953:75 (new combination)
Hesperocyon paterculus White, 1954:416 (new combination)
Pseudocynodictis nr. paterculus Hough and Alf 1956:136 (new combination)
Nanodelphys? mcgrewi Russell, 1972:7
cf. Hyaenodon? minutus Russell, 1972:47 (NMC 9353 only)
Hesperocyon gregarius Wang, 1994:26, figs. 9-10. Wang and Tedford, 1996:436, figs. 1-2 (new combination)

Referred Specimens— BADL 61614, partial dentary with left m1; BADL 63455, left P4; BADL 63456, left M1.

Known Occurrences—*Hesperocyon gregarius* is one of the most common carnivores in Chadronian through Whitneyan localities and correlative stratigraphic units in Colorado, Montana, South Dakota, Nebraska, North Dakota, and Wyoming, United States and Saskatchewan, Canada.

Comments—The P4 of BADL 63455 has a protocone that is fairly well developed and slightly anterior to the protocone. In *Archaeocyon pavidus* (*"Hesperocyon" pavidus*), the protocone is closely appressed to the paracone. BADL 63455 also has a small anterior cingulum that persists to the paracone, in contrast to *H. coloradensis* where the anterior cingulum disappears laterally. In BADL 63456 the labial cingulum is relatively prominent anterior and lateral to the paracone, as opposed to the reduced labial cingulum seen in *A. pavidus*.

The only Chadronian occurrence of Canidae besides *H. gregarius* is *Prohesperocyon wilsoni*, which is restricted to a single locality in Texas representing the early-middle Chadronian (Gustafson, 1986). We chose to leave *Prohesperocyon* out of this discussion owing to significant morphological differences between that taxon and these specimens, regardless of the combined biogeographic and biochronologic removal (see Wang, 1994). Canid specimens recovered from the Scenic Member of the Brule Formation are predominantly referable to *H. gregarius*. *Hesperocyon coloradensis* has yet to be identified from outside of the White River Group in northeast Colorado, and a few specimens of *"Hesperocyon" pavidus* are known from the same location (Wang, 1994). Though

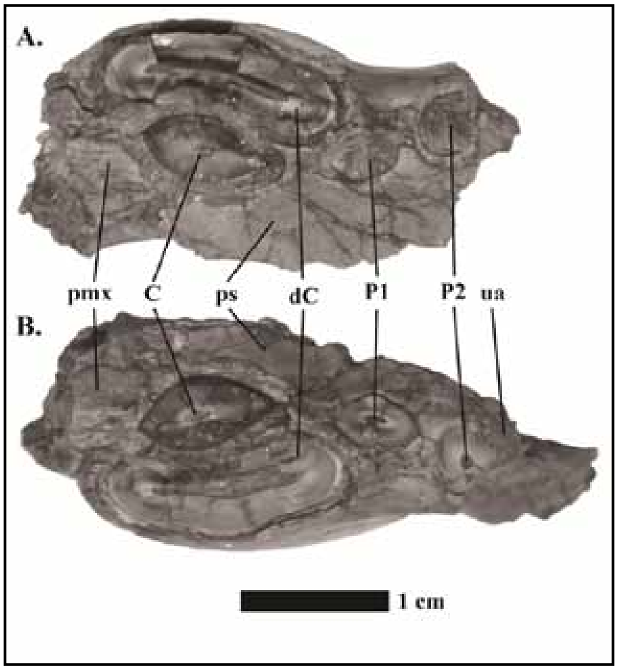

FIGURE 3. Photographs of BADL 61617 (*Dinictis* sp. indet.): **A**, left premaxilla and maxilla in ventral view; **B**, right premaxilla and maxilla in ventral view. Abbreviations: pmx, premaxilla; C, canine; dC, deciduous canine; ps, palatal shelf; ua, unidentified alveolus.

"Hesperocyon" pavidus has been synonymized with the borophagine *Archaeocyon* (in part), none of the Orellan occurrences, all in Colorado, were included (Wang et al., 1999). Wang et al. (1999) did not give any specific assignment to the Colorado material, but suggested that the material might represent a distinct species that could potentially bridge the Hesperocyoninae to the Borophaginae. The only other canid taxa known to occur in the Orellan are *"Meoscyon" temnodon* and *Osbornodon renjiei*, both hesperocyonines (Wang, 1994). Both taxa are significantly larger than *Hesperocyon*. Only a single Orellan specimen of *"Mesocyon" temnodon* known from South Dakota and the only specimens of *O. rengiei* are restricted to the late Orellan of North Dakota (Wang, 1994).

Family AMPHICYONIDAE Haeckel, 1866
DAPHOENUS Leidy, 1853

Daphoenus Leidy, 1853 (original description)
Galecynus Cope, 1874 (original description)
Canis Cope, 1883 (new combination)
Proamphicyon Hatcher, 1902:95 (original description)
Pseudocynodictis Schlosser, 1902 (new combination)
Cynodictis Thorpe, 1922c:427 (in part) (new combination)
Pericyon Thorpe, 1922a:172, Fig. 3 (original description)
Pseudocynodictis Galbreath, 1953:75 (in part) (new combination)
Daphoenus Hunt, 1998:204 (revised diagnosis)

DAPHOENUS sp.

Referred Specimens—BADL 63451, an unidentified premolar; BADL 63452, left maxillary fragment with M1-2.

Comments—The molars of *Daphoenus* are nearly indistinguishable between species, and there are no current studies distinguishing species of *Daphoenus* based on the morphology of the upper molars (Hough, 1948; Hunt, 1998). In BADL 63542 the M2 is not reduced relative to the size of the M1, supporting the referral of this specimen to *Daphoenus* as opposed to the similar-sized *Brachyrhynchocyon* that displays a reduced M2 (Hunt, 1998).

Family NIMRAVIDAE Cope, 1880
DINICTIS Leidy, 1854

Dinictis, Leidy, 1854:127 (original description)
Daptophilus Cope, 1873b:2 (original description)
Dinictis Bryant, 1996:456 (new combination)

DINICTIS sp.
(Fig. 3)

Referred Specimens—BADL 61617

Comments—BADL 61617 consists of left and right partial premax-maxillary fragments with broken dC1's, erupting C1's, and alveoli with broken P1 through P2. Among North American nimravines, the presence of the P1 is typically indicative of the taxon *Nimravus brachyops* (Martin, 1998), though this feature is also present in the European taxon *Eofelis edwardsi* (Peigne, 2003). Within those taxa, the presence of P1 varies between specimens (present in 63% of *N. brachyops* specimens and 50% of *E. edwardsi* specimens examined by Peigne [2003]). This characteristic can also vary within individual specimens, with the P1 absent on the right side of a specimen of *Nimravus brachyops* (SDSM 348), but present on the left side. Examination of nimravid specimens during the course of this study resulted in the identification of well-preserved specimens referred to the taxa *Hoplophoneus* (CSC-41-42) and *Dinictis* (UNSM 25524) that also retain the P1. Referral of specimens to a given taxon cannot be based solely on the number of upper premolars because this feature is variable across all nimravines, despite the known probability of the P1 being present among nimravids at the generic level.

General statements have been made regarding variation in the size and spacing of the serrations on the upper canines across nimravines (e.g., Martin, 1980), but these differences have yet to be quantified. Current studies are beginning to test the taxonomic utility of nimravine canine serration morphology and density along with the overall dimensions of the tooth (Boyd and Welsh, 2013). Those preliminary inquiries are based on a similar study conducted by Currie and Rigby (1990) that examined in situ theropod dinosaur teeth to assess the identify criteria that could be used refer isolated and/or fragmentary specimens to specific taxa. The erupting adult canines of BADL 61617 display a serration density count that falls within the range recently reported for *Dinictis* (3-3.5 serrations per millimeter). Based on that evidence, we tentatively refer BADL 61617 to *Dinictis* sp., contingent the publication of additional research into the taxonomic utility of canine serrations in nimravines.

CARNIVORA incertae sedis
PALAEOGALE von Meyer, 1846

Palaeogale von Meyer, 1846 (original description)
Bunaelurus Cope, 1873e:8 (original description)
Palaeogale Flynn and Galiano, 1982:47 (new combination)
Palaeogale Baskin, 1998:165 (new combination)

PALAEOGALE SECTORIA (Gervais, 1848)
(Fig. 2)

Mustela sectoria Gervais, 1848:plate 28 (original description)
Bunaelurus lagophagus Cope, 1874:8 (original description)
Canis osorum Cope, 1873e:8 (original description)
Palaeogale sectoria Schlosser, 1887 (new combination)
Bunaelurus infelix Matthew, 1903:210 (original description)
Bunaelurus parvulus Matthew and Granger, 1924:8 (original description)
Bunaelurus ulysses Matthew and Granger, 1924:8 (original description)
Palaeogale infelix Simpson, 1946:4 (new combination)
Palaeogale lagophaga Simpson, 1946:12 (new combination)
Palaeogale lagophaga Galbreath, 1953:77
Palaeogale sectoria de Bonis 1981:50 (new combination)
Palaeogale sectoria Baskin and Tedford, 1996:495 (new combination)
Palaeogale sectoria Morlo, 1996:200 (new combination)
Palaeogale sectoria Baskin, 1998:165 (new combination)

Referred Specimens—BADL 63558, a right dentary fragment with p4, m1 (broken), and m2.

Known Occurrences—Early Oligocene of Eurasia and North America, with Late Eocene occurrences in Montana.

Comments—BADL 63558 is one of a very few specimens of Palaeogale held in the BADL collections. The protoconid on the m1 is broken off, and there is no trace of the metaconid, making the trigonid wide and open. The m1 talonid is labiolingually trenched with the hypoconid positioned posteromedially. The m2 paraconid, protoconid, and entoconid are in a linear position with no development of a trigonid or talonid. The m1 and m2 are tightly compressed to where the m1 hypoconid is situated buccally from the m2 paraconid.

Palaeogale sectoria is the only species of *Palaeogale* known in the Chadronian and Orellan in North America, with the next occurring species, *P. dorothiae*, occurring in the Arikareean (Baskin, 1998). The differences demonstrated between BADL 63558 and the holotype of *P. dorothiae* (SDSM 53326) is a distinct ridge extending anteriorly from the hypoconid, removing the talonid trench as seen previously, and a slightly more reduced m2. Original interpretations of *Palaeogale* place the taxon within the Mustelidae, but more recent assessments demonstrate a closer relationship to Vivverravidae (Hunt, 1974; Flynn and Galiano, 1982; Baskin and Tedford, 1996). Despite *Palaeogale* being removed from the Mustelidae, there are no well-defined affinities of this taxon to either Caniformia or Feliformia (Flynn et al., 1988; Baskin and Tedford, 1996).

Order LAGOMORPHA Brandt, 1855
Family LEPORIDAE Gray, 1821
MEGALAGUS Walker, 1931

Megalagus Walker, 1931:234 (original description)
Megalagus Dawson, 1958:10 (revised diagnosis)

MEGALAGUS sp.

Referred Specimens—BADL 63473, right dentary fragment with p3 through m1; BADL 63474, right dentary fragment with p4 (broken) through m3.

Comments—BADL 63473 is referred to the taxon Megalagus based on the combined presence of a hypoflexid and absence of a mesoflexid on p3, the almost complete lack of cement on the teeth, and the large size of the specimen (Dawson, 1958). BADL 63474 is referred to the taxon *Megalagus* based on the almost complete lack of cement on the teeth and the large size of the specimen (Dawson, 1958). Dawson (1958) noted the difficulty in distinguishing *Megalagus* from *Palaeolagus intermedius*, stating that the lower cheek-teeth are slightly smaller and more hypsodont in the latter taxon. Based on those differences and comparison to other specimens of *Megalagus*, we support referral to this taxon over *P. intermedius*. However, all of the morphologies used to differentiate species of *Megalagus* are situated in the skull or upper dentition, making the referral of these partial dentaries to a given species impossible (Dawson, 1958).

PALAEOLAGUS Leidy, 1856

Palaeolagus Leidy, 1856:89 (original description)
Tricium Cope, 1873b:4 (original description)
Protolagus Walker, 1931:230 (original description)
Palaeolagus Dawson, 1958:19 (new combination)
Palaeolagus Dawson, 2008:298 (new combination)

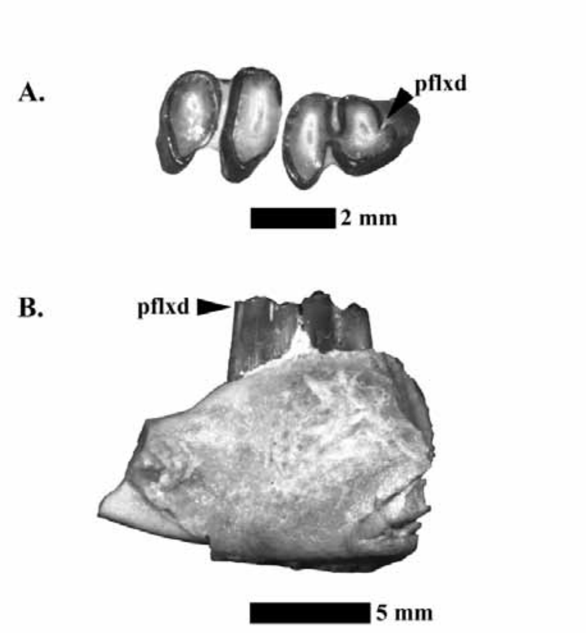

FIGURE 4. Photographs of BADL 63472, Leporidae gen. et sp. indet., right dentary fragment with P3 through P4. **A**, crown view of P3 through P4; **B**, dentary fragment with P3 through P4 in lingual view. Abbreviation: pflxd, paraflexid.

PALAEOLAGUS HAYDENI Leidy, 1856

Palaeolagus haydeni Leidy, 1856:89 (original description)
Palaeolagus agapetillus Cope, 1873a:1 (original description)
Tricium avunculus Cope, 1873b:5 (original description)
Tricium leporinum Cope, 1873b:5 (original description)
Tricium annae Cope, 1873e:4 (original description)
Protolagus affinus Walker, 1931:231 (original description)
Archaeolagus striatus Walker, 1931:236 (original description)
Palaeolagus haydeni Dawson, 1958:20 (new combination)
Palaeolagus hemirhizis Korth and Hageman, 1988:144 (in part) (new combination)
Palaeolagus haydeni Prothero and Whittlesey, 1998:50 (new combination)

Referred Specimens—BADL 63475, left dentary fragment with p3 through p4; BADL 63476, left dentary fragment with p3 through p4; BADL 63477, right dentary fragment with p4 through m1; BADL 63478, left dentary fragment with p4 through m1; BADL 63479, left dentary fragment with m1 through m2; BADL 63480, right dentary fragment with m1 through m2; BADL 63481, right dentary fragment with p4 through m1; 63482, right dentary fragment with p3 through p4; BADL 63483, left dentary fragment with p3 through p4; BADL 63484, left dentary fragment with m1 through m3; BADL 63485, left dentary fragment with p3 through m1; BADL 63486 left dentary fragment with p3 through p4; BADL 63487, left dentary fragment with p4 through m1; BADL 63488, right dentary fragment with p3 through m2; BADL 63489, left dentary fragment with p3 through p4 and two associated lower cheek teeth.

Comments—When evaluating the taxonomic status of these specimens, the recommendation of Prothero and Whittlesey (1998) was followed in that *Palaeolagus hemirhizis* was considered to be an invalid species that was based on a mixed sample of specimens referable to the species *Palaeolagus temnodon* and *Palaeolagus haydeni*. The specimens listed above are here referred to *P. haydeni* based on the presence of an internal reentrant (mesoflexid) between the trigonid and talonid on p3, long axis of mesoflexid and trigonid oriented roughly mediolaterally on p3 (as opposed to angled from anterointernal to posterolateral), and the presence of a lingual bridge composed of enamel and dentine between the trigonids and talonids of p4 through m2 (Dawson, 1958). In these specimens the mesoflexid is retained longer during wear (based on the extent of the mesostriid on the lingual surface of p3), but would have eventually become enclosed into an isolated enamel lake late in wear. Alternatively, in the morphologically similar taxon *Palaeolagus temnodon* the mesoflexid closes relatively early in wear (Dawson, 1958). These specimens also fall within the size range reported for *P. haydeni*, which is smaller than *P. temnodon* (Korth and Hageman, 1988:fig. 6).

Several leporid maxillae were also recovered from the locality. The morphology of those specimens is consistent with *P. haydeni*, but we have yet to determine if any may represent the morphologically similar taxon *P. temnodon*. Those maxillae are here referred to *Palaeolagus* sp. until further refinement of their taxonomic identities is completed.

LEPORIDAE gen. et. sp. indet.
(Fig. 4)

Referred Specimens—BADL 63472, right dentary fragment with p3 through p4.

Comments—The morphology of this specimen is consistent with that of P. haydeni with the exception of a single feature of the p3. The crown of the p3 displays a relatively early stage of wear based on the presence of a narrow bridge composed of dentine and enamel between the mesoflexid and the hypoflexid that connects the talonid and trigonid. Based on the extent of the mesostriid on the lateral surface, the mesoflexid will eventually become enclosed with increased wear, as in *P. haydeni*. However, this specimen differs from all species of *Palaeolagus* in the presence of an anterointernal reentrant (paraflexid) on the p3. In lingual view, a slight parastriid is present that extends further ventrally than the mesostriid, indicating that the paraflexid will persist slightly longer during wear than the mesoflexid, ruling out the presence of a paraflexid in this specimen being the result of the early wear stage represented by this tooth. A paraflexid is unknown from any palaeolagine leporid (though an anteroexternal reentrant can be variably present in *Palaeolagus burkei* and is present in *Palaeolagus hypsodus*) and is only known from the archaeolagines *Hypolagus apachensis* (Barstovian?–Clarendonian of California) and *Notolagus velox* (late Hemphillian of Mexico) (Dawson, 1958). However, these taxa also display a corresponding anteroexternal reentrant (Dawson, 1958), a feature that is clearly lacking in BADL 63472. The Asian leporid *Gobiolagus tolmachovi* from the Late Eocene of Mongolia displays a similar paraflexid and lack of an anteroexternal reentrant, but it lacks a mesoflexid and the hypoflexid is positioned further posteriorly on the crown (Meng et al., 2005:fig. 2). Additional study of BADL 63472 is necessary to determine if the presence of a paraflexid (and the associated parastriid) in this specimen is the result of individual variation within *P. haydeni*, or if this specimen represents a new leporid species, perhaps one that emigrated from Asia.

Order RODENTIA Bowdich, 1821
Family ISCHYROMYIDAE Alston, 1876
ISCHYROMYS Leidy, 1856

Ischyromys Leidy, 1856 (original description)
Ischyromys Leidy, 1869 (revised diagnosis)
Colotaxis Cope, 1873a (original description)
Gymnoptychus Cope, 1873b (original description)
Ischyromys Miller and Gidley, 1920 (new combination)
Titanotheriomys Miller and Gidley, 1920 (original description)
Ischyromys Troxell, 1922 (new combination)
Titanotheriomys Wood, 1976 (new combination)
Ischyromys Wood, 1980 (new combination)
Ischyromys Heaton, 1993
Ischyromys Korth, 1994 (original description)
Ischyromys Heaton, 1996:373 (new combination)

ISCHYROMYS sp.

Referred Specimens—BADL 61909, nearly complete dentary with p4 though m2; BADL 63470, left dentary with m1 through m3; BADL 63471, right dentary with m2 and left dentary with m1 through m2.

Known Occurrences—Cypress

Comments—The lower cheek teeth of the above listed specimens do not display the sinusoidal trench of the anterior lingual valley, precluding referral to the *Ischyromys (Titanotheriomys)* subgenus (Heaton, 1996). However, the most detailed study of the taxon *Ischyromys* yet conducted demonstrated the difficulty of distinguishing individual species of *Ischyromys* within the Plains region (Heaton, 1996). As a result, we refrain from identifying these specimens to the species level at this time.

Family APLODONTIDAE Miller and Gidley, 1918
BRACHYGAULUS Korth and Tabrum, 2011

Brachygaulus Korth and Tabrum, 2011:69 (original description)

cf. BRACHYGAULUS sp.
(Fig. 2)

Referred Specimens–BADL 63453, left dentary fragment with m2-3.

Diagnosis–The main character difference between *Brachygaulus* and other prosciurine aplotontids is the lophid that develops from the mesostylid to the posterior arm of the protoconid, enclosing the trigonid (Korth and Tabrum, 2011). BADL 63543 contains a rudimentary lophid from the mesostylid on the m2 (see Fig. 4). However, there are slight differences between BADL 63453 and the known species of *Brachygaulus*, including lower lophids and a relatively wider m3. This specimen might be referable to the referred, but undesignated *Brachygaulus* sp. specimen in Korth and Tabrum (2011; see fig. 4 D.), where this lophid is more reduced and the mesostylid to paraconid lophid form a zig-zag pattern. Korth and Tabrum (2011) referred to *Brachygaulus* as the possible prosciurine origin towards the promylagauline mylagaulids, all being found in the Late Orellan. BADL 63453 might be a more primitive form preceding the material from Montana. With the exception of the mesostylid loph, BADL 63433 closely resembles *Prosciurus* (see also Korth, 1989).

Family EUTYPOMYIDAE Miller and Gidley, 1918
EUTYPOMYS Matthew, 1905
EUTYPOMYS cf. THOMSONI Matthew, 1905
(Fig. 2)

Eutypomys thomsoni Matthew 1905:21 Fig. 2 (original description)

Referred Specimens—BADL 61621, partial maxilla with P4 through M1, right dentary with p4 through m1, left denary with m1 through m3; BADL 63459, right dentary fragment with m1 through m2; BADL 63460, left maxilla fragment with M1 through M3 and right maxilla fragment with P4 through M1.

Comments—*Eutypomys* is characterized by complicated enamel lake and reentrant patterns. *Eutypomys thomsoni* is the typical species that occurs throughout the Scenic Member of the Brule Formation. These specimens are similar in size to *E. thomsoni*, but have a less complicated crown pattern, similar to a description of an indeterminate species of *Eutypomys* from Montana described by Wood (1937). The arrangement of enamel lakes and reentrants is somewhat similar to what has been previously described in the Chadronian taxon *E. parvus* (Lambe, 1908; Worley-Georg and Eberle, 2006; Kihm, 2011); however, specimens of *E. parvus* are noticeably smaller than both *E. thomsoni* and the specimens mentioned herein. We refer these specimens to *Eutypomys cf. thomsoni* because while

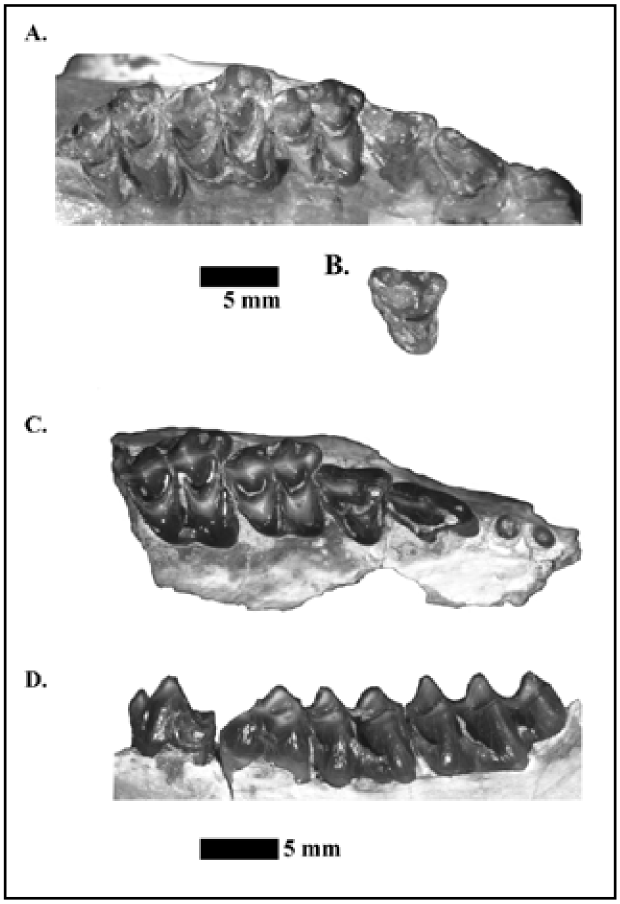

FIGURE 5. Comparative photographs of Hypertragulidae gen. et sp. indet (BADL 61620) and *Hypertragulus calcaratus* (SDSM 32102). **A**, right P2 through M3 of *H. calcaratus* (SDSM 32102); **B**, horizontally reversed image of left P4 of SDSM 32102; **C**, crown view of P3 through M2 from Hypertragulidae gen. et sp. indet.(BADL 61620); **D**, labial view of p4 through m3 of Hypertragulidae gen. et sp. indet.(BADL 61620).

that taxon is the closest match, the morphology of the referred specimens does differ slightly from that reported in *E. thomsoni*.

Family EOMYIDAE Winge, 1887
ADJIDAUMO Hay, 1899
ADJIDAUMO LOPHATUS Korth, 2012
(Fig. 2)

Adjidaumo lophatus Korth, 2012:7 Fig. 1 (original description)

Referred Specimens—BADL 61615, coprolite with a left dentary with a broken incisor and p4 through m2 either attached with sediment or incorporated into the coprolite.

Known Occurrences—Dunbar Creek Formation, Montana.

Comments—The crown morphology of this specimen matches that reported for *Adjidaumo* and possesses the lophate brachydont cheek teeth diagnostic of *Adjidaumo lophatus* (Korth, 2012). This species was previously only known from the Chadronian of Montana, representing a temporal and geographic range extension for this taxon (see Discussion).

This specimen was found attached to a piece of carnivorous mammal coprolite; however, it appears that the jaw was secondarily attached to the coprolite with matrix and was not originally part of the coprolite. However, some uncertainty remains regarding the relationship between this dentary and the coprolite, so the two remain affixed together, making photography of this specimen difficult.

Family HELISCOMYIDAE Korth, Wahlert, and Emry, 1991
HELISCOMYIDAE indet.

Referred Specimens—BADL 63461, isolated right M3.

Comments—The M3 of BADL 63461 has a subcircular crown with the only visible cusps being a paracone and large, centrally placed protocone with a faint protoloph. This is the only representative material of this taxon at this site. It is likely that this specimen is referable to the taxon *Heliscomys*, but the contemporaneous presence of additional taxa lacking comparable material (i.e., *Apletotomeus* and *Akmaiomys*) and the fragmentary nature of this specimen prevent the confident referral of this specimen to that taxon.

Order PERISSODACTYLA Owen, 1848
Family RHINOCERATODAE Gray, 1821
SUBHYRACODON Wood, 1927

Rhinoceros Leidy, 1850b (in part) (original description)
Aceratherium Leidy, 1851a (in part) (original description)
Aceratherium (Subhyracodon) Brandt, 1878 (new combination)
Anchisodon Cope, 1879 (original description)
Caenopus Cope, 1880 (in part) (original description)
Leptaceratherium Osborn, 1898 (original description)
Subhyracodon Wood, 1927 (new combination)
Subhyracodon Prothero, 1998:599. (new combination)
Subhyracodon Prothero, 2005:40, figs. 4.10-4.14. (new combination)

SUBHYRACODON sp.

Referred Specimens—BADL 63554, nearly complete skull with right P1 through M3 and left I1 through M3.

Comments—Several of the diagnostic dental features of Subhyracodon are difficult to examine in this specimen owing to the advance wear of the premolars. According to Prothero (2005), the molarization of the P2 distinguishes *Subhyracodon* from the much larger genus *Amphicaeno-*

pus. The size of the molars in BADL 63554 falls well within the size range of *S. occidentalis* (Prothero, 2005) and the skull does not appear to be broad enough or to possess the flared lamboid crest. *Amphicaenopus* is known to sporadically occur in the Chadronian and Whitneyan in South Dakota and questionably in the Arikareean of North Dakota (Prothero 2005). Though the general features of BADL 63554 allow confident referral of this specimen to *Subhyracodon*, we prefer not to refer this specimen to a species based on size alone.

Family EQUIDAE Gray, 1821
MESOHIPPUS Marsh, 1875

Palaeotherium Leidy, 1850c (original description)
Anchitherium Leidy, 1852 (original description)
Miohippus, Marsh, 1874 (in part) (original description)
Mesohippus Marsh, 1875 (original description)
Miohippus Hay, 1902 (in part) (new combination)
Pediohippus Schlaikjer, 1935:141 (in part) (original description)
Mesohippus Prothero and Shubin, 1989:143 (new combination)
Mesohippus MacFadden, 1998:544 (new combination)

MESOHIPPUS sp.

Referred Specimens—BADL 63458, right maxilla fragment with P4 through M3 and associated fragments.

Comments—It is difficult to discern the taxonomic identification of this specimen owing to the advanced wear of the upper dentition. One of the more useful characters for identifying equids from the White River Group is the structure of the hypostyle (Prothero and Shubin, 1989). This specimen lacks the ovate hypostyle described in *M. exoletus* and *Miohippus* (Prothero and Shubin, 1989), supporting referral to the taxon *Mesohippus*. However, referral of this specimen to a specific species of *Mesohippus* is not possible given the highly worn state of the dentition.

Order ARTIODACTYLA Owen, 1848
Family ENTELODONTIDAE Lydekker, 1883
ARCHAEOTHERIUM Leidy, 1850a

Entelodon Aymard, 1846:307 (in part) (original description)
Archaeotherium, Leidy, 1850a:92 (original description)
Arctodon, Leidy, 1851c:275 (original description)
Entelodon Leidy, 1853:392 (original description)
Elotherium Leidy, 1857:175 (new combination)
Pelonax Cope, 1874:504 (original description)
Ammodon Marsh, 1893:409 (in part) (original description)
Archaeotherium Peterson, 1909:47 (new combination)
Megachoerus Troxell, 1920:431 (original description)
Scaptohyus Sinclair, 1921:480 (original description)
Archaeotherium Scott, 1940:379 (new combination)
Archaeotherium Russell, 1980:5 (new combination)
Archaeotherium Effinger, 1998:378 (new combination)
Archaeotherium Foss, 2007:126 Figs.9.5-9.7 (new combination)

ARCHAEOTHERIUM sp.

Referred Specimens—BADL 61622, fragmentary mandible with c1 and p2, partial crown of p3, and additional mandible fragment with dp4; BADL 63457, left maxilla with M1 through M3, associated P3 and other fragments.

Comments—BADL 63457 preserves the molar row in situ, demonstrating the typical quadrate, bunodont, and cuspate dentition. The only entelodontid known from the Chadronian–Orellan of the White River Group is *Archaeotherium*. Specimens previously attributed to the taxa *Megachoerus* and *Pelonax* are known from deposits containing Whitneyan taxa, but those taxa were synonymized with *Archaeotherium* by Foss (2007). The referred material is too complete to permit further taxonomic resolution.

Family MERYCOIDODONTIDAE Thorpe, 1923
MERYCOIDODON Leidy, 1848

Merycoidodon Leidy, 1848 (original description)
Oreodon Leidy, 1851a (original description)
Cotylops Leidy, 1851a (original description)
Oreodon Cope, 1884:505 (new combination)
Merycoidodon Thorpe, 1937:45 (new combination)
Prodesmatochoerus Schultz and Falkenbach, 1954:225 (original description)
Otionohyus Schultz and Falkenbach, 1968:106 (original description)
Genetochoerus Schultz and Falkenbach, 1968:134 (original description)
Merycoidodon (Merycoidodon) Stevens and Stevens, 1996:514 (new combination)
Prodesmatochoerus Lander, 1998:411 (new combination)
Merycoidodon Stevens and Stevens, 2007:160 (new combination)

MERYCOIDODON CULBERTSONI Leidy, 1848

Merycoidodon culbertsonii Leidy, 1848:48 (original description)
Oreodon priscum Leidy, 1851a:237 (original description)
Cotylops speciosa Leidy, 1851a:239 (original description)
Oreodon robustum Leidy, 1851b:276 (original description)
Oreodon culbertsonii Leidy, 1852:548 (new combination)
Oreodon culbertsonii periculorum Cope, 1884:512 (new combination)
Oreodon macrorhinus Douglass, 1903:163 (original description)
Merycoidodon macrorhinus Douglass, 1907:821 (new combination)
Merycoidodon culbertsonii Thorpe, 1937:47 (new combination)

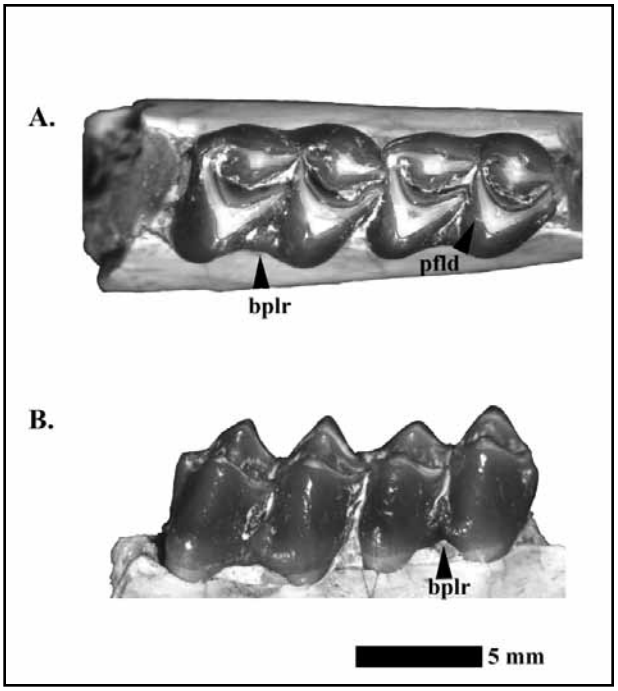

FIGURE 6. Photographs of BADL 63550, *Leptomeryx* sp. indet. right dentary fragment with m1 through m2. **A**, crown view; **B**, labial view. Abbreviations: bplr, buccal pillar (character of *L. speciosus*); pfld, *Palaeomeryx* fold (character of *L. evansi*).

Merycoidodon culbertsonii periculorum Thorpe, 1937:55 (new combination)
Merycoidodon lewisi Clark et al., 1967:53 (original description)
Merycoidodon culbertsonii Schultz and Falkenbach, 1968:38 (new combination)
Merycoidodon culbertsonii browni Schultz and Falkenbach, 1968:55 (original description)
Merycoidodon culbertsonii osborni Schultz and Falkenbach, 1968:57 (original description)
Merycoidodon macrorhinus Schultz and Falkenbach, 1968:72 (new combination)
Prodesmatochoerus meekae Schultz and Falkenbach, 1954:226 (original description)
Merycoidodon georgei Schultz and Falkenbach, 1968:86 (original description)
Otionohyus wardi Schultz and Falkenbach, 1968:107 (original description)
Otionohyus vanderpooli Schultz and Falkenbach, 1968:115 (original description)
Otionohyus (Otarohyus) bullatus Schultz and Falkenbach, 1968:118 (in part) (original description)
Genetochoerus (Osbornohyus) norbeckensis Schultz and Falkenbach, 1968:143 (in part) (original description)
Genetochoerus periculorum Schultz and Falkenbach, 1968:136 (original description)
Merycoidodon Harris 1967:3.
Merycoidodontidae genus and species indeterminate, no. 2 Wilson, 1971:46.
Merycoidodon culbertsoni Prothero 1982:406 (in part).
Merycoidodon culbertsonii Evanoff et al., 1992:123.
Merycoidodon (Merycoidodon) culbertsoni Stevens and Stevens 1996:518, figs. 2-3 (new combination)
Prodesmatochoerus periculorum periculorum Lander, 1998:411 (new combination)
Merycoidodon culbertsoni Stevens and Stevens, 2007:160.

Referred Specimens—BADL 63553, nearly complete skull with right and left P1 through M3.

Comments—This skull represents the species *Merycoidodon culbertsoni* as described by Stevens and Stevens (1996). The major feature distinguishing *M. culbertsoni* is the presence of relatively small auditory bullae. Other species of *Merycoidodon* found in the plains (e.g., *M. bullatus* and *M. major*) have significantly inflated auditory bullae, which appear to increase in size in cline with biochronologic time. *M. culbertsoni* differs from the early to middle Chadronian taxon *M. presidioensis* in number of features, including the position of the infraorbital foramen above P3 instead of P2, the lack of a diastema between the P1 and P2, and the relatively small size of M3 (Stevens and Stevens, 1996). The oreodont zonation recognized by previous authors (e.g., Schultz and Falkenbach, 1968; Stevens and Stevens, 1996) may serve as biochronologic indicators in their own right, but do not serve as significant biostratigraphic first appearance or index taxon, since each successive species crosses between the NALMAs recognized within the White River Group.

Family HYPERTAGULIDAE Cope, 1879
HYPERTRAGULUS Cope, 1873d

Leptauchenia Cope, 1873b:7 (original description)
Hypertragulus Cope, 1873d:419 (new combination)
Hypertragulus Scott, 1940:509 (new diagnosis)
Hypertragulus Webb, 1998:470 (new diagnosis)

HYPERTRAGULUS CALCARATUS (Cope, 1873b)

Leptauchenia calcarata Cope, 1873b:7 (original description)
Hypertragulus calcaratus Cope, 1873d:419 (new combination)
Hypertragulus tricostatus Cope, 1873d:419 (original description)
Hypertragulus calcaratus Scott, 1940:521 (new combination)

Referred Specimens—BADL 61903, fragmentary dentary with left m3; BADL 63469, fragmentary right dentary with m3.

Comments—These two specimens display the strong lateral cingulum, conical cusps on the metaconids, and deep valley between the entoconid and metaconid on the lower molars that diagnose *H. calcaratus* (Zanazzi et al.,

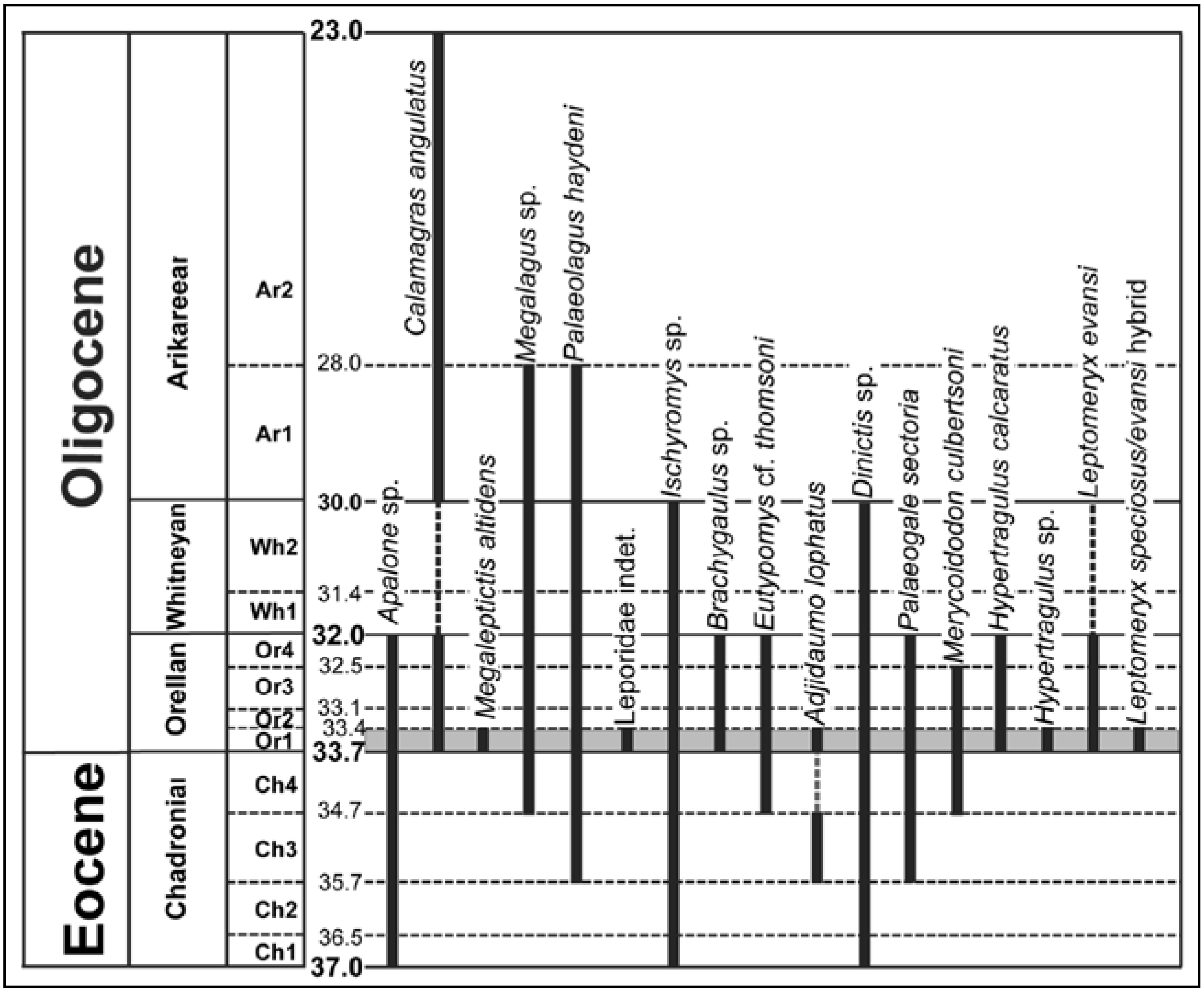

FIGURE 7. Overview of the biostratigraphic distributions of all taxa currently identified from the Bloom Basin local fauna (BADL-LOC-0293). The inferred age of the Bloom Basin local fauna (early Orellan: Or1) is indicated by the horizontal gray bar. The reported age of the Chadronian–Orellan boundary is based on the type section for the *Hypertragulus calcaratus* (Cope, 1873b) Interval Zone in Converse County, Wyoming (Prothero and Whittlesey, 1998) and may not represent the age of this biostratigraphic boundary in the Bloom Basin of South Dakota if the first appearance of *H. calcaratus* is diachronous across different White River locations as suggested by some studies (e.g., Zanazzi et al., 2009). The vertical segmented bars represent gaps in the fossil record.

2009). Additional specimens recovered from this locality (i.e., BADL 63492 through 63469) are also likely referable to this species, but as they are less complete and given the presence of a second hypertragulid at this locality (see below) we choose to refer those specimens to Hypertragulidae indet. at this time.

HYPERTRAGULIDAE gen. et sp. indet.
(Fig. 5)

Referred Specimens—BADL 61620, right partial maxilla fragment with P3-M2 and left dentary fragment with p4-m3.

Diagnosis—BADL 61620 is morphologically similar to H. calcaratus, but differs in several key morphologies. The P3 displays a lingual cone reduced to appear more like a small cuspule on the lingual cingulum and the prelabial crista extends farther anteriorly in this specimen. The labial surface of the P3 has a weaker contour in comparison to *Hypertragulus*. The anterior-posterior orientation of the P3 is also angled more labially, where *Hypertragulus* has a more lingually angled P3. In general, the cingula on the upper molars are less pronounced. The M2 of BADL 61620 bears an anterior cingulum, a lingual cingulum situated between the protocone and metaconule, and a reduced posterior cingulum, with no lingual continuations at the protocone or metaconule. *Hypertragulus* has a more complete cingulum that borders the entire lingual area of the M2 (see Fig. 5 for comparison). The cingula on the lower molars are more pronounced in BADL 61620 in comparison to *H. calcaratus*.

Currently, *H. calcaratus* is the only species of *Hypertragulus* known to occur in the Great Plains region (Webb, 1998; Métais and Vislobokova, 2007). However, confusion exists concerning several species named by Cook (1934) and Frick (1937). Cook (1934) named two additional species of *Hypertragulus*, *H. chadronensis* and *H. crawfordensis*, with both species representing the only known occurrences of the genus from the Chadron Formation at that time. Frick (1937) tentatively named *H. minor* from Nebraska and *H. dakotensis* from the '*Protoceras* channels' in South Dakota, but did not describe their variation from *H. calcaratus*. The issue with these taxa is that they are not discussed beyond their holotypical publications, and any recent evaluations of the Hypertragulidae were either unaware of these specimens, or simply inferred synonymy. Therefore, the taxonomic status of these species remains ambiguous until the holotypes are re-examined and their affinities are assessed. On an additional note, the morphology of the upper premolars, with the apparent reduction of the cingula, is approaching the condition seen in the Arikareean hypertragulid *Nanotragulus*. Overall, the morphology of the P3 bears the closest resemblance to Nanotragulus, but the cingula on this specimen are not lost entirely, as occurs in *Nanotragulus* (see Lull, 1922:116 Fig. 1). Thus, confident referral of this specimen to a specific hypertragulid taxon is not possible at this time.

Family LEPTOMERYCIDAE Zittel, 1893
LEPTOMERYX Leidy 1853

Leptomeryx Leidy, 1853:394 (original description)
Trimerodus Cope, 1873b:8 (original description)
Leptomeryx Scott, 1940:537 (new combination)

LEPTOMERYX EVANSI Leidy, 1853

Leptomeryx evansi Leidy, 1853:394 (original description)
Trimerodus cedrensis Cope, 1873b:8 (original description)
Leptomeryx lenis Cook, 1934:154 (original description)
Leptomeryx evasni Scott, 1940:553 (new combination)
Leptomeryx evansi Heaton and Emry, 1996 (new combination)
Leptomeryx evansi Korth and Diamond, 2002 (new combination)

Referred Specimens—BADL61901, nine dentary fragments including a right p4 through m2, right m1 through m3, right m1 through m2, right m2, right m2, right unidentified lower molar, left m1 through m2, and left m1 (broken) through m2; BADL 63526, left dentary fragment with erupting m3; BADL 63527, fragmentary, unidentified left lower molar; BADL 63528, right dentary fragment with m1 through m2; BADL 63529, left dentary fragment with m3; BADL 63530, left dentary fragment with m1 through m3 (m1 broken); BADL 63531, right dentary fragment with unidentified molar; BADL 63532, left dentary fragment with p4 through m2 (m2 broken); BADL 63533, unidentified left lower molar; BADL 63534, unidentified left lower molar; BADL 63535, left dentary with unidentified molar; BADL 63536, right dentary fragment with unidentified molar; BADL 63537, left dentary fragment with unidentified molar; BADL 63538, left dentary fragment with unidentified molar; BADL 63539, right dentary fragment with unidentified molar; BADL 63540, right dentary fragment with unidentified molar; BADL 63541, left dentary fragment with m2 through m3; BADL 63542, right dentary fragment with p4 through m1; BADL 63543, right dentary fragment with m2 through m3; BADL 63544, right dentary fragment with dp4 (broken); BADL 63545, right dentary fragment with m1 through m2 (broken); BADL 63546, right dentary fragment with m3 (broken).

Comments—All specimens here attributed to *L. evansi* display the longitudinal crenulations on the metaconid and entoconid, and the distinctive '*Palaeomeryx* fold' extending from the protoconid towards the hypoconid that are diagnostic of this taxon (Zanazzi et al., 2009). Numerous other leptomerycid specimens were collected that cannot be referred to the species level given the presence of two different leptomerycid morphs at this locality (see below).

LEPTOMERYX sp.
(Fig. 6)

Referred Specimens—BADL61902, right dentary fragment with m3 and left dentary fragment with m1-3; BADL 63552, right dentary fragments with p2 and p4 through m2; BADL 63550, right dentary fragment with m1 through m2; BADL 63549, right dentary fragment with broken m3; BADL 63551, right dentary fragment with unidentified molar.

Comments—The taxonomic affinities of these specimens remain enigmatic. All specimens display the '*Palaeomeryx* fold' diagnostic of *Leptomeryx evansi*, but they also display the buccal pillar (ectostylid) between the protoconid and hypoconid that typifies *Leptomeryx speciosus*, though these features are developed to varying degrees in each specimen. *L. speciosus* is typically only found in late Chadronian faunas; however, only five of the *Leptomeryx* specimens collected from this locality that are identifiable to the specific level display an ectostylid, with the rest all clearly referable to *L. evansi*, which is a characteristic component of Orellan faunas. The significance of presence of this morphologic hybrid at BADL-LOC-0293 is detailed in the Discussion section.

DISCUSSION

Biostratigraphy in the Northern Great Plains

Fossil vertebrates have been frequently documented within the deposits of the Big Badlands of South Dakota since the Hayden expeditions in the mid-1800's. There are several classic monographs thoroughly documenting the horizons and specimens of the White River Group (e.g.

Leidy, 1869; Cope 1883; Osborn and Wortman, 1894; Scott, 1940) due to the massive collections derived from the highly productive beds in the area that is now situated in and around Badlands National Park. The information compiled from these collections aided in establishing the North American Land Mammal Age (NALMA) system proposed by Wood et al. (1941). This biochronologic schema was founded on collections and literature-based information. However, there were no comprehensive local faunas established at that time, because older collections were not locality-based. These systems were horizon-based, following the conventions of Wortman (1893), Matthew (1899), Wanless (1923), and other published works. The problem was that these faunal divisions were based on lithostratigraphic divisions, which makes the assumption that lithologic facies and paleofaunas are biochronologically and biogeographically conformable. This assumption is exemplified by the use of classic faunal terminology based on geographically restricted lithologic facies such as the "*Protoceras* Channels" and "*Metamynodon* Channels" (e.g., Wanless, 1923). The namesake taxa for these zones are rarely found outside their respective and exclusive river channel facies, making them poor biostratigraphic index taxa unless they are associated with extensive, well-described local faunas that facilitate broader correlations.

The issues regarding lithologic disconformities were addressed by the work of Schultz and Stout (1955), who subdivided the White River formations in Nebraska while correlating local units from Toadstool to Scottsbluff. Shortly afterwards, Bump (1956) established different classifications of similar subdivisions in South Dakota based on the geographic disparity and lithologic dissimilarities. Schultz and Stout (1955) stated that these disconformities would likely be resolved by correlating the oreodonts zones that would later be established by Schultz and Falkenbach (1968). Again, this work did not correct, but perpetuated earlier difficulties because of the continued endorsement of fauna-defined stratigraphy. Extensive lithostratigraphic revisions by Terry (1998), Terry and LaGarry (1998), and LaGarry (1998) replaced the antiquated fauna-defined stratigraphy from Schultz and Stout's (1955) classic "Roundtop to Adelia" section.

The foundation of biochronologic units was facilitated after researchers began assessing lithology independent of biochronology. Formerly, the Chadron–Brule lithostratigraphic contact and the Chadronian–Orellan biochronological transition were defined by the last appearance of brontotheriids, as categorized by Wood et al. (1941). However, brontotheriids were discovered above the Purplish White Layer in Wyoming (PWL: Prothero and Whittlesey, 1998), which were above the Chadron–Brule/Chadronian–Orellan boundaries of Schultz and Stout (1955). Terry's (1998) lithostratigraphic revision removed any conflict with those formerly defined boundaries. The disappearance, or last appearance datum (LAD: Walsh, 1998), of a single taxon is inadequate by itself for biochronologic orientation, so Prothero and Whittlesey (1998) recognized the need for revision of the existing biostratigraphic schema, redefining the Chadronian Orellan boundary at the first appearance datum (FAD: Walsh, 1998) of the hornless ruminant *Hypertragulus calcaratus*. Additionally, that transition is also characterized by the first appearance datum (FAD: Walsh, 1998) of other abundant taxa, including the hornless ruminant *Leptomeryx evansi* and the leporid *Palaeolagus intermedius*, as well as the LADs of several taxa, including brontotheriids (Prothero and Whittlesey, 1998). Subsequent revisions of those biochronologic intervals have also occurred to improve their accuracy and resolution (e.g., Prothero and Emry, 2004). Refined biostratigraphic zones have improved our understanding of faunal succession throughout the North American Cenozoic.

Biostratigraphic Age of the Bloom Basin Local Fauna

Vertebrate fossils are relatively abundant at BADL-LOC-0293 and specimens representing a diverse faunal assemblage have been recovered. Though research focused on elucidating the entirety of the vertebrate fauna at this locality is ongoing, the preliminary faunal list (Table 1) includes taxa previously reported from disparate biochronologic ages (Fig. 7). The rodent *Adjidaumo lophatus* was previously only reported from the Chadronian of Montana (Korth, 2012). The FAD of *Merycoidodon culbertsoni* characterizes the late Chadronian (Prothero and Emry, 2004) and this taxon persists into the late Orellan before being replaced by *M. bullatus* in that taxon's corresponding zone (Prothero and Emry, 2004; Stevens and Stevens, 1996). Clarity is provided via the identification of specimens of *L. evansi* and *H. calcaratus* at this locality, which are characteristic of the Orellan NALMA. The presence of those latter two taxa confirms that the Bloom Basin local fauna is from the Orellan, not the previously expected Chadronian NALMA, given its position relative to the Bloom Basin limestone bed, which was thought to be at the top of the Chadron Formation, and the recognized unconformity between the Chadron and Brule formations in this area (Prothero and Whittlesey, 1998).

The Orellan biostratigraphic age was subdivided into four parts by Prothero and Whittlesey (1998; see also Prothero and Emry, 2004), which characteristic taxa denoted for each subdivision. These zones are characterized by the FADs of *Hypertragulus calcaratus* (Or1), *Miniochoerus affinis* (Or2), *Miniochoerus gracilis* (Or3), and *Merycoidodon bullatus* (Or4) (Prothero and Whittlesey, 1998; Prothero and Emry, 2004; see also fig. 7). At this time, none of the taxa that characterize the latter three subdivisions are recognized in the Bloom Basin local fauna, indicating that this fauna may correlate with the earliest Orellan biostratigraphic age. This biostratigraphic interval, also referred to as the *Hypertragulus calcaratus* Interval Zone (Prothero and Whittlesey, 1998), is currently unrecognized within South Dakota owing to the unconformity present in most areas between the Chadron and Brule formations which is estimated to span at least 400,000 years (Prothero and Whittlesey, 1998). That unconformity results in a sudden transition between the Chadronian and Orellan faunas precisely at the contact between the Chadron and Brule Formations within much of South Dakota (Prothero and Emry, 2004). While basing a biostratigraphic assignment on the absence of taxa can be problematic, the pattern of morphological variation observed within *Leptomeryx* specimens collected from BADL-LOC-0293 lends some support to an earliest Orellan age.

The specimens above referred to *Leptomeryx* sp. display a combination of the characters used to differentiate the Chadronian taxon *L. speciosus* and the Orellan taxon *L. evansi*. The dual presence of the '*Palaeomeryx* fold' and an ectostylid on the lower molar is also observed within the Chadron and Brule sections in Douglass, Wyoming (Heaton and Emry, 1996). Similarly, gradual development and increased prominence of the '*Palaeomeryx* fold' in stratigraphically controlled specimens of *Leptomeryx* across the Chadronian–Orellan transition in Toadstool Park, Nebraska (Zanazzi et al., 2009). These observations support the hypothesis proposed by Heaton and Emry (1996) that *L. speciosus* and *L.evansi* represent a chronospecies that demonstrates anagenesis across the Chadronian–Orellan transition. The presence of this transitional form supports the conclusion that the Bloom Basin local fauna is an earliest Orellan fauna situated very close, but subsequent to the termination of the Chadronian–Orellan transition.

Implications for the Age and Stratigraphic Position of the Bloom Basin Limestone Bed

The Bloom Basin limestone bed is traditionally placed either at the Chadron–Brule contact, or within the uppermost Chadron Formation (Welzenbach, 1992; Benton and Reardon, 2006). Between South Dakota and Nebraska collectively, the Chadron Formation is subdivided into four members that are positioned from oldest to youngest as follows: Ahern, Crazy Johnson, Peanut Peak, and Big Cottonwood Creek (Terry, 1998; Terry and LaGarry, 1998). Within South Dakota, an unconformity is recognized between the Chadron and Brule formations (Terry, 1998; Prothero and Whittlesey, 1998), and sediments correlative with the Big Cottonwood Creek Member are considered to be absent (Terry, 1998; Terry and LaGarry, 1998; Prothero and Emry, 2004). This observation is based largely on surveys conducted in the South Unit of Badlands National Park and within the Kudrna Basin and Sage Creek Wilderness Area within the North Unit of the park (e.g., Terry, 1998; Evanoff et al., 2010). However, Terry (1998) suggested that the Big Cottonwood Creek Member in northwestern Nebraska may be temporally equivalent with the BBLB and other lacustrine limestones near the top of the Chadron Formation within South Dakota. Little work has been done on the stratigraphy within the more northerly positioned Bloom Basin aside from studies directly dealing with the BBLB (e.g., Welzenbach, 1992; Evans and Welzenbach, 1998), and much of that work was completed prior to the formal recognition and description of the Big Cottonwood Creek Member by Terry and LaGarry (1998).

In northwest Nebraska, the closest geographic region with a relatively complete record of this time span, the Chadronian–Orellan boundary is set at two ± five meters above the "upper purplish white layer" (UPW: Zanazzi et al., 2009). The upper boundary of the Big Cottonwood Creek Member in northwest Nebraska is placed nine to ten meters above the UPW (Terry and LaGarry, 1998), meaning that in Nebraska the transition between the Chadronian and Orellan NALMAs occurs within that member of the Chadron Formation and not at the boundary between the Chadron and Brule Formations. These data suggest that the Chadronian–Orellan boundary may be located within the upper Chadron Formation in South Dakota if a complete stratigraphic section were preserved. Therefore, recognition of an earliest Orellan fauna situated below the BBLB would not necessarily contradict prior placement of the BBLB within the upper-most Chadron Formation or at the Chadron–Brule contact. However, that placement would require the sediments containing the Bloom Basin local fauna to be correlative with the Big Cottonwood Creek Member of Nebraska. Alternatively, the age of the Bloom Basin local fauna may indicate that the BBLB is positioned stratigraphically higher than previously proposed, within the Scenic Member of the Brule Formation. At the moment, the detailed sedimentological and stratigraphic data required to evaluate these conflicting hypotheses is lacking, though this work is currently in progress.

The position of an earliest Orellan fauna below the BBLB is also in agreement with prior faunal studies of the BBLB itself. In the original description of the BBLB, Welzenbach (1992) reported that the ostracod fauna was indicative of the early Oligocene and noted the presence of the gastropod taxon *Planorbis*, which is known from the Oligocene to the Recent. No definitively Eocene taxa were reported. Thus, the inferred ages of both the Bloom Basin local fauna and that of the Bloom Basin limestone bed itself are perfectly compatible.

CONCLUSION

Erosion is a powerful force that is constantly transforming the landscape and changing the distribution and density of exposed paleontological resources. In large management units, it is not feasible for resource managers to maintain perfectly up-to-date inventories of paleontological resources under these ever-changing conditions, regardless of how often those resources are surveyed. Thus, paleontological monitoring of high-impact activities is an irreplaceable tool for maintaining the integrity of the resource and ensuring significant scientific data and irreplaceable aspects of our national heritage are protected and conserved. This report highlights the scientific benefits of such programs. Had it not been for paleontological monitoring of fencing work at Badlands National Park, this significant fauna would remain unreported, our understanding of the age and stratigraphic position of the Bloom Basin limestone bed would be diminished, and important paleontological resources could have been damaged or lost. While maintaining the integral assets of a park (e.g., roads and fences) is a significant priority, it cannot come at the expense of the resources that the park was originally designated to protect. The implementation of paleontological monitoring activities bridges the gap between the need to construct and maintain park assets and the duty to follow the park's primary mission: protection of the natural resources.

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ARTICLE

IT'S NOT YOUR PARENTS' ERG DEPOSIT ANYMORE: FOSSIL MANAGEMENT IMPLICATIONS OF A PALEONTOLOGICAL STUDY OF THE NUGGET SANDSTONE IN NORTHEASTERN UTAH

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ABSTRACT—The Late Triassic–Early Jurassic Nugget Sandstone was deposited in a vast desert dominated by giant dunes. The Nugget and equivalent units are geographically widespread in the Rocky Mountain region and well exposed on public lands, but have been regarded as relatively unfossiliferous. Recent field work in northeastern Utah, however, has shown that a diverse fauna represented by invertebrate and vertebrate trace fossils and vertebrate skeletal remains can be found within these erg deposits. In the light of these discoveries, land managers should be alert to the possibility of important paleontological resources within these units. Use of techniques found to be effective for the discovery of such fossils in the field and appropriate documentation and collection of specimens and data can maximize conservation of these scientifically significant resources.

INTRODUCTION

Managing, protecting, and preserving fossil resources is a major responsibility of federal land management agencies and is required by law (Omnibus Public Land Management Act, 2009). With this in mind, it is important for land managers to have an accurate idea of the potential for the occurrence of paleontological resources within particular stratigraphic units. For a number of years a concentrated field project has been underway, centered at Dinosaur National Monument (DINO), to study the paleontology and paleoenvironments of the Nugget Sandstone in northeastern Utah, a desert deposit of Late Triassic–Early Jurassic age. Although only a few footprint sites had been previously documented, this new effort has revealed a remarkable diversity of fossil resources in a rock unit that has been regarded as containing few fossils.

Given the extent of the Nugget and its equivalents in the western United States, our experience with the types of fossils in the Nugget and their distribution, as well as an improved strategy for finding fossils in this unit, may be of help to other land managers and Earth scientists working in these ancient erg deposits. Our study demonstrates that the Nugget has abundant fossil secrets locked away in its sandstones and should no longer be dismissed as a formation with no paleontological significance.

FIGURE 1. Map showing the extent and relations of the Nugget, Navajo, and Aztec sandstones, after Good (2013).

GEOLOGICAL SETTING

During the Late Triassic and Early Jurassic much of the western United States was covered by a vast sand dune complex covering more than 2.2 million km2 (850,000 miles2) across Idaho, Wyoming, Utah, Colorado, New Mexico, Arizona, Nevada, and California (Kocurek and Dott, 1983; Milligan, 2012) (Fig. 1). The deposits of this dune complex have been named the Aztec Sandstone and the Navajo Sandstone to the south and the Nugget Sandstone to the north (Sprinkel et al., 2011).

Much of the sand of this desert was blown southward from deflating floodplains of large transcontinental river systems that originated in the Appalachian mountains (Dickinson and Gehrels, 2009, 2010). The age of these beds is poorly constrained due to a lack of age-diagnostic fossils or datable minerals. These ancient eolian sandstones have extensive surface exposures and have been studied by geologists with interests as diverse as paleoecology (Stokes, 1978; Irmis, 2005; Riese et al., 2011; Lockley, 2011), energy potential (Beitler et al., 2003), and a better understanding of Martian geology (Chan et al., 2011; Potter et al., 2011).

PALEONTOLOGY, GEOLOGY, AND ENVIRONMENTS

Given their wide surface exposure and resistance to erosion, these erg deposits are frequently encountered by land managers grappling with issues of development, preservation, wilderness, and resource management (see Sprinkel et al., 2000 and papers therein). They are generally considered to have low potential for containing fossils and hence to be a rock unit of minimum concern (ex. Kirkland et al., 2006). However, our work over the last several years in the Nugget Sandstone in Dinosaur National Monument and adjacent lands administered by the Bureau of Land Management has shown that these sandstones preserve a fossil record that can be rich, diverse, and of great scientific significance.

Dune Deposits (Figs. 2, 3)

The sandstones of most of the Nugget are dominated by large scale dune deposits, with sweeping, high angled cross bedding (Fig. 2B). These cross beds were deposited along the steep fronts of dunes, which were tens to possibly hundreds of meters tall. Winds blowing up and over a dune transport sand which falls onto the steep, down-wind surface where it is deposited. Individual cross bed layers may reflect storm events or other causes of fluctuating wind transport and could represent a frequency of episodes that is daily or seasonal, according to the local climatic regime. Although this would seem to be an unlikely environment in which to find fossils, these dune face bedding surfaces do contain trace fossils, such as tracks, trails, and burrows (Sanders and Picard, 1999; Good 2013), sometimes in remarkable abundance (Fig. 3C, 3E). These trace fossils probably record the passage of nocturnal animals that were active when temperatures were lowest. We have not found any body fossils in such dune deposits.

Arthropods are common in modern deserts, so it is no surprise that we find the trackways of *Paleohelcura* (scorpion) and *Octopodichnus* (spider) (Fig. 3A, 3B, 3D), some trails as long as 1.5 m (5 ft) (Good, 2013). *Brasilichnium* is the track of a small vertebrate (Fig. 3F), attributed to tritylodontids, a therapsid group close to mammals. At one site (Fig. 3E), close to 400 individual *Brasilichnium* tracks occur on a surface only ~10 m2 (110 ft2) (Engelmann et al., 2010). In general, we find *Octopodichnus* and *Paleohelcura* as isolated trackways. At only one site have we found *Brasilichnium*, *Octopodichnus*, and *Paleohelcura* on the same surface (Chure et al., 2014). No dinosaur tracks have been found on these dune surfaces.

In addition to trace fossils made by animals crossing the dune face, there are also burrows made by invertebrates living in and feeding just below the surface of the dune face. These occur as both trails parallel to bedding and circular cross sections of burrows oriented perpendicular to bedding pertaining to *Entradichnus*, *Planolites*, *Taenidium*, and several unnamed forms (Fig. 3C). These burrows were likely produced by larval and adult arthropods such as beetles (Good, 2013).

Other burrows occur further out on the toe of the dune face, where the dip of the beds is less. Some have a much greater diameter than *Entradichnus* and are closely spaced, although they are probably not contemporaneous (Fig. 3G). These burrows are attributable to either large scorpions or small vertebrates (Engelmann et al., 2014).

Although trace fossils can be locally abundant in dune deposits they are not common throughout those beds. However, they often occur on many surfaces in one or a few sets of stacked dune deposits. This pattern is of climatic significance and reflects longer time periods when the amount of moisture in the Nugget dune fields increased, animal populations expanded, and there was improved preservation potential (Ekdale et al. 2007; Good, 2013).

Interdunal Deposits (Figs. 2, 4-6)

Not all of the Nugget/Navajo erg was composed of sand dunes. Other depositional environments occurred between the major dune fields within the erg and between some dunes. Additionally, during hiatuses of dune formation, dunes degraded, giving rise to large, relatively flat surfaces. All of these depositional environments are sandwiched between the dominant eolian sands and often they have evidence of moisture and sometimes permanent bodies of water. Diverse environments are represented by these interdunal deposits and they have considerable paleontological potential (Parrish and Falcon-Lang, 2007; Wilkens, 2008; Chure et al., 2009; Engelmann et al., 2009; Riese et al., 2011).

Carbonates (Figs. 2, 4)—Carbonate beds within the Nugget Sandstone and coeval erg deposits are rare and of limited lateral extent. These are chemical precipitates deposited in bodies of standing water. In the study area, carbonates are often thin and discontinuous although occasionally they may reach thicknesses of up to 2 m (7 ft) and be traceable for hundreds of meters or more (Vanosdall et al., 2012). Some of the carbonates are stromatolitic, reflecting the presence of microbial mats on the depositional surfaces (Fig. 2E). We have unsuccessfully searched for ostracods, charophytes, and other small fossils in the carbonates. It is unclear whether this lack of success is due to an absence of life or a preservational bias, as such fossils have sometimes been found in carbonates in the equivalent Navajo Sandstone farther south (Wilkens, 2008; Dorney, 2009; Dorney and Parrish, 2009). In two carbonate horizons we have discovered external molds of freshwater snails (Fig. 4A, B), the first gastropod fossils reported from the Nugget/Navajo/Aztec erg system sandstone deposits (Good, 2013).

In a few areas, horizontally bedded sandstones immediately below the carbonates are full of horizontal and vertical invertebrate burrows (*Taenidium*?). These sands were kept wet by groundwater during the time when the overlying carbonates were being deposited (Figs. 4C–F). In one area, both external molds of snails and invertebrate burrows are associated with three dimensionally preserved, carbonate spring mounds (Fig. 2D) that built up where water came to the surface (Good, 2013).

Moist Interdunal Sands (Figs. 2, 5)—Dinosaur footprints sometimes occur in interdunal sands deposited in moist conditions. These horizontally-bedded sandstones, up to 3 m (10 ft) thick, often consist of interbedded white and red layers, sometimes weathering to a dark brown (Fig. 2F). Because of this color distinction, such deposits can be recognized at a considerable distance. These interdunal intervals are most frequent and extensive in the upper part of the Nugget, especially within the uppermost 10% of the eolian sandstone section. Dinosaur trackways occur at multiple horizons in these intervals and often the sands are heavily bioturbated by the dinosaurs. Because of the moisture in the sands and the effects of overprinting, tracks are often distorted and deform many layers of sand beneath them (Fig. 5D). Some sites preserve hundreds of dinosaur tracks, primarily of *Otozoum* (prosauropod), *Eubrontes*, and *Grallator* (?) (theropods) (Figs. 5A–D). Trackways of other vertebrates have not been observed in these deposits in the study area (Lockley, 2011). One site within this distinctive facies has produced plant fossils (Figs. 5E–F) in the form of sphenophyte plant compressions (Good, 2013).

Sandy Interdunal Lake Deposits (Figs. 2, 6)—Some interdunal intervals include sediments deposited in shallow interdunal lakes. The Saints and Sinners Quarry is a bone bed in a 1 m (1.5 ft) thick sandstone deposited in the shallow margin of such a lake. The bone bed occurs relatively low in the eolian section, about 55 m (180 ft) above the base of the eolian unit (Fig. 2G). This locality is, by far, the most important vertebrate body fossil deposit in the entire erg system. Although surface exposure is limited (~60 m2 [650 ft2]), thousands of bones have been collected and collection and preparation activities continue.

The most common vertebrate is a new genus of coelophysoid theropod dinosaur, known from a minimum of 20 individuals exhibiting small to large growth stages. Soaking in quiet water with little transport, skulls often separated along sutures and simply fell apart (Fig. 6B). In spite of the thinness of the bone (some skull elements are only a few mm thick), minimal compaction of the sand after burial has preserved the bones in an uncrushed state (Fig. 6C). Preliminary CT scanning has shown that the radiodensity the matrix differs substantially from, and therefore permits excellent imaging of, the bones affording an unmatched opportunity to study the complex internal structure of the braincase and other bones (Britt et al., 2010, 2011; Engelmann et al., 2011; Vanosdall and Engelmann, 2013).

The quarry preserves many other members of the vertebrate community inhabiting this ancient oasis. There are two species of small sphenodonts, abundant remains (including multiple skeletons and skulls) of a small (<0.5 m [18 in] long) protosuchian crocodilian, and multiple skeletons and skulls of a new genus and species belonging to the drepanosaurs (Fig. 6D), an enigmatic group of diapsid tetrapods. Unidentified small bones throughout the quarry suggest the presence of yet other groups of small vertebrates. No other site has produced as rich and diverse a record of the vertebrate life in this ancient desert (Engelmann et al., 2012, 2013; Chure et al., 2013). Plant remains are rare, but some poorly preserved cycad fronds are preserved as faint impressions. In addition to these body fossils, small (<10 cm) tridactyl dinosaur tracks are also preserved in these shoreline deposits.

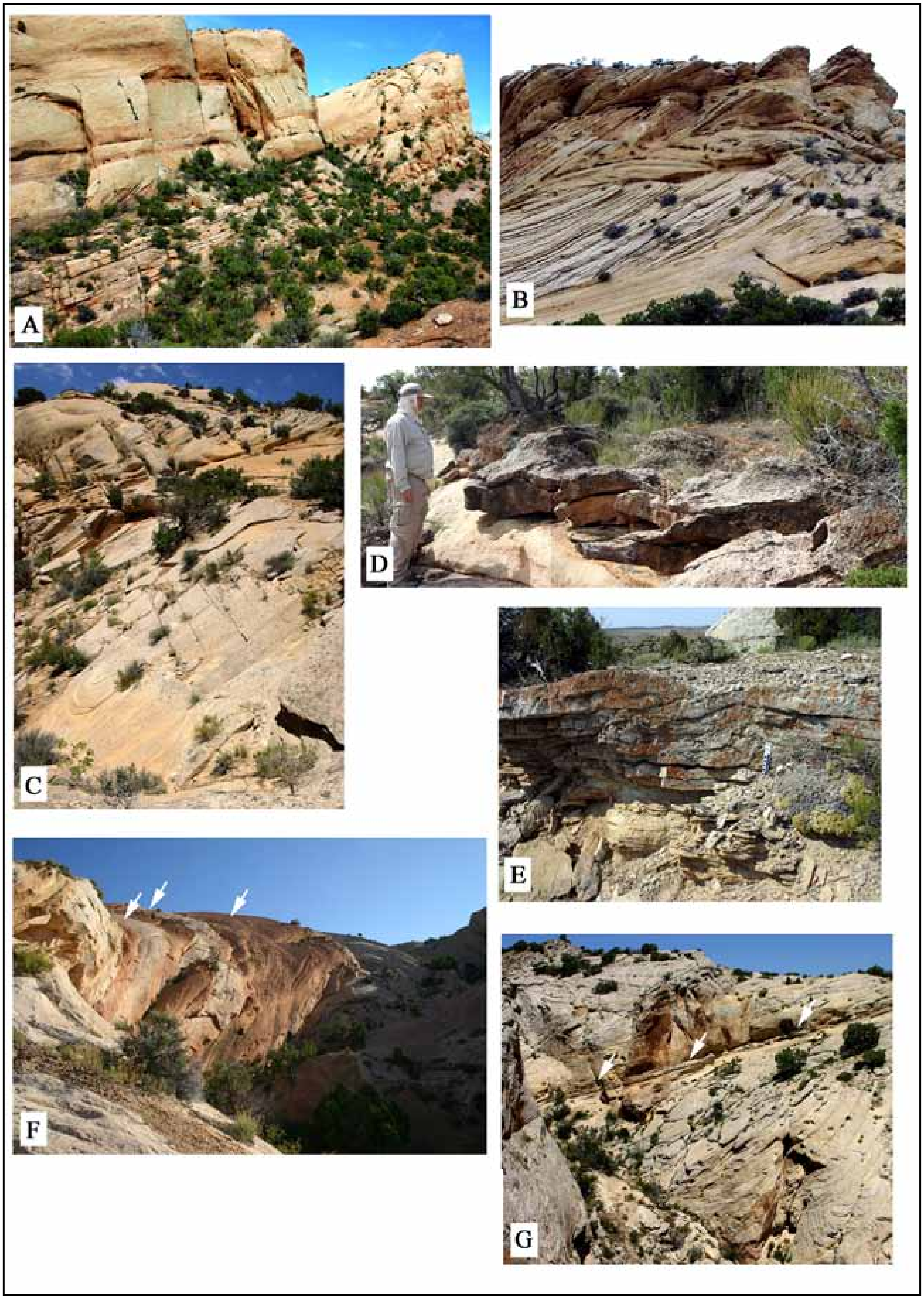
The long-limbed theropod dinosaurs were capable of traveling long distances in the erg. However, protosuchians, sphenodonts, and especially drepanosaurs could not. Thus the latter groups, coupled with the remains of cycads, plants of notoriously slow growth rates, indicate that the lake was permanent, not ephemeral or seasonal, and must have existed for many decades.

It is worth noting that no evidence of the dune track makers has been found in the Saints and Sinners Quarry, nor are any of the dune traces attributable to animals found in the Saints and Sinners Quarry. This likely reflects ecological segregation in the vertebrates of the Nugget, with some groups preferring drier environments and other groups preferring wetter ones.

Lower Non–eolian Pre–Erg Sediments (Figs. 2, 7)

The lower part of the Nugget Sandstone in the vicinity of Dinosaur National Monument consists of sandstones and finer sediments deposited in non-eolian environments. They have been referred to the Bell Springs Member or as an informal subdivision of the Nugget Sandstone (Sprinkel et al., 2011). Several track sites in and around DINO, within this interval, preserve tracks and trackways of small theropod dinosaurs (*Grallator*) (Fig. 7C-D), sauropod dinosaurs (*Pseudotetrasauropus*, *Tetrasauropus*), and quadrupedal archosaurs (*Brachychirotherium*) (Fig. 7A-B) (Lockley and Hunt, 1995; Anderson et al., 2011;

FIGURE 2 (next page). Major lithologies in the Nugget Sandstone, NE Utah. **A**, Pre-erg deposits forming the horizontally bedded lower part of the cliff, eolian dune deposits form the bulk of the cliff face; **B**, cross-bedded dune deposits; **C**, dune front deposits exposed along bedding planes, the flat bedding surfaces in this photo contain vertebrate and invertebrate traces fossils at multiple horizons; **D**, carbonate mounds; **E**, bedded carbonate deposits; **F**, red sandstone moist interdunal beds (arrows); **G**, horizontally bedded lake sandstone (arrows) containing the Saints and Sinners Quarry, sandwiched between thick cross bedded dune deposits.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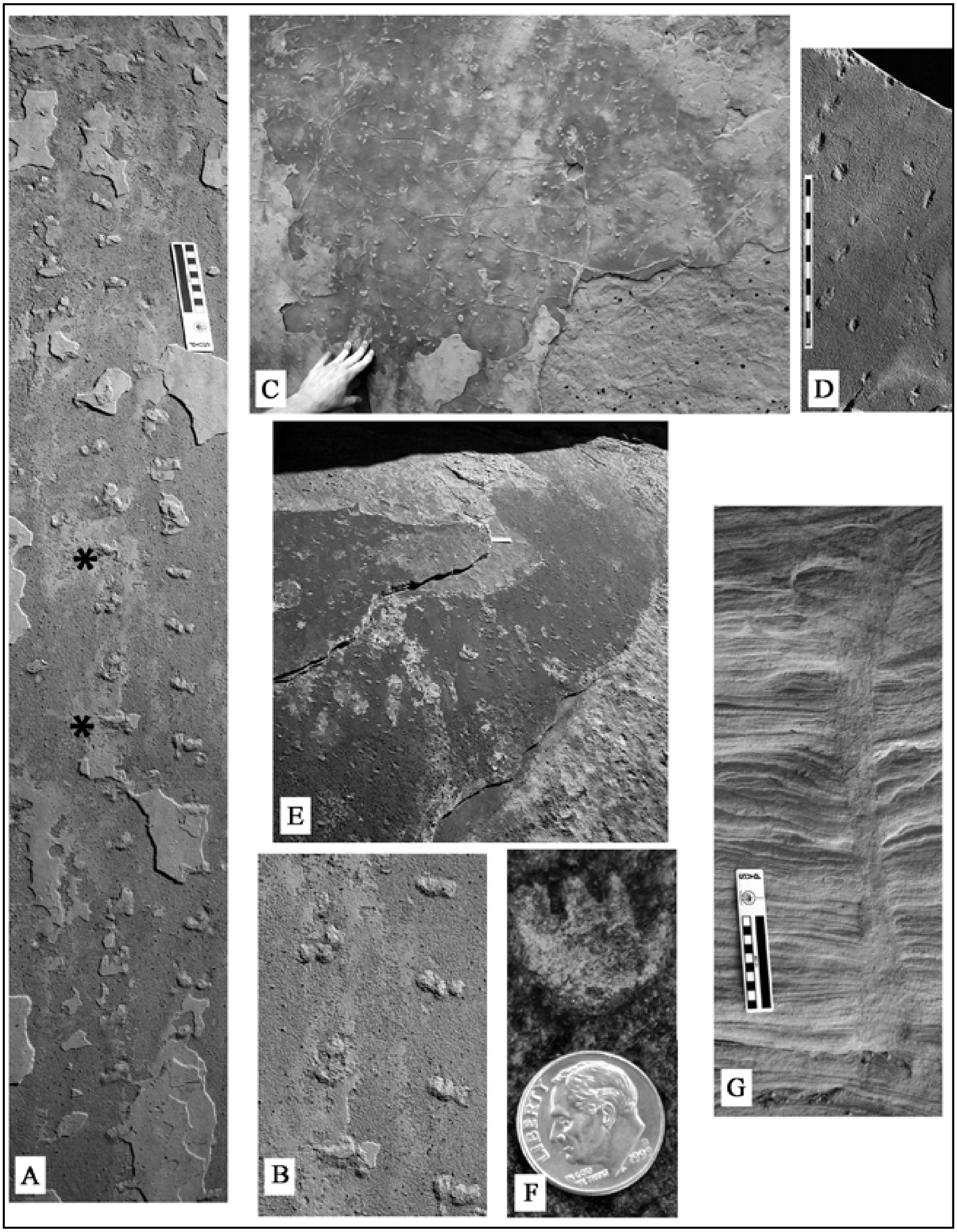


FIGURE 3. Fossils from dune face deposits in the Nugget Sandstone, NE Utah. **A**, *Paleohelcura* sp. trackway; **B**, detail of A, as delineated by *, showing individual leg impressions; **C**, bedding plane exposure of abundant horizontal and vertical *Entradichnus* invertebrate burrows; **D**, *Octopodichnus* sp. trackway; **E**, abundant small tracks of *Brasilichnium* sp.; **F**, detail of *Brasilichnium* sp. track from C showing individual toes and push up rim along heel margin; **G**, burrow of small vertebrate or large scorpion, cutting across dune beds. Scale bar increments in cm.

Sprinkel et al., 2011). The latter are known only from these lower beds. At the Bourdette Draw site, at the base of the Nugget, rippled bedding planes are exposed, and at least five different horizons of footprints can be observed, as well as some long invertebrate burrows that have yet to be identified (Fig. 7A). The Bourdette Draw site has been described by Lockley and Hunt (1995) as the Cub Creek site. Also occurring within this interval, but at a different locality, are possible large burrows. The burrows are visible on the underside of sandstone bodies. They appear to be within the interface between the sandstone and the underlying mudstones, and are 10–20 cm (4–8 in) in diameter (Fig. 7E). The relatively large size of these burrows makes it likely that that they were made by vertebrates such as those documented in the Navajo Sandstone by Riese et al. (2011).

DISCUSSION

The Nugget exposures along the south flank of the Uintah Mountains have received little paleontological attention and even the details of the geology of the formation were poorly studied. We planned a study of the formation that focused on both paleontology and paleoenvironments, with that goal of improving our understanding of the Nugget and why fossils might or might not be expected to occur in it. Given the paucity sparse of fossils in the Navajo/Nugget/ Aztec sandstones we began our study with low expectations. However, the chance discovery of a prosauropod dinosaur in the Navajo Sandstone by a hiker in southern Utah (Sertich and Loewen, 2010) suggested that a concentrated effort might be productive. We were satisfied to find locally abundant trace fossils representing a moderately diverse ichnofauna. The discovery of the Saints and Sinners Quarry bonebed far exceeded any reasonable expectation.

Given the frantic pace of energy development in the Uintah Basin with associated roads and backcountry travel, trenching for pipelines, and so forth, it is a unit that is likely to see significant impacts. Our study indicates that although fossils are rare in the Nugget, they can be locally abundant and of great scientific significance.

To aid land managers in fulfilling their stewardship responsibilities we present several recommendations that we hope will aid future paleontological inventories and assessment of the Nugget Sandstone and similar eolian units.

It is important to understand the nature of deposition in the Nugget and other eolian units in order to find fossils. Obviously, the bulk of such units consist of the remains of dunes (Fig. 2B). These often weather to expose large, flat, sloped surfaces that approximate bedding planes, i.e., the original slip faces of the leeward side of the dunes. Both vertebrate and invertebrate trackways occur on these surfaces (Fig. 3). The tracks can be well defined or faint. They can occur as single tracks, trackways, or as many as hundreds of tracks on a small surface. The visibility of such trace fossils is highly dependent on lighting. Tracks are barely visible when the sun is high in the sky, but low-angle morning and afternoon light makes tracks easier to see. Bedding surfaces that have a slight mineral coating (patina/desert varnish) often preserve tracks better than those without. Some of the tracks, such as *Paleohelcura*, *Octopodichnus*, and *Brasilichnium*, are small, with individual leg impressions or footprints no more than 1.5 cm (0.6 in) in width. Although they may be visible at a distance, often they are only detected on close examination of bedding surfaces under optimal light conditions.

Invertebrate burrows (*Entradichnus*, *Planolites*, *Taenidium*) are often better seen with low angle illumination. Where such traces do occur, they are usually abundant on the surface (Fig. 3C) and can be recognized on even small exposures just barely protruding above the modern soil. The abundance of *Entradichnus* and *Planolites* is probably indicative of a climatically wetter interval in the erg (Ekdale et al. 2007; Good, 2013) and trace fossils should be expected on multiple, closely spaced, bedding planes.

Horizontally-bedded, interdunal deposits stand out clearly from the steeply cross-bedded dune deposits that make up the bulk of the Nugget and can be seen easily from a distance (Fig. 2G). The inter-dunal beds containing the Saints and Sinners Quarry were first seen on an exposed sandstone face, looking through binoculars across a drainage. Such horizontally-bedded, largely structureless interdunal deposits should receive close attention, especially if broad, bedding surfaces are exposed. Although bone might be seen in a cross section of the sandstone, inspection of the greater area exposed by bedding plane surfaces greatly improves the chances of finding bones.

Although dinosaur footprints distort bedding and sometimes can be recognized in cross section, they are most easily found on bedding surfaces. The wet, interdunal sands that preserve dinosaur tracks in our study area show contorted bedding and red-brown mineral staining. These features can be recognized at a distance, even with the naked eye (Fig. 2F). If tracks occur at one locality in such beds, it is likely that they occur throughout that interval and other exposures should be examined. Keep in mind that these sediments were soft when being trampled by dinosaurs and that tracks in a single interval can run the gamut from well-preserved specimens showing pad and claw impressions to highly distorted shapes unrecognizable as footprints (Fig. 5A–D). If some tracks are easily seen in the interval it is likely that other, distorted and less easily recognizable tracks are also present.

Carbonates, especially bedded carbonates, might be expected to have much potential for fossils, as they are often formed in lake environments. However, few of the carbonates studied by us contain any fossils. Although microfossils and brown algae have been found in similar carbonates farther south on the Colorado Plateau (Wilkens, 2008; Dorney, 2009; Dorney and Parrish, 2009), they are never common and the relative rarity may reflect differing chemistry of the water. Nevertheless, samples of promising carbonates should be thin sectioned for microfossil analysis. Attention should be paid to sandstones immedi-

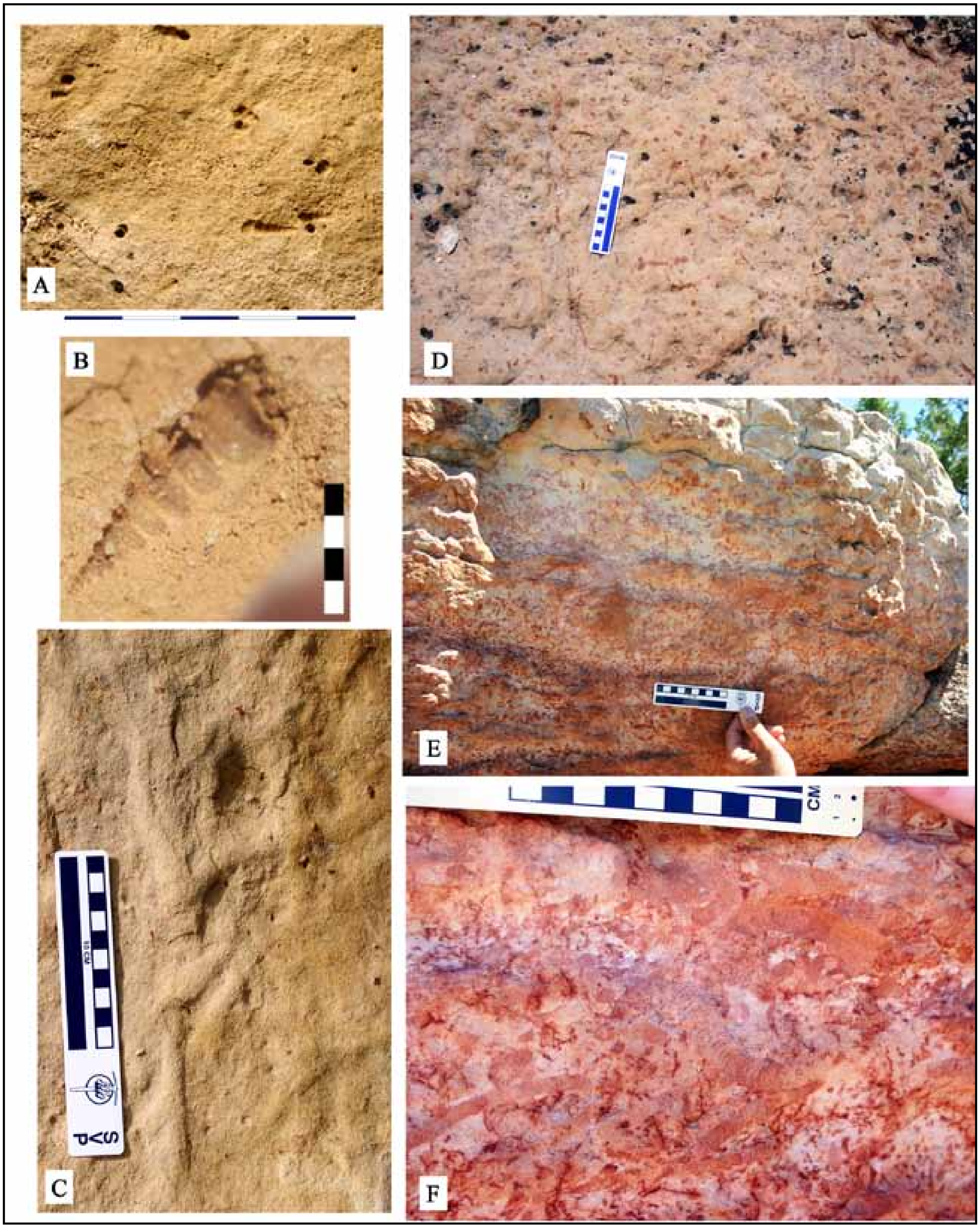
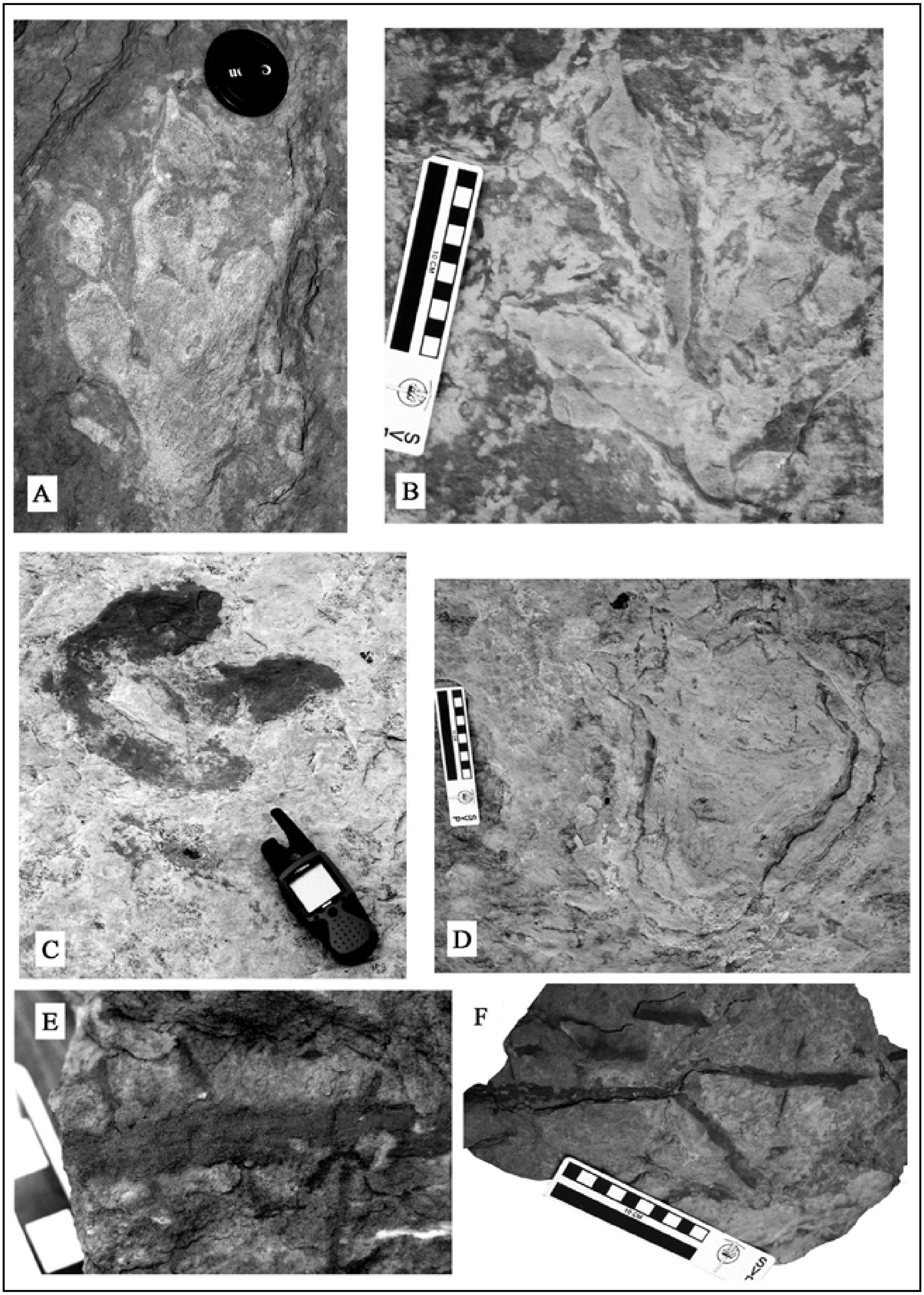


FIGURE 4. Fossils from carbonate lake deposits in the Nugget Sandstone, NE Utah. **A**, external molds of unidentified, small, freshwater gastropods oriented at various angles to bedding; **B**, external mold of unidentified gastropod; **C**, bedding surface exposure of horizontal invertebrate burrows in sandstones immediately below carbonate beds; **D**, bedding plane exposure showing dense concentration of vertical and horizontal invertebrate burrows in sand immediately below carbonates; **E**, outcrop showing vertical distribution of *Taenidium* sp. invertebrate burrows in sand immediately below carbonates; **F**, close up of E showing details of *Taenidium* burrows. Scale bar increments in cm.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ately below carbonates as they have potential for abundant invertebrate ichnofossils (Fig. 4C-F).

Winkler et al. (1991) suggested concentrating searches for fossil vertebrate skeletal remains in mudstones occurring at bounding surfaces between dune packages in the Navajo. This was based on the discovery of a skeleton of the tritylodont *Kayentatherium* in such sediments in Arizona. This is certainly a strategy with considerable merit and any mudstone in the Nugget is worthy of close examination regardless of the nature of its occurrence. However, although we actively searched for such mudstones we saw few in our study area.

Standard search strategies for fossils, especially vertebrate fossils, are of limited applicability in these erg deposits. For example, in the Late Jurassic Morrison Formation, one can walk drainage floors, looking for bits of fossils, then follow the fragments upslope to locate the source horizon. In the Nugget, such telltale indicators seldom survive. Sandstone slabs that weather and are transported simply disintegrate if they fall any significant distance. Bone is so rare and fragile that fragments would similarly be destroyed or so reduced in size and morphological detail as to not be noticeable in a drainage. Thus it is necessary to find both body and trace fossils in place. This requires prospecting outcrop surfaces, especially where bedding surfaces are exposed. This might be on the underside of overhangs or across broad exposures of rock, but also where steep dip slope surfaces are exposed. Given that significant fossils may occur in a very limited exposure, close inspection is often needed.

What are land managers to do once they have discovered that fossils do occur in Nugget, Navajo, or Aztec exposures in their area of responsibility? There are various approaches that can be taken depending on the nature of the occurrence and the types of fossils involved.

If bones are discovered, excavation is the preferred management action. Bones are so rare in the sandstones of the Nugget/Navajo/Aztec erg that any discovered are of high scientific importance. To date, most bone occurrences are of partial, individual skeletons, sometimes only a scattering of a few bones. Even so, they should be given high priority for collection. It should be kept in mind that a few bones on the surface might indicate a greater concentration of bones still hidden in the rock, as at the Saints and Sinners Quarry (Fig. 6A), so exploratory excavation should be pursued.

Trackways, trails, and burrows on dune face beds are often quickly damaged by erosion and weathering. In our study area, the Nugget Sandstone is only weakly cemented and therefore highly susceptible to weathering. Surfaces are subjected to daily summer temperature fluctuations of 50 °F (28 °C) and fluctuations of up to 150 °F (83 °C) over a year's time. Thermal expansion and contraction and freeze thaw cycles during the winter and spring cause the dune cross beds to separate along bedding surfaces, creating friable slabs that often move easily under gravity. Fossils in such a setting are endangered but the slabs are often too large to collect.

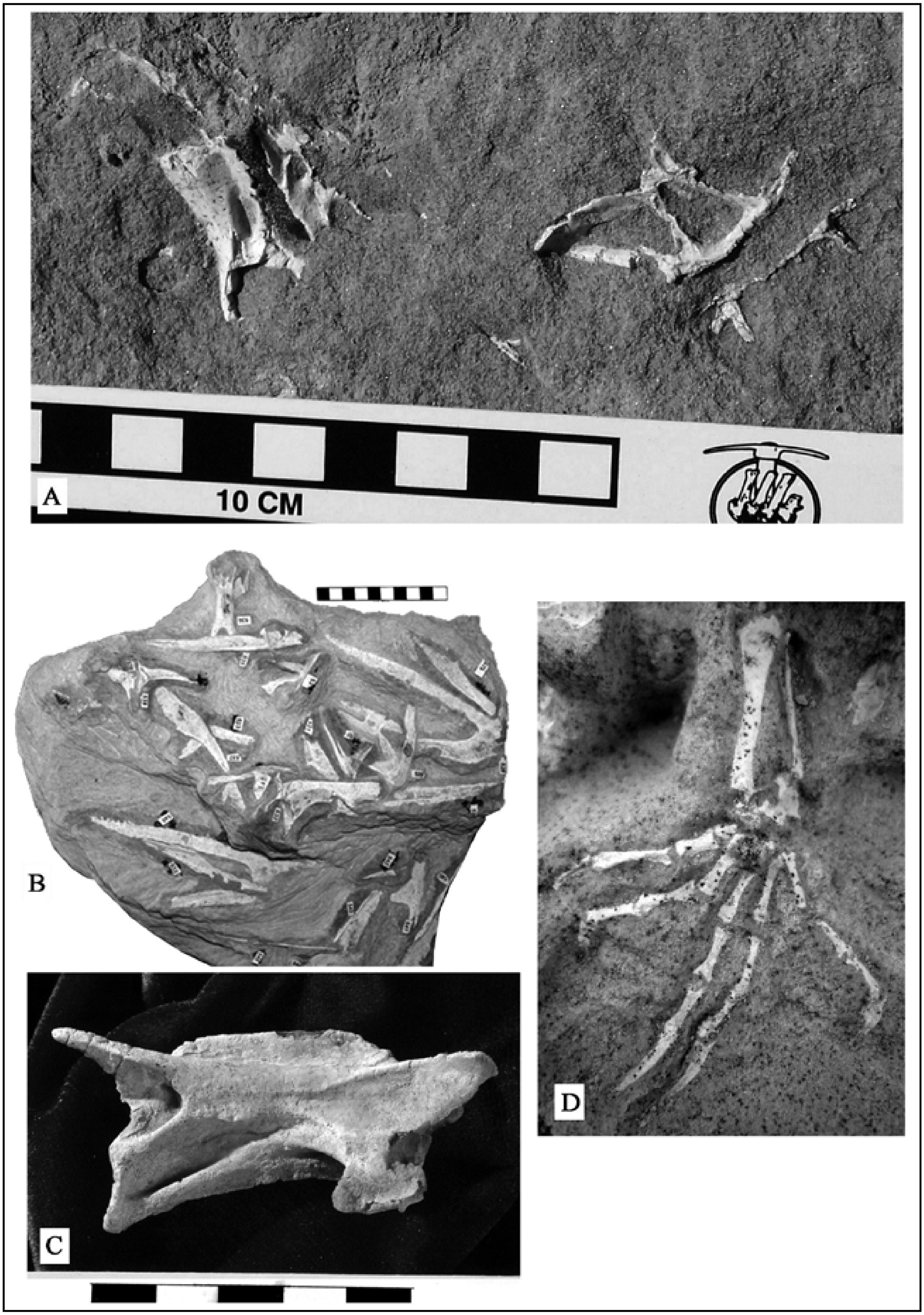
Ichnofossils can be documented by mapping, photography, and collection of good representative specimens if collecting is possible. Alternatively, molds can be made in the field of individual tracks or entire trackways (Fig. 8A). The resulting casts from these molds can be deposited in a museum collection and used in interpretive programs and exhibits. We have molded an entire single *Brasilichnium* trackway that is 3 m (10 ft) long (Fig 8B) and a scorpion trail 1.5 m (5 ft) in length (Fig. 8C). Given that seeing the subtle details of tracks and trails is often highly dependent on lighting, controlled artificial light on a cast can provide information that is difficult or sometimes impossible to see in the specimen in the field. Photogrammetry provides another means of documenting such fossils in extraordinary detail (Matthews and Noble, 2010; Matthews et al., 2006; Milner et al., 2012).

Trace fossils can also be found on the undersides of overhangs (Fig. 5A-E). Sheltered from the effects of direct sunlight, snow and rain, these occurrences may be in better condition to survive longer in the field than dune face beds. However, collection of specimens from overhangs is often difficult to impossible, so photographing, photogrammetry, mapping, and molding and casting are equally useful approaches to the preservation of these fossils.

Regardless of the search strategy used, fossils will be rare occurrences in these erg beds. They can be locally abundant, but finding them requires a concerted effort over a significant amount of time. Clearly the diversity of trace and skeletal fossils, along with paleoenvironmental analysis of the sediments, has revealed a diverse desert fauna of vertebrates, invertebrates, and plants that made a living in

FIGURE 5 (previous page). Vertebrate trace and plant fossils from moist interdunal deposits in the Nugget Sandstone, NE Utah. **A**, well preserved *Grallator* theropod track showing pad and claw impressions; **B**, distorted *Grallator* track with abnormally thin toe impressions due to collapse of wet sediments; **C**, large theropod track preserved as a hematite-lined depression; **D**, *Otozoum* prosauropod track with five short stubby toe impressions and distorted surrounding sediments; **E**, Iron-stained sphenophyte plant compression fossil showing whorls of elongated leaflets around spaced internodes; **F**, unidentified iron-stained plant compression fossil showing branching structure. Scale bar segments in cm.

FIGURE 6 (next page). Vertebrate body fossils from the sandy lake deposits of the Saints and Sinners Quarry, Nugget Sandstone, NE Utah. **A**, two theropod vertebrae, naturally weathering out, as found at the initial discovery of the quarry; **B**, disarticulated theropod skull, with individual bones separated along sutures from immersion in water; **C**, theropod cervical vertebra in right lateral.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a harsh Early Jurassic desert. This is in stark contrast to the previously known record of just a few dinosaur tracks in the study area.

For land managers the lesson is clear – the Nugget should not be ignored and when it is being impacted by development, those activities and affected outcrops should be monitored. It is unlikely that the Saints and Sinners Quarry is the only bonebed in the Nugget, even in the area of Dinosaur National Monument. Pedestrian paleontological surveys prior to construction may reveal still more. There are large exposures of the Nugget Sandstone in northeastern Utah and the erg deposits are extensive in the Intermountain West. We have examined only a very small portion of it in our study area. There is undoubtedly a great deal remaining to be discovered, and those discoveries will reveal more about an amazing lost world of dunes, interdunes, lakes, ponds, dinosaurs, crocodiles, scorpions, spiders, and other creatures.

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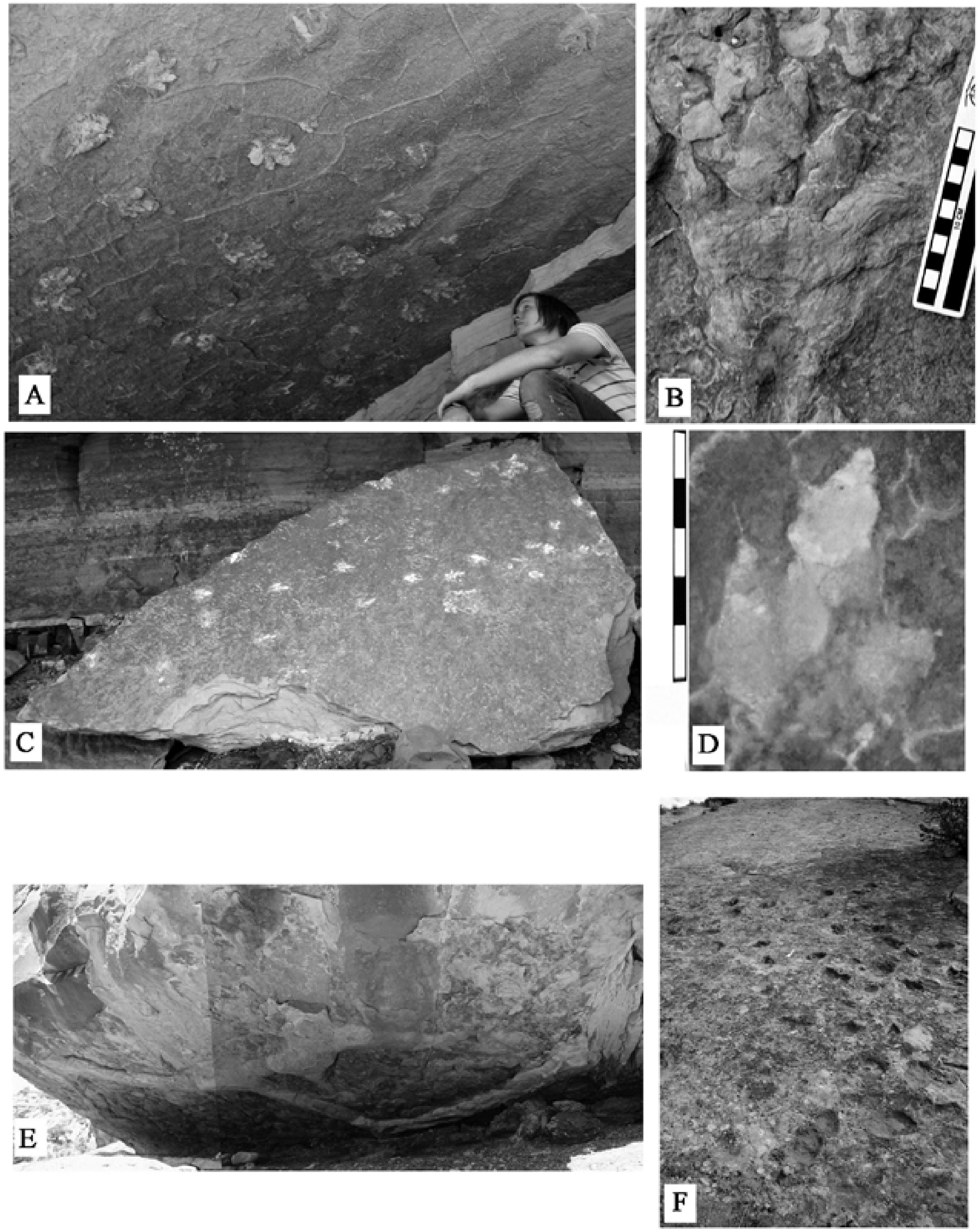

FIGURE 7. Trace fossils from pre-erg deposits at the base of the Nugget Sandstone, NE Utah. **A**, numerous *Brachychirotherium* sp. tracks and long invertebrate burrows or trails preserved on underside of an overhang; **B**, detail of *Brachychirotherium* pes impression on overhang in A; **C**, large block fallen from overhang, showing multiple small *Grallator* trackways; **D**, detail of single Grallator track in C; **E**, large horizontal vertebrate burrows on overhang, width of burrows ~ 20 cm; **F**, bedding surface exposure of abundant but poorly preserved *Brachychirotherium* manus and pes impressions. Scale bar segments in cm.

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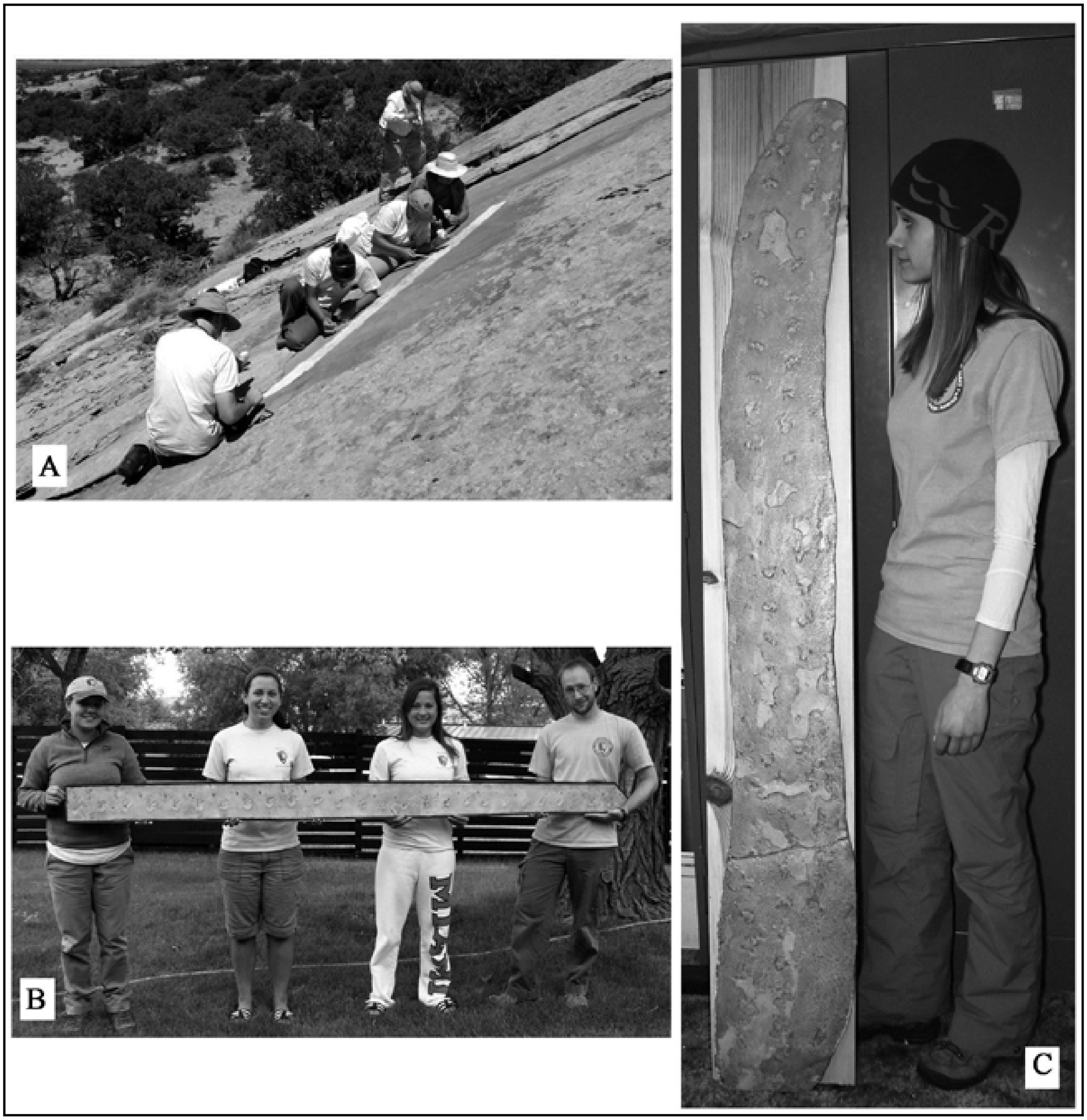

FIGURE 8. Molding and casting of trace fossils in the Nugget Sandstone, NE Utah. **A**, molding of ~3m long *Brasilichnum* trackway from dune front deposit, front to back Dave Tarailo, Mindy Homan, Sarah Crump, Ashley Dineen, George Engelmann; **B**, painted cast of *Brasilichnium* from the mold being made in A, left to right Sarah Crump, Ashley Dineen, Mindy Homan, Dave Tarailo; **C**, Meredith Dennis next to cast of 1.5 m (5 ft) long *Paleohelcura* sp. trackway.

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ARTICLE

VERTEBRATE PALEONTOLOGY AND STRATIGRAPHY OF THE LATE CRETACEOUS HOLMDEL PARK SITE, MONMOUTH COUNTY, NEW JERSEY

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ABSTRACT—The New Jersey State Museum and the County of Monmouth have successfully partnered in the study of two exceptional fossil sites, Ellisdale and Holmdel Park. The County owns the tracts in question, provides a permit system, and retains ownership of the fossils (primarily in order to determine the proper repository). The Museum conducts field studies and makes the collections, serves as repository, performs research, provides interpretive and education information, and makes specimens available for exhibition. The Ellisdale Site, recently featured in many technical papers at a symposium of the Society of Vertebrate Paleontology, is especially noted for pioneering studies of fossil mammals of Cretaceous age in the eastern North American subcontinent. The methods and permit systems developed for the Ellisdale Site are now being applied to the Holmdel Park Site, the subject of this summary report. More than sixty taxa of fossil vertebrates have been recovered from this site, and the project is ongoing.

INTRODUCTION

The brook exposures of Monmouth County, New Jersey, have long been sources of Late Cretaceous vertebrate remains. Big Brook is very well known for its wealth of vertebrate fossils, primarily shark teeth and teeth and skeletal material of bony fish, and for a diverse reptilian fauna including mosasaurs, plesiosaurs, turtles, crocodiles, and dinosaurs. Nearby sites, like Ramanessin Brook, show a similar diversity, but little work has been done on their faunas. Along the eastern border of Holmdel Park, in Monmouth County, New Jersey, a tributary of Ramanessin Brook exposes an excellent segment of the basal Navesink Formation. A transgressive lag within this exposure is rich in vertebrate fossils of Late Cretaceous (latest Campanian) age and may be one of the primary sources of the numerous fossils found as float within the main streambed of lower Ramanessin Brook. In October 2009 a cooperative agreement for a paleontological study of this area within Holmdel Park was entered into between the Monmouth County Board of Recreation Commissioners, Monmouth County Park System, and the New Jersey State Museum. This report is a summary of the results of the study to date.

The site hereafter referred to as the ‘Holmdel Park Site’ or ‘Site HP’ is located along a small tributary that flows along the northeastern border of Holmdel Park roughly paralleling Crawfords Corner Road. The fossil-bearing outcrops are found on both sides of the streambed for a distance of approximately 0.12 km (0.7 miles). GPS coordinates are on file with the New Jersey State Museum. The preliminary in situ sampling of the site revealed a diverse assemblage of marine, estuarine, fluvial, and terrestrial vertebrate remains. Further investigation has revealed a unique fauna that differs from the typical basal Navesink lag fauna exposed elsewhere in northern Monmouth County.

The site has been visited 17 times between November 21, 2009 and July 7, 2012, and a total of approximately 60 man-hours have been spent on-site. An estimated additional 40–50 hours have been spent processing bulk material, identifying specimens and preparing scientific papers on the site.

On-site activities have included: walking the outcrops to measure the stratigraphic section, hand-picking visible fossils, and retrieving small bulk samples for later screening and picking for microfossils. These activities are covered in detail in the Materials and Methods section below.

MATERIALS AND METHODS

Vertebrate remains at Site HP were collected from deposits that mark the base of the Navesink Formation and the beginning of the Navesink transgressive sequence.

Many in situ specimens were removed directly from the outcropping lag deposit by picking. Splashing water on the exposed sediment exposed underlying fossils without the need to excavate. These specimens were labeled and stored in vials or in plastic storage bags. Bulk samples were taken from approximately 5–10 cm (2–4 in) below the outcrop surface and placed into labeled one liter storage bags. Offsite, the matrix was soaked in a solution of warm water and Calgon, to aid in deflocculation, and then screened through U.S. Standard Sieve Series Number 4, 20 and 80. Larger teeth and bone fragments were recovered from the 3.5 mm mesh and number 4 screens. Sediments from the finer screens were air-dried and then sorted using a dissecting microscope. Most of the microvertebrate material was recovered from the 1.6 mm mesh and number 20 (850 micron) screens. Bulk fossils are stored in small plastic or cardboard boxes and individual microfossils are stored on 4-hole microfossil slides. The fact that the fossils from Site HP have been collected in situ not only assures their stratigraphic context, but also increases the chances of finding elements that rarely survive intact. All excavations were minimal and small excavations for bulk sampling were rapidly reduced by natural weathering.

STRATIGRAPHY

The fossil-bearing sediments are concentrated in a transgressive pebble lag that marks the boundary between the Wenonah Formation and the overlying Navesink Formation. The Mt. Laurel Formation is missing entirely from these sections. The disconformity at the base of the lag represents a sequence boundary that separates the Marshalltown depositional sequence from the Navesink sequence (Martino and Curran, 1990; Miller et al. 1999; Miller et al., 2004). The lag formed at the beginning of the Navesink transgression. Lithological descriptions of the Wenonah, Mt. Laurel and Navesink Formations can be found in studies by Minard et al. (1961), Owens and Sohl (1969), Gallagher et al. (1986), and Martino and Curran (1990). Several of these authors place the pebble lag above the Mt. Laurel Formation. Krinsley and Schneck (1964) placed the pebble bed within the uppermost Mount Laurel formation. However, according to Garb et al. (2007), the ammonite distribution within these beds suggests that the Mt. Laurel Formation does not occur in outcrop north of the "Crosswicks basin" and points northeast, most likely due to either erosion or nondeposition. The lithology below the lag is typical of that of the Wenonah Formation and the similarities of some of the Wenonah Formation beds to those of the Mount Laurel Formation have made distinguishing between the two formations, by lithology, difficult in areas of limited exposure. The base of the lag at the Wenonah/Navesink formational contact at Site HP displays an irregular surface that suggests a relatively high-energy erosional event, either the scour surface from shallow water, wave and/or storm action, or a time of subaerial erosion. Most of the fossils are believed to have been reworked from the subadjacent Wenonah Formation during the initial transgression, but some of the material was likely deposited later, undergoing less energetic remixing, and therefore is better preserved.

In order to understand the unique importance of the Holmdel Park Site it is necessary to describe briefly the more typical basal Navesink lag exposures that outcrop in northeastern Monmouth County. The following section describes a classic locality along the main stream of Ramanessin Brook north of Monmouth County Route CR 520 and along a small tributary to Ramanessin informally called Ralph's Run. We will refer to this locality as the Ramanessin Brook Site (Site RB). Site RB is 3.57 km (2.22 miles) slightly east of due south from Site HP.

Figure 1 shows the stratigraphic columns for the two sites. Age determinations and correlation with the western interior ammonite zones are based on Kennedy et al. (1995) and Cobban et al. (2006).

The Ramanessin Brook Site (site RB)

Site RB includes approximately 63 cm (25 in) of fine dark gray, micaceous quartz sand with a few poorly preserved molluscan steinkerns, occasional small shark teeth and other fish teeth, and abundant lignite. This is the uppermost Wenonah Formation. It is extensively burrowed and the burrows are often filled with the coarse pebble sand from the overlying transgressive lag.

The Wenonah Formation is uncomformably overlain by approximately 58 cm (23 in) of dark gray to reddish orange pebble sand with numerous small to microscopic vertebrate fossils. Shark, ray, and bony fish teeth, vertebrae, and bone fragments are the most common elements. This layer represents a transgressive lag deposit at the base of the Navesink Formation and the unconformity marks a major sequence boundary (Martino and Curran, 1990; Miller et al. 1999). This sequence boundary was originally thought to mark the Campanian-Maastrichtian boundary (Becker et al., 1996; Bennington, 2003). Recent evidence from ammonites collected just above the pebble lag suggests that the pebble bed itself represents a very late Campanian age fauna (Garb et al. 2007).

The basal Navesink lag deposit rests disconformably on the under-lying Wenonah Formation and coarsens upward into semi-consolidated, limonitic red-orange pebble sand. The contact with the overlying glauconitic sand facies of the Navesink Formation is marked at Site RP by a distinct diastem (Martino and Curran, 1990; Gallagher, 2002). The diastem likely represents a period of non-deposition due to sediment starvation following the initial transgression. It is probably within this interval that the Campanian–Maastrichtian boundary occurs.

The overlying sands of the Navesink Formation, above the basal diastem, extend upward from the contact for 1.7 m (5.6 ft) where they are overlain by Pleistocene pebbles and gravel. At Site RB this interval is very weathered and contains only small amounts of glauconite. Claws of callianassid ghost shrimp are common in this interval and are often found articulated. Internal molds of the gastropods *Lunatia* and *Gyrodes* are also present. upstream from Site RB, along tributaries of Ramanessin Brook, this interval can be traced upward into the more typical, glauconitic facies of the Navesink containing the oysters *Exogyra* and *Pycnodonte* and the cephalopod *Belemnitella*.

The Holmdel Park Site (site HP)

Site HP is located in a small tributary at the headwaters of Ramanessin. It extends along the tributary for approximately 0.12 km (0.07 miles). Measured from stream level the thickness of the exposures at Site HP include approximately 30 cm (12 in) of fine, muddy, micaceous quartz sand with some glauconite. We consider this to be the uppermost Wenonah Formation. As at Site RB, an erosional disconformity separates the micaceous sand from the fossil bearing superadjacent, pebble sand layer. The pebble layer reaches a maximum thickness of 46 cm (18 in) and consists of muddy, fine to medium course pebbly silt and sand. The base of the pebble layer is marked by a scour surface of moderate relief and numerous clay rip-up clasts.

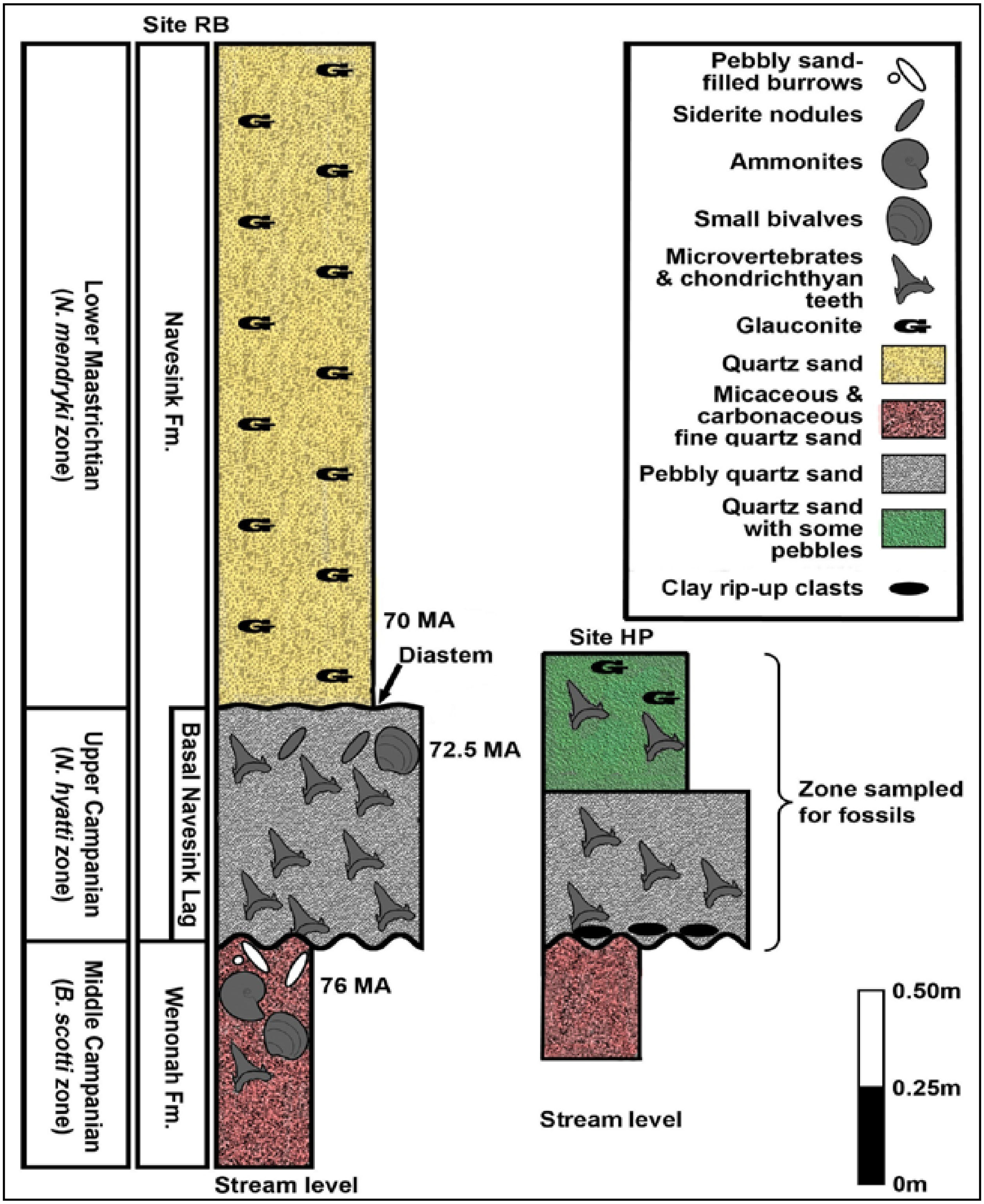

FIGURE 1. Sections at Sites RB and HP along Ramanessin Brook. Age dates are estimates based on ammonite correlations with western ammonite zones and radiometric dates of bentonites. Note that the tops of both sections do not show post Cretaceous gravels and soil.

Above the pebble layer there is no noticeable diastem but rather some 40 cm (16 in) of fine, muddy quartz sand, very similar to the sand below the pebble layer except for having less mica and containing scattered pebbles up to 4 mm (0.2 in) and broken vertebrate fossils, mostly bone fragments. Above the sand are Pleistocene gravels, stream deposits and modern soils.

The exposures at Site HP are limited vertically and cannot be traced for a very long distance. Therefore, the relationship of these sediments to those of the superadjacent more glauconitic sediments of the Navesink Formation is unclear. There is no apparent diastem above the main pebble lag at Site HP. Rather, it appears that after the initial transgression event, sediment deposition and winnowing continued at Site HP and the sands above the main pebble layer represent a continuation of the transgressive lag deposit. This site may represent a more landward environment, possibly an embayment close to the riverine source of the sediment. As sediment was emptying into the embayments and nearshore lagoons, the deeper water sections (e.g., Site RB) were being sediment-starved. Although there is no compelling evidence that the two sites were separated for some period of time by a barrier island, the differing sedimentary sequences between the two strongly suggests this is a possibility.

Lag deposits typically form at regressive/transgressive sequence boundaries. As sea level falls, shoreface retreat exposes and erodes material previously deposited on the sea floor. As sea level rises, during the transgressive phase of the sequence, the previously exposed sediments are subjected to the action of waves and storms that remove lighter and finer portions of the sediment. What remains is material that has 'lagged' behind, having been winnowed and condensed by the action of the advancing sea and redeposited on the old erosional surface. Further vertical mixing occurs due to prolonged bioturbation. During the maximum regression the upper portion of the Wenonah Formation was extensively eroded. If the Mt. Laurel Formation was ever deposited in northeastern Monmouth County, it also was eroded away at this time. This erosional surface can be seen as a disconformity. Garb et al. (2007) estimate the time represented by the disconformity to be on the order of 2 my. The lag deposit represents a condensed section and includes both reworked and freshly deposited material. The diastem at the top of the lag represents considerably less time than the lower disconformity.

The pebble lag or basal Navesink lag can also be seen in other places along Ramanessin Brook, Willow Brook, and its tributaries, and was exposed in various excavations along State Routes 34 and 35 in the 1960s (Cappetta and Case, 1975). Because it is such an easily recognized layer, has a unique vertebrate fauna, and is traceable over a wide area, we suggest that it be referred to as the Holmdel Marker Bed.

The vertebrate fauna at Site HP consists of many of the same marine fossils as at Site RB, including a significant number of microvertebrates, but it is much richer in shallow water, estuarine, fluvial, and terrestrial forms.

Paleontology

Table 1 lists the fossils recovered so far from the Holmdel Park Site. Fossils are listed by taxa, elements recovered, and relative abundance.

DISCUSSION

The vertebrate fossils recovered so far from the Holmdel Park Site suggest that the site is unique among localities exposing the basal Navesink Formation in that is contains a mixed fauna of marine, estuarine, fluvial, and terrestrial vertebrates. In this respect it is similar to the fauna from the middle Campanian Marshalltown Formation as exposed at the Ellisdale Site. Although fossils of Late Cretaceous mammals have not yet been recovered from Site HP it is almost certain they will be found. Krause and Baird (1979) reported on a small multituberculate (an early mammal) femur that was found as float along Ramanessin Brook not far downstream from Site HP and it is certainly possible that it was weathered out of the lag from the site. Additional screening for microfossils may also recover other terrestrial vertebrates, including lizards and amphibians.

Other unresolved questions remain and continued study of the site will, hopefully, resolve at least some of these. Late in the 2012 season two *Enchodus* teeth with serrated edges were recovered from the site. These appear to represent the genus *Enchodus ferox* which is considered to be of Maastrichtian age. This occurrence would seem to suggest that either (a) *E. ferox* first appeared in the latest Campanian, or (b) the upper part of the lag at HP actually spans the Campanian–Maastrichtian border. Additional sampling from the upper part of the basal Navesink at Site HP may help resolve this if additional earliest Maastrichtian taxa are recovered.

Because marine transgressions and regressions are related to eustatic changes in sea level, it should be possible to correlate transgressive lags of the same age from other areas where Late Cretaceous sediments are exposed along the Atlantic and Gulf Coastal Plains. Site HP affords an excellent fossil assemblage to aid in that type of correlation. It may also be possible that studying the effects of dramatic sea level changes in the past may provide insight into the consequences of sea level rise along the coastal sections of New Jersey today.

Owens and Sohl (1969) infer what they believed to be the Mt. Laurel Formation (what we now consider the upper Wenonah) as part subaqueous plain, part nearshore gulf; Martino and Curran (1990) favor a nondeltaic barrier interpretation for the formation. Gallagher (1993:76) has pointed out that the traditional "layer cake" reading of the stratigraphy of the coastal plain deposits, along with the propensity for considering nearshore deposits to be deltaic in origin, "fails to account for some of the subtleties of faunal and facies changes both along strike within individual units and between units within the entire section".

TAXA	ELEMENTS RECOVERED	ABUNDANCE
CHONDRICHTHYES (sharks and rays)		
Meristodonoides sp.	Teeth, dorsal fin spines, claspers	Common teeth, uncommon spines and claspers
Meristodonoides sp. 1	Teeth with cusplets	Uncommon
Lonchidion babulski	Teeth	Common
Squatina hassei	Teeth, vertebrae with calcified cartilage	Uncommon
Heterodontus sp.	Dorsal fin spine	Single specimen
Ginglymostoma globidens	Teeth	Uncommon
Cantioscyllium cf. C. decipiens	Teeth	Rare
Chiloscyllium greeni	Teeth	Single specimen
Cretalamna appendiculata	Teeth	Abundant
Odontaspis aculeatus	Teeth	Uncommon
Eostriatolamia holmsdelensis	Teeth	Uncommon
Carcharias samhammeri	Teeth	Uncommon
Protolamna borodini	Teeth	Uncommon
Archaeolamna kopingensis	Teeth	Common
Paranomotodon angustidens	Teeth	Common
Scapanorhynchus texanus	Teeth	Abundant
Squalicorax lindstromi	Teeth	Common
Squalicorax pristondotus	Teeth	Uncommon
Synechodus sp.	Tooth	Single specimen
Rhinobatus casieri	Teeth	Common
Ischyrhiza mira	Rostral spines and denticles, oral teeth	Common
Ischyrhiza ?avoncola	?Rostral spines	Rare
Ptychotrygon vermiculata	Teeth, rostral spines	Teeth common, spines rare
Ptychotrygon cf. slaughteri	Teeth	Rare
Ptychotrygon cf. winni	Teeth	Rare
Ptychotrygon cf. agujaensis	Teeth	Rare
Brachyrhizodus wichitaensis	Teeth, mid-dorsal denticles	Common
Rhombodus laevis	Teeth, ?denticles	Teeth abundant
Ischyodus bifurcatus	Palatine and mandibular jaw plates	Uncommon
Chondrichthyan denticles	Various types including denticles that have been described by others as teeth of albulid bonefish	Uncommon
Selachian vertebrae	Calcified vertebrae	Common
Batoid vertebrae	Calcified vertebrae	Common
Chondrichthyan calcified cartilage	Indet. fragments	Uncommon
Chondrichthyan coprolites	Spiral coprolites	Uncommon
OSTEICHTHYES (SARCOPTERYGII)		
Coelacanth indet.	Quadrate	Single specimen
OSTEICHTHYES (ACTINOPTERYGII)		
Anomoeodus latidens	Pharyngeal teeth, partial tooth plates, branchial teeth (branchial teeth had formerly been assigned to the genus *Stephenodus*)	Common
Enchodus cf. E. ferox	Teeth	Rare
Enchodus gladiolus	Teeth and jaw fragments	Uncommon
Enchodus petrosus	Teeth, jaw and skull fragments, vertebrae	Teeth abundant, other elements common
Paralbula casei	Phyllodont tooth plates, isolated teeth	Uncommon
Xiphactinus vetus	Teeth	Rare
Congorhynchus (=Hemirhabdorhynchus) elliotti	Rostrums	Rare
Lepisosteidae	Ganoid (?gar) scales	Uncommon
Osteichthyan bones and vertebrae	Indeterminate	Common

TAXA	ELEMENTS RECOVERED	ABUNDANCE
REPTILIA		
Chelonia		
?Peretresius ornatus	Carapace fragments	Rare
cf. Osteopygis emarginatus	Partial peripheral scute	Single specimen
Trionyx sp.	Costal scutes, peripheral scutes	Uncommon
Dollochelys sp.	Costal scutes, peripheral scutes	Uncommon
Chelonia indet.	Carapace fragments, vertebra	Uncommon
Squamata		
Mosasaurus conodon	Teeth	Uncommon
Mosasaurus cf. M. maximus	Teeth	Rare
Mosasauridae indet.	Partial dentary with replacement tooth in resorption pit	Single specimen
Plesiosauria		
Cimoliasaurus magnus	Teeth	Rare
Crocodilia		
cf. Borealosuchus sp.	Osteoderms, ?teeth	Rare
Crocodyliformes indet.	Teeth, osteoderms; a vertebra possibly referable to *Hyposaurus rogersii*	Teeth common
Ornithischia		
Hadrosauridae indet. teeth and bones	Teeth and partial rib	Rare
Theropoda		
?Dryptosauridae	Partial tooth, and indet ?theropod phalanx	Very rare
MISCELLANEOUS		
Mollusks		
Gastropods	Indet. naticid gastropod steinkerns	Rare
Bivalves	Indet. bivalve steinkerns, pholodid clam borings in fossil wood	Rare
Ammonites	Stienkern fragments of *Placenticeras minor*	Rare
Decapod crustaceans		
Hoploparia sp.	Carapace fragments	Rare
Mesostylus mortoni	Chilipeds, callianassid burrows	Common
Plants		
Sideritized wood		Uncommon

TABLE 1. Fossils recovered from the Holmdel Park Site. Chondrichthyan tooth identification and terminology follow first Cappetta (1987), then Welton and Farrish (1993). Various sources were used in the identification of bony fish remains. Many elements of the fauna remain under study and have not yet been identified.

As can be seen along the southern coast of New Jersey today, a wide variety of environments exist within very close proximity to each other. This must also have been true during the Late Campanian and Early Maastrichtian.

The subtle differences between the faunas of sites in close proximity, such as Site RB and Site HP, should help us to better understand the coastal dynamics that existed during the Late Cretaceous along the New Jersey coastline. The numerous fossils that have been collected over the years from the streambeds and bank of the Monmouth County brooks are a valuable resource for demonstrating the diversity of life during the Late Cretaceous. However, without the stratigraphic context that sites like the Holmdel Park Site afford, the fossils, by themselves, can only begin to offer us the insight necessary to piece together the environments that existed then and the processes that led to the deposition and preservation of these fossils.

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ARTICLE

THE CHESAPEAKE AND DELAWARE CANAL: TWO CENTURIES OF PALEONTOLOGY ON A PUBLIC TRACT

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ABSTRACT—The cuts and spoil piles of the Chesapeake and Delaware Canal, in New Castle County, Delaware have been productive sites since 1804. The canal is currently administered by the United States Army Corps of Engineers. Collecting along the canal is neither encouraged nor discouraged, thus providing a case study in unregulated public access to fossil collecting. The tracts are of little interest to commercial collecting, but have been widely exploited for scientific, personal, and recreational recovery of fossils, many of which have remained in personal collections. While many significant specimens have no doubt gone unrecognized by the scientific community, many others have been placed in public repositories, studied, and published. The assemblage described herein, a comprehensive study of a local fauna from one exposure, the Deep Cut, is exemplary of the importance of the scientific potential of the canal sites. It is worthy of consideration as to whether regulated collecting would have benefited the public interest. Largely based on one personal collection, conscientiously maintained and donated to a public repository, it includes more than sixty taxa of Cretaceous age, including one poriferan, twenty pelecypods, fifteen gastropods, six ammonites, eight arthropods, one echinoid, and eleven vertebrates.

THE DEEP CUT SITE AS A CLASSIC FOSSIL LOCALITY

As early as 1661, a Dutch surveyor of the Colonial Period, Augustine Herman, is said to have suggested the advantages of a canal across what would become known as the Delmarva Peninsula. The advantages of connecting the Delaware River with the Chesapeake Bay seemed obvious to many, but the proposal did not reach fulfillment until the Nineteenth Century, in the newly independent United States of America. Work commenced in 1804, was suspended in 1806, resumed in 1823, and was completed (and the canal opened) in 1829. Approximately 21 km (13 miles) long with four locks, it was originally approximately 11 m (36 ft) wide and 3 m (10 ft) deep. It is now about 140 m (460 ft) wide and 11 m (36 ft) deep. Most of the canal is in the state of Delaware. The Army Corps of Engineers provided information and resources that supported the Canal as a company enterprise.

Excavation of the canal provided the paleontological community with an important window to the Mesozoic Era. Research on the Cretaceous System of New Jersey could now be extended to the south and west. Collections were made and interpretations extended. One especially important locality was located just west of the town of Saint Georges, near a present day railroad bridge. Popularly known as the Deep Cut (a simplistic engineering designation), the new exposure contained a stratigraphic sequence of three lithologic units of general usage: in ascending order, the Merchantville, Englishtown, and Marshalltown Formations, all named from type localities in New Jersey.

The Deep Cut became even more important as the canal was deepened, widened, and straightened. Actions of tides and waves accelerated the erosion processes, and numerous fossils could be found on the 'beach' areas during low tides. In 1920 the federal government had purchased the Canal and the Army Corps of Engineers had complete authority to alter the widths and depths, creating more spoil piles. The site gained particular importance during the 1970s and 1980s, as dedicated paleontologists and volunteers made frequent trips to the sites, notably Delaware Valley Paleontological Society members and students from Sharon Hill High School. Many fossils were retained in personal collections, largely because the United States Army Corps of Engineers, which now had responsibility for the canal, did not regulate collecting. The sites, whether engineered excavations, spoil heaps, or erosional exposures, were open to all collecting.

During 1982, the Army Corps of Engineers began to level the Deep Cut cliff face and placed boulder-sized rocks on the beach areas. The announced purpose of this construction was to reduce erosion in an adjoining inlet that had been created by straightening of the canal. Protection of recreational users by halting the digging of the cliffs was another announced reason for the construction, but the paleontological community objected vigorously. (Interested parties suspected that a major reason for the construction was to enable a marina to be developed on the inlet.) It was noted that the cliff-burrowing swallows probably penetrated the exposures more profoundly than did fossil collectors. Complete destruction of the cliffs was halted, but collecting has diminished substantially since then, and the very productive strata of the Merchantville Formation now are mostly buried.

As the Deep Cut Locality is essentially no longer accessible, a summary study of this important locality is justified, especially because much of what is reported herein is based on one collection of the senior author, conscientiously acquired over the course of many years with appropriate study, and which is now in a public repository, the New Jersey State Museum (NJSM). Reference is also made to specimens in repository at the Academy of Natural Sciences of Philadelphia (ANSP). With minor exceptions, the taxa documented in this present work include all species ever reported for the Deep Cut Local Fauna, a publicly accessible site from which fossils have been collected during two centuries, effectively without regulation.

PREVIOUS PUBLICATIONS

Morton (1829) was the first to record and describe fossils from the Chesapeake and Delaware Canal, with a report based on his studies of the "Secondary Formation" published the year the completed canal opened for business. It was also the first publication that listed the "Deep Cut" by name. Six new genera were named in Morton's early studies. In February of 1837, the Delaware Legislature passed an act providing for a general geologic survey of the state. James Booth was hired as State Geologist, and completed and published a summary work only four years later (Booth, 1841), in which the Deep Cut is cited among the formations of the "Upper Secondary Formation" of Delaware. The description notes that the upper stratum of his Green Sand Formation is clearly visible at the Deep Cut along the Canal. The section on the Black Micaceous and Tenacious Sand notes that "The deep-cut of the canal presents a view of the various strata constituting the green sand formation as they repose in their native beds…" (Booth, 1841:73). Booth further explained that there is a ferruginous sand and clay which contains ammonites, *Baculites*, *Scaphites*, and casts of simple univalve and bivalve shells.

A detailed study and historical review of the stratigraphic work at the Canal during the latter part of the 1800s and early 1900s was published by Grout et al. (1954). This work also contains descriptions and identifications of fossils, accompanied by plates, and includes specimens from the Deep Cut Locality.

The extensive studies published as Richards et al. (1958, 1962) are primarily about fossils from New Jersey, but also include substantial information about Delaware localities and specimens, with good quality plate illustrations. Some of the specimens were from the Deep Cut and other nearby localities, and comments are included with the species accounts herein, noting relevance of these two benchmark publications. An additional systematic study of the macroinvertebrate fauna from the Canal was published by Richards and Shapiro (1963), which served as a guidebook for identifications for the many years it was in print.

The stratigraphy of the Canal was remapped by Pickett (1970, 1972), with reprinted plates from some of the previous publications, but no new systematic studies of the taxa were included.

The less extensive vertebrate fauna was collected by many paleontologists and was well represented in collections, but received relatively little in the way of published studies. A major review of dinosaur bones from the Canal's spoil piles was published by Baird and Horner (1977), followed by a study of pterosaur bones (Baird and Galton, 1981). Additional pterosaur specimens have been recovered for this report and are described herein.

A guide designed for general public usage was published by Lauginiger and Hartstein (1981), which includes sketches and line drawings of typical Canal fossils, including those taxa found at the Deep Cut. Gallagher (1982) described hadrosaurian dinosaurs from the Canal in a newsletter report to the Delaware Valley Paleontological Society, an organization that had come to represent a large number of paleontologists who had interests there. Lauginiger and Hartstein (1983) continued their work with a detailed study of chondrichthyan fossils from the Canal. Such specimens are often comparable to those of New Jersey brook localities (Lauginiger, 1986). Gallagher (1984) summarized knowledge of the Canal sites. A study of the trace fossil *Ophiomorpha* from the Englishtown Formation was published by Curran (1985). Pickett (1975) described the Canal stratigraphy in a field guide. Records of the uncommon mosasaur Halisaurus were published by Baird (1986). A more extensive field guide for students and amateurs was provided by Lauginiger (1988). Weishampel and Young (1996) gave further information on the dinosaurs from the canal sites, and included a photograph of the Deep Cut Locality.

A review of crustacean fossils, including descriptions of new taxa from both New Jersey and Delaware, has recently been published by Feldmann et al. (2013).

STRATIGRAPHY

Three lithostratigraphic units are exposed at the Deep Cut, in ascending order (oldest to youngest) the Merchantville, Englishtown, and Marshalltown Formations (Fig. 1). The formations have a dip of less than 1% southeastward (Scharf, 1888). They traditionally have been interpreted as a transgressive-regressive-transgressive sequence from base to cliff.

The Merchantville Formation, located at beach level, begins as a dark gray to dark blue glauconitic micaceous sand and grades into fine sand and silt before a final gradational contact with the Englishtown Formation. The Merchantville Formation sediments are interpreted to be from a medium to shallow open marine paleoenvironment. Fossils are common and include many ammonites, arthropods, and echinoids, the taxa that comprise the essence of this report. Fossils are less common in the upper levels of the formation; the best specimens were found at or near beach level.

The Englishtown Formation is the thickest and most spectacularly exposed unit at the Deep Cut, with sequences of white, gray, and red-brown sands readily observed. The fine quartz sands are poorly cemented, with only traces of glauconite, and are interpreted as shallow water deposition. The strata are extensively burrowed, predominantly by the ichnotaxon *Ophiomorpha nodosa*, as noted by Pickett et al. (1971) and Curran (1985). Curran inferred that the Englishtown Formation was deposited in an up-

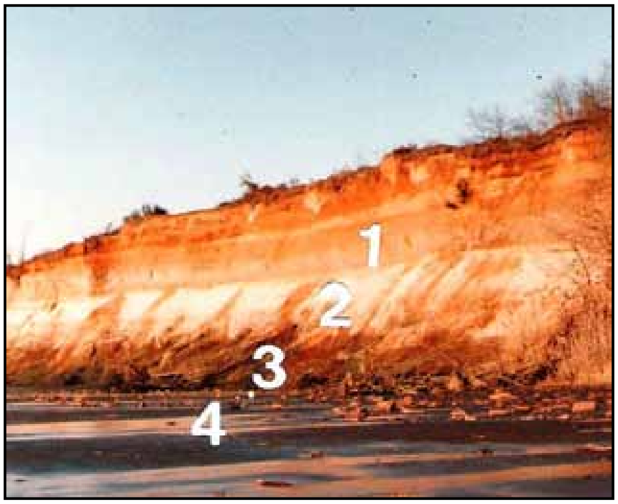

FIGURE 1. Deep Cut formations, as exposed for much of the twentieth century. 1. Marshalltown Formation, 2. Englishtown Formation, 3. Merchantville Formation, 4. beach level. Photograph by E. Lauginiger.

per shore face-lower foreshore environment. The only other fossils of this formation at the Deep Cut are poorly preserved remains of the gastropod Turritella and a few limonite-encrusted pelecypods that have been found on the beach at low tide. The top of the Englishtown Formation is interpreted as an unconformity, corresponding to the falling of sea level and the beginning of an erosional interval. While generally not noted for fossil content, the Englishtown Formation has produced a significant flora elsewhere (Gallagher et al., 1999).

The dark gray glauconitic silts and sands of the Marshalltown Formation were deposited after the erosional interval and mark the advent of another transgressive event. Although some localities in the formation have produced many invertebrate and vertebrate fossils, the Deep Cut exposure has yielded very few fossils. This is probably because only the basal portion of the formation is exposed; more fossiliferous strata are generally found higher in the formation. Spoil piles of the Marshalltown Formation elsewhere along the Canal, including the nearby area of the railroad bridge, have produced many fine and unusual specimens. Lauginiger (1984) reported a significant fauna from the Marshalltown Formation. Above the Marshalltown Formation at the Deep Cut is a Quaternary overburden, less than a few meters of sands, rounded pebbles, and gravel, which are commercially mined elsewhere.

PALEONTOLOGICAL MATERIALS AND METHODS

The fossils found at the Deep Cut Locality are primarily molds and casts of invertebrates, exoskeletons of crustaceans, and isolated teeth and bones of vertebrates. Plant remains include lignite and a few possible cones. Internal molds (steinkerns) are the most common fossils at the site. They are difficult to identify with precision due to lack of detail, often being determinable to generic level at most.

The fossils were collected both as 'float' and in situ on the beach at low tide; some were eroded out and deposited at the base of the cliff. Most of the lobsters were dug from the beach level in the lower strata of the Merchantville Formation, which was exposed during low tides. The fresh wet specimens were soft and fragile when first collected and required very delicate handling. After drying (and thus becoming more stable), they were soaked in a solution of water-based glue, diluted from normal strength. The exoskeletons of the arthropods were coated with a layer of clear fingernail polish in order to prevent cracking and flaking. The bones and teeth were also soaked in the glue solution in an attempt to prevent pyrite/marcasite deterioration, known as 'pyrites disease'. Encrustation with iron sulfides greatly limits the degree to which some of the vertebrate specimens can be safely prepared, and some are not identified with precision as a result.

As noted, the vast majority of the specimens are attributed to the Merchantville Formation and include invertebrates of the phyla Porifera, Mollusca, Arthropoda, and Echinodermata, with mollusks being most common. Vertebrates include taxa belonging to Chondrichthyes, Osteichthyes, and at least three groups of Reptilia. Original designations are numbers given in the Lauginiger collection.

ANNOTATED LIST OF TAXA

PHYLUM PORIFERA

Cliona cretacica Fenton and Fenton, 1932

Referred specimen: NJSM GP23042. A single specimen of a gastropod with the distinctive borings of this species has been recovered. (original designation A-243)

Cited by Howell (1958) as a Delaware fossil, but the Deep Cut was not cited as a locality.

PHYLUM MOLLUSCA
CLASS BIVALVIA

Cucullaea cf. antrosa Morton, 1834

Referred specimens: NJSM GP23014–23020. The seven examples are three single left valves and four complete double shells. (original designation A-208)

Listed by Richards (1958), who did not attribute the species to Delaware, nor any other sites outside New Jersey.

Glycymeris mortoni (Conrad) 1869

Referred specimens: NJSM GP23044. Two specimens, one single shell and one double shell have been collected from the Deep Cut. (original designation A-238)

Cited by Richards (1958) as a Delaware fossil, but the Deep Cut was not given as a locality.

Pinna laqueata Conrad, 1858

Referred specimens: NJSM GP22543, 23027, 23563. The six examples include the first Deep Cut fossil to become part of the Lauginiger Collection, and it is the largest of the specimens. (original designation A-210)

Cited by Richards (1958) as a Delaware fossil, but the Deep Cut was not given as a locality.

Gervilliopsis ensiformis (Conrad) 1858

Referred specimens: NJSM GP23048. The two examples included a fractured and healed individual and a smaller poorly preserved one.

Cited by Richards (1958) as a Delaware fossil, but the Deep Cut was not given as a locality.

Inoceramus proximus Tuomey, 1854

Referred specimens: NJSM GP22545, 22347, 22549–22551. There are three full-sized mature specimens, a small one, and a section of a large shell more than 15 cm (6 in) in at least one dimension. (original designation A-207)

Cited by Richards (1958) as a Delaware fossil, but the Deep Cut was not given as a locality.

Pteria cf. petrosa (Conrad) 1853

Referred specimens: NJSM GP22562, 23002–23013, 23101. The specimens include two small colonies, each with four or more individ uals with single valves exhibiting the characteristic wing shapes. (original designation A-209)

Cited by Richards (1958) as a species with a Chesapeake and Delaware Canal type specimen (apparently lost), but the Deep Cut was not given as a locality.

Exogyra sp.

Referred specimens: NJSM GP23040, 23043, 23045–23046. All examples from the Deep Cut are young small individuals no more than five centimeters in any dimension. A small colony of three single and three double shell individuals was identified by comparison to better-preserved specimens from elsewhere. (original designation A-245)

Several species of the genus were attributed to Delaware by Richards (1958).

Trigonia sp.

Referred specimen: NJSM GP23029. The only recorded specimen from the Deep Cut has the distinctive shape and ribbed surface characteristic of the genus. (original designation A-218)

Several species were attributed to Delaware by Richards (1958).

Pecten conradi (Whitfield) 1886

Referred specimen: NJSM GP23026. This small scallop is represented by but one specimen, a double-shelled individual with some original shell material. (original designation A-241)

Not listed for Delaware by Richards (1958).

Pecten (Neithea) quinquecostata Sowerby, 1814

Referred specimen: NJSM GP23025. Although there is but one specimen, it is especially identifiable, having the distinctive thick primary costae. (original designation A-244)

Cited by Richards (1958) as a Delaware fossil, but the Deep Cut was not given as a locality.

cf. Anatimya sp.

Specimen tentatively referred: NJSM GP23030. One subelliptical shell may pertain to this genus of rather large clams.

Genus not listed for Delaware by Richards (1958).

Liopistha protexa (Conrad) 1853

Referred specimens: NJSM GP23028–23029. One double-shelled and one single shell are referred to this species, which has distinctive large descending ridges and grooves in the surface of the shell. (original designations A-236, A-242)

Cited by Richards (1958) as a Delaware fossil, but the Deep Cut was not given as a locality.

Etea delawarensis (Gabb) 1860

Referred specimen: NJSM GP23035. A single double-shelled specimen has the distinctive subtriangular shape with a wide anterior. The occurrence is especially significant because Richards (1958) noted that Gabb had indicated that the Deep Cut was the type locality, hence the specific epithet. This was questioned by subsequent authors, who believed the species to be of Eocene age. However, it has also been recorded from the Main Fossiliferous Layer at the Inversand Site in New Jersey (Gallagher et al., 1986), and this present work further confirms that it occurs in Cretaceous strata. (original designation A-235)

Crassatellites sp.

Referred specimens: NJSM GP23031, 23032. Two complete specimens are identifiable to genus, despite being encrusted in pyrite/marcasite. (original designation A-238)

Several species of the genus were attributed to Delaware by Richards (1958).

Granocardium sp.

Referred specimen: NJSM GP23033.The only known specimen from the site is not identifiable to species. (original designation A-238)

The genus was not listed for Delaware by Richards (1958), although some taxa from the Family Cardiidae were cited.

Cyprimeria sp.

Referred specimens: NJSM GP23038, 23041. Two poorly preserved specimens are identifiable as this genus. (original designation A-222)

One species of the genus was attributed to Delaware by Richards (1958).

Legumen concentricum Stephenson, 1923

Referred specimen: NJSM GP23034. This species of elongate clam is represented by one double-shelled specimen. (original designation A-239)

Cited as a Delaware species by Richards (1958), but the Deep Cut was not given as a locality.

Linearia multistriata Conrad, 1860

Referred specimen: NJSM GP23037. One double-shelled specimen has been identified. (original designation A-244)

Cited as a Delaware species by Richards (1958), but the Deep Cut was not cited as a locality.

Panopea decisa Conrad, 1853

Referred specimen: NJSM GP23036. The single specimen of this Cretaceous "geoduck" includes some original shell material. (original designation A-234)

Cited as a Delaware species by Richards (1958), but the Deep Cut was not given as a locality.

Kummelia americana (Gabb) 1860

Referred specimens: NJSM GP23049–23052. Four tubular specimens are inferred to have been made by this species. (original designation A-212)

Cited as a Delaware species by Richards (1958), but the Deep Cut was not listed as a locality.

CLASS GASTROPODA

Gyrodes petrosus (Morton) 1834

Referred specimen: NJSM GP23087. This large species, recognized for its sizeable umbilicus, is represented by but one specimen in the Lauginiger Collection. (original designation A-215)

Cited by Richards and Ramsdell (1962) as a Delaware species, but the Deep Cut was not listed as a locality.

Gyrodes supraplicatus (Conrad) 1858

Referred specimens: NJSM GP23099. There are two large specimens, one of which is attached to a fragment of the rare ammonite *Cirroceras* (Fig. 2). (original designations A-213, A-214)

Cited by Richards and Ramsdell (1962) as a Delaware fossil, but the Deep Cut was not listed as a locality.

Gyrodes cf. spillmani Gabb, 1861

Referred specimens: NJSM 23098, 23103. Four nearly complete specimens are comparable to this species, another which is characterized by a prominent umbilicus. (original designation A-217)

This species was not listed in any reference included within Richards (1962).

Polinices altispira (Gabb) 1861

Referred specimens: NJSM GP23088. There are two incomplete specimens and one large nearly complete individual. (original designation A-271)

This species was not listed as occurring in Delaware by Richards and Ramsdell (1962).

FIGURE 2. NJSM GP23099, rare ammonite *Cirroceras conradi* (Morton) partial whorl attached to steinkern of *Gyrodes supraplicatus* (Conrad). Length of ammonite approximately 70 mm (2.8 in). Photograph by E. Lauginiger.

Amauropsis punctata (Gabb) 1860

Referred specimens: NJSM GP23100. This small species is represented by three nearly complete steinkerns. (original designation A-269)

The species was not listed for Delaware by Richards and Ramsdell (1962).

Xenophora leprosa (Morton) 1834

Referred specimens: NJSM GP23086. Two excellent examples are referred to this species, both with some evidence of the characteristic debris attachment. (original designation A-216)

The species was not listed for Delaware by Richards and Ransdell (1962), nor had it been listed for any formation other than the Mount Laurel and Navesink Formations as of that time.

Cerithium pilsbryi Whitfield, 1893

Referred specimens: NJSM GP23096. The species is represented by one nearly complete specimen (about 4cm long and ornamented) plus a fragmentary second specimen. (original designation A-221)

The species was listed as occurring in Delaware by Richards and Ramsdell (1962), but the Deep Cut was not listed as a locality.

Piestochilus bella (Gabb) 1860

Referred specimens: NJSM GP23093. There are three incomplete specimens.

The species was listed as occurring in Delaware by Richards and Ramsdell (1962), and the Chesapeake and Delaware Canal was given as the type locality, but all occurrences as of that time were from the Mount Laurel and Navesink Formations.

Bellifusus sp.

Referred specimens: NJSM GP23097. There is a single specimen, with conspicuous ribbed sculpture characteristic of the genus. (original designation A-220)

The species was not listed for Delaware by Richards and Ramsdell (1962).

Napulus sp.

Referred specimens: NJSM GP23094. This species is represented by one steinkern. (original designation A-229)

Several species of the genus were listed for Delaware by Richards and Ramsdell (1962).

Turbinella intermedia Weller, 1907

Referred specimens: NJSM GP23047, 23095. One small incomplete specimen seems referable to this species. (original designation A-240)

This species was not listed for Delaware by Richards and Ramsdell (1962).

Pyrifusus sp.

Referred specimens: NJSM GP23089. Two specimens belong to this species, one nearly complete and one fragmentary.

No species of this genus were listed for Delaware by Richards and Ramsdell (1962).

Volutomorpha conradi (Gabb) 1860

Referred specimens: NJSM GP23090. There are three specimens of this moderate-sized species. (original designation A-223)

The species was listed for Delaware by Richards and Ramsdell (1962).

Volutomorpha delawarensis (Gabb) 1861

There is one specimen of this large species, and a second smaller but better preserved specimen.

The type specimen ANSP 14266 was reported from the Chesapeake and Delaware Canal (Richards and Ramsdell, 1962), but the lithostratigraphic occurrence was not given.

Volutomorpha sp.

Referred specimens: NJSM GP23091. Two specimens are identifiable only to the generic level. (original designation A-250)

CLASS CEPHALOPODA

Baculites ovatus Say, 1820

Referred specimens: NJSM GP23054–23056. Of the three specimens of this straight ammonite, two show the suture patterns quite clearly. (original designation A-203)

This widespread and long-ranging species was not listed for Delaware by Reeside (1962).

Cirroceras conradi (Morton) 1841

Referred specimen: NJSM GP23099. A single partial whorl specimen was found, attached (as noted above) to a gastropod (Fig. 2). This very rare species was known essentially from casts of the type specimen, according to Reeside (1962) and was only known from New Jersey at that time.

Scaphites hippocrepis (DeKay) 1827

Referred specimens: NJSM GP23053, 23057–23060. The five specimens of this semi-coiled ammonite may be considered particularly important for age determination and correlations. (original designation A-202)

This ammonite was reported for Delaware by Reeside (1962) and the Deep Cut was given as the type locality. The type specimen was apparently lost, but the major reference specimen ANSP 19483 is also from the Deep Cut.

Placenticeras placenta (DeKay) 1827

Referred specimens: NJSM GP22565–22575. This is the most common ammonite from the Deep Cut. Eleven essentially complete specimens have been catalogued and many other fragments have been found as well. The largest is more than 13 cm (5 in) in diameter. Three specimens were found with bivalve shells attached or in chambers. (original designation A-200).

The Chesapeake and Delaware Canal was given as the type locality by Reeside (1962) although the type specimen itself could not be located.

Menabites (Delawarella) delwarensis (Morton) 1830

Referred specimens: NJSM GP22537–22542. This species appropriately associated with Delaware, is a coiled form represented by two nearly complete and four partial specimens (Fig. 3). (original designation A-201)

As noted by Reeside (1962) the type specimen, probably lost, was supposed to be from the Deep Cut.

The type specimen of *Solenoceras annulifer* (Morton, 1841) was cited as a Deep Cut specimen (ANSP 4789). It remains unique.

PHYLUM ECHINODERMATA

CLASS ECHINOIDEA

Pygidiolampas geometrica (Morton) 1833

Referred specimens: NJSM GP23076–23085. The seven nearly complete and three partial specimens of this echinoid were identified from general shape and presence of petal-like structures on the dorsal (aboral) side. George Phillips (Mississippi Museum of Natural Science) confirmed identifications. (original designations A-205-C and A-205-D)

Cited as Faujasia geometrica by Cooke (1958), the type locality was given as "north side of the Chesapeake and Delaware Canal, 2000 feet east of the Railroad Bridge" (Cooke, 1958:46). If correct, this would not pertain to the Deep Cut and would almost certainly mean that the specimen was from the Marshalltown Formation, as noted in the entry. The footnote by Richards raises the possibility

FIGURE 3. NJSM GP22542, ammonite *Menabites (Delawarella) delawarensis*.

of the Wenonah Formation being the source, but that unit is no longer used in Delaware.

PHYLUM ARTHROPODA
CLASS MALACOSTRACA
Hoploparia gabbi (Pilsbry) 1901

Referred specimens: NJSM GP22485–22492, 22502, 22554–22561, 225787–22580, 23064: This species is one of the best represented at the Deep Cut, with thirteen nearly complete specimens (cephalothorax, abdomen, and partial claws), as well as numerous partial specimens. (original designations R-001, R-008, and R-009)

The species was recorded for Delaware by Roberts (1962).

Hoploparia gladiator Pilsbry, 1901

Referred specimen: NJSM GP22553. This species was noted by Feldmann et al. (2013).

Protocallianassa mortoni Pilsbry, 1901

Referred specimens: GP22493–22496, 22498–22504, 22506–22510, 22513–22516, 23065. This well-known fossil 'ghost shrimp' is particularly common at the Deep Cut, including many claw specimens. Although it has been widely believed that the majority of the exoskeleton was thin, fragile, or less chitinous (thus unpreserved), many Deep Cut claw specimens were attached to ovoid nodules which contained the cephalothorax, walking legs, and even the abdomen. These are among the first reported body parts of the species and are certainly among the most important occurrences of this fossil species on the Eastern Seaboard of North America. (original designations R-003, R-004)

The species was listed for Delaware by Roberts (1962).

cf. Protocallianassa sp. (burrows)

Referred specimens: NJSM GP23021, 23062. Numerous cylindrical tubes, some more than 30 cm (12 in) long, have been recovered at the Deep Cut. Most of them contain isolated body parts and fecal matter consistent with what would be expected of *Protocallianassa*. (original designation A-267)

cf. Protocallianassa sp. (fecal pellets)

Referred specimens: NJSM GP23001, 23024. Cemented masses of pellets from the base of the cliffs are attributed to *Protocallianassa* with considerable confidence. One particularly revealing specimen is a tapered tube with hundreds of pellets accumulated at the narrow (presumably bottom) end. A sizeable appendage of a ghost shrimp is embedded in the burrow above the mass. Mehling (2004) identified and described examples of such coprolitic material from New Jersey.

Mesostylus mortoni Pilsbry, 1901

Referred specimens: NJSM GP22497, 22505, 22512, 23022, 22023. This species of decapod was recently noted in the fauna of the Deep Cut by Feldmann et al. (2013).

Paleopagurus pilsbryi Roberts, 1962

Referred specimens: NJSM GP23061. Three fossil claw fragments are referred to this hermit crab paleospecies, of which only the claw would be expected to fossilize, due to the habitus and soft body of most of the animal. (original designation R-007)

The species as described by Roberts was said by him to occur in the Merchantville Formation of Delaware, listing Summit Bridge as a locality, equated by some authorities with the Deep Cut.

Linuparus richardsi Roberts, 1962

Referred specimens: NJSM GP22517–22523. Six nearly complete and two partial specimens are referred to this flat lobster species, including specimens with spines and other fine details. Two of the specimens show ventral surfaces and mouthparts. (original designation R-002)

In his original description of the species, Roberts (1962) listed no occurrences for Delaware.

PHYLUM CHORDATA
CLASS CHONDRICHTHYES
Ischyodus sp.

Referred specimens: NJSM GP22525. This callorhynchid chimaeroid is represented by a right lower (mandibular) tooth plate with tritors evident (Fig. 4). (original designation A-255)

Scapanorhynchus texanus (Roemer) 1852

Referred specimens: NJSM GP22528. There are two

FIGURE 4. NJSM GP22525, right mandibular plate of chimaeroid *Ischyodus* sp.

teeth of this extinct goblin shark, one of which is typical of anterior tooth form, but embedded in a pyrite/marcasite nodule. (original designation A-257)

Chondrichthyes incertae sedis

Referred specimens: NJSM GP22531. Three complete and two partial calcified vertebral centra are clearly chondrichthyan, but not further identifiable.

CLASS OSTEICHTHYES

Anomoedus phaseolus Hay, 1899

Referred specimen: A palatine section with about 25 teeth, somewhat obscured by pyrite/marcasite, is referable to this fish. (original designation A-261).

Enchodus petrosus Cope, 1874

Referred specimens: NJSM GP22529, 22576, 22585. Three palatine sections with fangs and three isolated teeth are attributed to this species. (original designations A-256, A-258, A-259, A260)

Teleostei, incertae sedis

Referred specimens: NJSM GP22524, 23000. An isolated scale and three isolated and encrusted vertebrae are presumed to be teleost, but not further determinable. (original designations A-247, A-249, A-251, A-254)

CLASS REPTILIA

cf. Bothremys sp.

Referred specimens: NJSM GP23074. A large costal bone and a second fragment, probably the same individual, have the thick and relatively smooth shell characteristic of this turtle genus.

Trionyx cf. priscus

Referred specimen: NJSM GP23073. A single neural bone, identified by the pitted sculpture, is attributed to a soft-shelled turtle. (original designation A-248)

cf. Osteopygis sp.

Referred specimens: NJSM GP23067. Four incomplete costal fragments are comparable to New Jersey specimens of this genus, and are tentatively referred.

Halisaurus platyspondylus Marsh, 1869

Referred specimen: NJSM GP23225. A single dorsal vertebra of this uncommon genus was identified and cited by Donald Baird of Princeton University (Baird, 1986), only the second record from Delaware (Fig. 5). (original designation A-035)

Mosasaurus sp.

Referred specimen: NJSM GP22465. A single posterior caudal vertebra is undiagnostic to species level. (original designation A-273)

cf. Nyctosaurus sp.

Referred specimen: NJSM GP23071. Also identified by Donald Baird, the specimen is a scapulocoracoid of a medium-sized pterosaur (Fig. 6), comparable to this genus (Baird, pers. comm., 1994). (original designation A-266)

cf. Pteranodon sp.

Referred specimens: NJSM GP23072, 23073. Two pieces of the same bone, collected on different days, plus an additional fragment of the same bone (collected by Eugene Hartstein), are identified as portions of the wing (fourth) digit of a large pterosaur, comparable to this genus. All are now in the New Jersey State Museum collections, plus a partial terminal phalanx of the wing digit (IV-4), i.e., the distal tip. (original designations A-264, A-265, Hartstein B-646).

SUMMARY AND RECOMMENDATIONS

At a time when sites for amateur and avocational collecting continue to diminish, the importance of the collection reported herein, and the venerable status of the locality from which it comes, should provoke considerable thought and discussion for public land managers and policy makers. Despite being one of the first public tracts in the United States to yield fossils, the Chesapeake and Delaware Canal has had essentially no regulation, no permit system, no funding for paleontology, and no requirement of public repositories. The sophistication and public-spirited dedication of the amateur community, in cooperation with major institutions, has been the mainstay of scientific productivity. Whether or not any differences of policy and actions would have been more beneficial (or less) to science is a question worthy of discussion. We submit the study of this collection for consideration.

ACKNOWLEDGEMENTS

Identification of the specimens was accomplished by comparison with known material in public repositories, including type specimens, and with assistance from pale-

FIGURE 5. NJSM GP23225, dorsal vertebra of mosasaur *Halisaurus platyspondylus*.

FIGURE 6. NJSM GP23071, pterosaur scapulocoracoid, *cf. Nyctosaurus*.

ontologists D. Baird, G. Bishop, R. Feldmann, W. Gallagher, E. Hartstein, S. Homsey, R. Johnson, G. Phillips, and C. Schweitzer. Reviews and editing were contributed by W. Gallagher and J. Schein. Technical support for production of the manuscript was provided by D. Kaukeinen, A. Lauginiger, and S. Parris. Curatorial assistance in production of the manuscript was provided by Douglass College Externs B. Wasserman, A. Borgida, and H. Ben Cheikh.

We dedicate this publication to the many competent and knowledgeable collectors who have walked the banks and searched the spoil piles in search of the fossil treasures of the State of Delaware. Among them were many students of Sharon Hill and Academy Park high schools, who spent many hours in selfless pursuit of specimens and scientific knowledge.

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ARTICLE

FOSSIL PLANTS FROM THE NATIONAL PARK SERVICE AREAS OF THE NATIONAL CAPITAL REGION

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ABSTRACT—Paleontological resource inventories conducted within the parks of the National Park Service's National Capital Region yielded information about fossil plants from 10 parks. This regional paleobotanical inventory is part of a service-wide assessment being conducted throughout the National Park System to determine the scope, significance and distribution of fossil plants in parks. Fossil plants from the Paleozoic, Mesozoic, and Cenozoic are documented from numerous localities within parks of the National Capital Region. A Devonian flora is preserved at Chesapeake and Ohio Canal National Historic Park. Fossil plants from the Cretaceous Potomac Group are identified in several parks in the region including two holotype specimens of fossil plants described by Smithsonian paleobotanist Lester Ward from Fort Foote Park. Cretaceous petrified wood and logs are preserved at Prince William Forest Park. Pleistocene plant fossils and petrified wood were found at President's Park near the White House. A comprehensive inventory of the plant fossil resources found on National Park Service administered lands in the National Capitol Region will aid in our understanding of past climates and ecosystems that have existed in this region through time.

INTRODUCTION

Fossils are an important resource because they allow us to study past organisms, ecosystems, and climates. Fossils are preserved in 245 of the 401 National Park Service (NPS) park units. Of the parks that preserve fossils, 128 have documented plant fossils. Collectively, these paleobotanical resources reflect a taxonomically diverse representation of fossil plants which span from the Precambrian to the Recent. Leaves, flowers, seeds, cones, nuts, fruits, pollen, petrified wood, amber and other types of fossil plant remains preserved in park strata all contribute to scientific understanding of paleoecology, paleoclimatology, and the evolutionary history of plants.

Recent inventories of paleontological resources from National Park Service's National Capital Region yielded information about fossil plants from 10 parks in the region (Fig. 1) (Kenworthy et al., 2005; Clites and Santucci, 2011; Santucci and Knight, 2013). This regional paleobotanical inventory is part of a servicewide assessment being conducted throughout the National Park System. Fossil plants from the Paleozoic, Mesozoic, and Cenozoic are documented from numerous localities within parks of the National Capital Region. A Devonian flora is preserved at Chesapeake and Ohio Canal National Historic Park including specimens of *Archaeopteris*, which is considered to be the first modern tree. Many of the plant fossil occurrences in the National Capitol Region are reported from the Cretaceous Potomac Group. Two holotype specimens of Cretaceous-aged fossil plants were described by Smithsonian paleobotanist Lester Ward from Fort Foote Park. Cretaceous petrified wood and logs are preserved at Prince William Forest Park. Pleistocene plant fossils and petrified wood were found at President's Park near the White House. A comprehensive inventory of the plant fossil resources found on National Park Service administered lands in the National Capitol Region will aid in our understanding of past climates and ecosystems that have existed in this region through time.

BALTIMORE WASHINGTON PARKWAY (BAWA)

Virtually the entire length of the parkway was constructed within areas mapped as the Potomac Group of Early Cretaceous age (Glaser, 1976; Crowley et al., 1976; Glaser, 2003; Kranz and Santucci, 2004). The Potomac Group (or Potomac Formation of some early authors) is a unit well-known for its fossils, and has been the subject of study since the late 1880s. In 1886, W. J. McGee first applied the name "Potomac Formation" to Cretaceous-aged sediments in and around Washington, D.C. Marsh (1888), Ward (1888, 1895, 1897), Fontaine (1889), Bibbins (1895), Clark and Bibbins (1897), Ward (1905), and Clark et al. (1911) subsequently published a number of early paleontological studies of the Potomac Group. BAWA passes near many of the historic fossil collecting localities mapped by Ward (1905).

The Potomac Group includes (from oldest to youngest) the Patuxent Formation, the Arundel Clay, and the Patapsco Formation. All three formations include sands and silt-clays that are interbedded to varying degrees in different locations. The Potomac Group is considered to be the result of deposition in a variety of fluvial environments including braided streams, river channels, floodplains, marshes, swamps, and abandoned channels (Glaser, 1969, 1976, 2003).

The Patuxent Formation contains fossils of ferns, horsetails, cycads, and conifers (Clark et al., 1911; Cooke, 1952; Johnston, 1962). The ferns commonly include species of *Cladophlebis* and *Onyhiopsis*, with a number of other genera also represented (Clark et al. 1911). Two species of the horsetail *Equisetum* were reported by Clark et al. (1911). Cycad fronds are more commonly found in the Virginia exposures of the Patuxent, but are also found in

Maryland and include species from many different genera such as *Dioonites*, *Ctenopteris*, *Ctenopsis*, *Zamiopsis*, *Nilsonia*, *Zamites*, *Cycadeospermum*, and *Podozamites* (Clark et al., 1911). The conifers are represented by species of *Sphenolepsis*, *Baiera*, *Brachyphyllum*, *Frenelopsis*, *Nageiopsis*, *Arthrotaxopsis*, *Sequoia*, and *Cephalotaxopsis* (Clark et al., 1911). Fossil pollen is also known from the Patuxent Formation (Brenner, 1963).

The most significant fossils of the Potomac Group, however, are some of the first 'advanced' angiosperms found in the North American fossil record. Approximately 25 different angiosperm species are known from the Patapsco Formation. These represent a number of genera, including *Cyperacites*, *Plantaginopsis*, *Alismaphyllum*, *Populus*, *Populophyllum*, *Nelumbites*, *Menispermites*, *Sapindopsis*, *Celastrophyllum*, *Cissites*, *Sassafras*, and *Araliaephyllum* (Clark et al., 1911). As stated by Hickey (1984), the Potomac Group flora provides the "longest and most complete sample of data on early angiosperm evolution where both pollen and megafloral [leaves, flowers, etc.] records can be examined together with the sedimentology." Doyle (1969, 1973), Doyle and Hickey (1976), Hickey and Doyle (1977), Hickey (1984), and Friis et al. (1987) described this early evolution and radiation of the angiosperms. Other plant fossils from the Patapsco Formation include lignitized stems and twigs, leaf and frond impressions, and pollen of ferns, horsetails, cycads, and conifers, including many of the same genera found in the Patuxent Formation (Clark et al., 1911; Carr, 1950; Cooke, 1952; Johnston, 1962; Glaser, 1969).

The Potomac Group sediments have also produced over 100 fragments of fossil cycadeoid assigned to the genus *Cycadeoidea* (described in greater detail by Ward, 1905). The majority were discovered at dozens of localities between Baltimore and Washington, D.C., generally within a radius of a few km/miles of what is now BAWA. For example, a number of partial cycadeoid tree trunks were collected from the J. A. Disney farm property near what is now BAWA at Hanover, Maryland. These tree trunks, originally collected between 1898 and 1899 and described by Ward (1905), are now on display in the library of the Maryland Geological Survey in Baltimore (D. Brezinski, pers. comm., 2004). Another cycadeoid fragment was discovered in Greenbelt Park (GREE) and is further described in the GREE section of this report.

Overall, the Potomac Group includes somewhere between 135 and 175 different species of plants. However there has been no attempt to update the taxonomy since the work of the late 1800s and early 1900s. The fossil pollen and spores of the Potomac Group were described by Brenner (1963) and used by Doyle and Robbins (1977) to divide the Potomac Group into palynological zones. Fossils from the Patapsco Formation are known from Fort Foote Park and indicate the potential for similar fossils in other National Capital Region Network parks.

CHESAPEAKE AND OHIO CANAL NATIONAL HISTORIC PARK (CHOH)

The Elbrook Formation consists of a sequence of gray shaly limestone and calcareous shale that occurs stratigraphically between the Waynesboro and Conococheague formations (Brezinski, 1992). Outcrops of this formation in Maryland are considered "poor" (Brezinski, 1992) but stromatolites are abundant and can be found along the

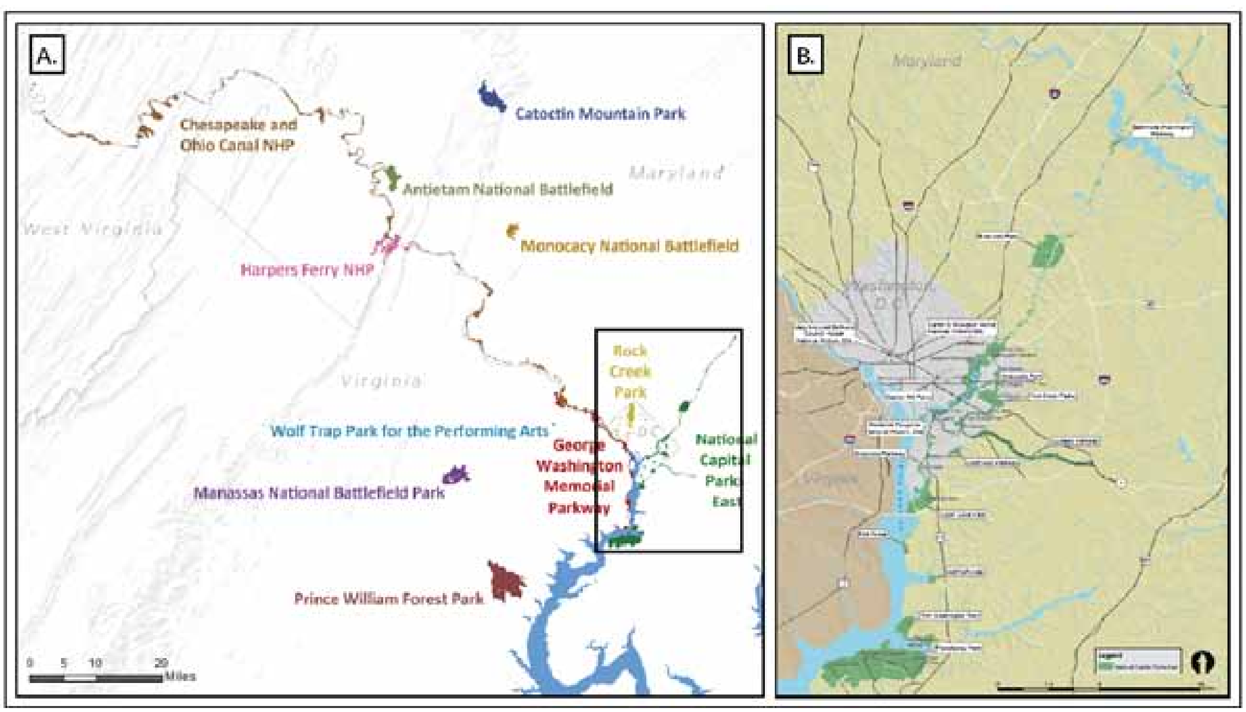

FIGURE 1. **A**, Map showing the National Park Service areas within the National Capital Region. **B**, Detail area delineated by black box in A.

FIGURE 2. Specimen of the oldest modern tree, *Archaeopteris*, collected in the Devonian Foreknobs Formation near Indigo Tunnel. Specimen number is CHOH 53648. Photograph by Tom Paradis, NPS.

Chesapeake and Ohio Canal (Southworth et al., 2001). Southworth et al. (2001, figure 114) illustrate one such stromatolite near canal mile marker MM109.5, east of McCoys Ferry.

Several outcrops of the Late Devonian age Foreknobs, Brallier, and Scherr formations are known to preserve impressions, compressions, and coalified fragments of *Archaeopteris* (Fig. 2) (Clites and Santucci, 2010; Loughney and Santucci, in prep). The Foreknobs, Brallier, and Scherr formations represent swamp and fluvial environments. Fragments of *Archaeopteris* and other plants have been found in situ at eight localities in CHOH (Loughney and Santucci, in prep., appendix C). Samples of *Archaeopteris* (CHOH 53648 and 53649) from the Foreknobs Formation were collected and placed in the Museum Resource Center in Landover, Maryland (Clites and Santucci, 2010). The genus *Archaeopteris* is considered to be the first modern tree and shows several adaptations to support large growth (achieving several meters in height), including modern wood anatomy (Meyer-Berthaud et al., 1999; Donaghue, 2005). *Archaeopteris* thrived early in the radiation of plants onto land. It is interpreted to be the dominant component of the earliest flood-plain forests during the Late Devonian (Meyer-Berthaud et al., 1999).

FORT CIRCLE PARKS (FOCE)

The Miocene Calvert Formation is mapped within forts Dupont, Davis, and Stanton. Excellent exposures of the Calvert Formation were found in the now-filled quarry west of Fort Stanton as well as on Good Hope Hill. The Good Hope Hill exposure was mapped by Darton and Keith (1950, site Number 19) and described by Carr (1950). The Good Hope Hill exposure is located just east of the Fort Davis Park boundary on the east side of Naylor Road. Marine invertebrate fossils, shark teeth (*Carcharocles*) (Carr, 1950), and plant fossils found at the Good Hope Hill exposures (Berry, 1916) indicate the potential for similar fossils to be found within Calvert Formation exposures in the Fort Circle Parks.

Fossil plants discovered within the Good Hope Hill exposures occur within a shallow marine unit, and likely indicate that the deposits near Good Hope Hill, and within the Fort Circle Parks of NACE, were closer to the Miocene shoreline than the deposits at Calvert Cliffs State Park, Maryland (D. Bohaska, pers. comm., 2004). Some of these plants include *Quercus chapmanfolia* and *Quercus lehmanni* (oak), *Ulmus basicordata* (elm), *Phyllites cercocarpifolia*, *Ilex calvertensis* (holly), *Caesalpina ovalifolia* and *Cassia toraformis* (bean), *Rhus milleri* (sumac), *Berchemia priscaformis* (supplejack), *Vaccinium* (blueberry) and *Pieres scrobiculata* (fetterbrush) (Carr, 1950).

FORT FOOTE PARK (FOFO)

Fontaine (in Ward, 1905) described the plant fossil assemblage collected within Fort Foote along Rosiers Bluff below the Notley Hall wharf. These plants are likely from the Patapsco Formation (silt-clay facies as mapped by Glaser [2003]) of the Potomac Group. USGS paleobotanist Lester Frank Ward collected 279 fossil specimens from 35 different plant species during two collecting trips to the Rosiers Bluff site in 1891. The most common specimens collected were from three species of the soapberry *Sapindopsis* (now *Lepisanthes*) which account for 146 specimens. Other genera collected include *Cycadeospermum* (cycadophyte), *Zamites* (cycadeoid), *Leptostrobus* (seed plant), *Thinnfeldia* (seed fern); the ferns *Baieropsis*, *Cladophlebis*, *Onychiopsis*, and *Thyrsopteris*; the conifers *Abietites*, *Araucarites*, *Brachyphyllum*, *Nageiopsis*, *Pinus* (including the holotype of *P. schista*; Fig. 3a), *Podozamites*, *Sequoia*, and *Sphenolepidium*; the angiosperms *Aristolochiaephyllum*, *Celastrophyllum*, *Eucalyptus* (including the holotype of *E. rosieriania*; Fig. 3b), *Ficus*, *Menispermites*, *Populophyllum*, and *Sapindopsis* (Fontaine, 1905).

Paleontologist Edward Wilber Berry also made a collection of plant fossils in 1909 from Fort Foote as recorded in the USGS Paleobotany Locality Register. These fossils came from the Potomac Group-Patapsco Formation, according to their associated specimen notes. One specimen was identified by Berry as *Brachyphyllum crassicaule* (Fig. 4). Part of this collection is located in the Cretaceous General Collection of the Paleobiology Department at the Smithsonian Institution's National Museum of Natural History (NMNH). Clark et al. (1911) also listed the fossils found at Fort Foote and include a stratigraphic section of the locality. Leo Hickey of Yale University (formerly of the Smithsonian) visited Fort Foote in the 1970s, although he did not collect or discover any plant fossils from the Patapsco Formation at this locality (L. Hickey, pers. comm., 2004).

GREENBELT PARK (GREE)

The silt-clay facies of the Potomac Group was mapped in the northeastern section of GREE (Glaser, 2003). The silt-clay facies includes the Arundel Clay and much of

FIGURE 3. Type specimens from Fort Foote Park. *Pinus schista* (USNM 31789) (A), and *Eucalyptus rosieriana* (USNM 31799) (B). Scale bars are 1 cm (0.4 in).

the lower Patapsco Formation. Fossils from this unit are well known and include significant plant and dinosaurian remains. Many of these fossils came from the Beltsville/ Muirkik area a few km/miles north of Greenbelt Park, Maryland.

A partial cycadeoid tree trunk fossil was discovered within GREE on September 15, 1970 by Leo Hickey of Yale University (formerly of the Smithsonian) and NPS research biologist Dr. L. K. Thomas, Jr. (now retired) during an informal site visit to Greenbelt Park (Fig. 5) (Thomas, 1970). The hand-sized cycadeoid fossil was discovered within an area mapped by Glaser (2003) as the sand-gravel facies of the Potomac Group, likely from the Patapsco Formation (Thomas, 1970). Hickey (pers. comm., 2004) tentatively identified the specimen as *Cycadeoidea marylandica* and was accessioned into the National Park Service collections. According to Thomas (1970; pers. comm., 2004), the cycadeoid fossil was discovered near the edge of the known distribution of *Cycadeoidea marylandica* at the time of discovery. The reported range for this species extends between College Park, Maryland and Baltimore, Maryland, a distance of 56.7 km (35.5 miles), and is never more than 13.3 km (8.5 miles) in width (Thomas, 1970). The vertical distribution is no more than 91.4 m (300 feet) (Bibbins in Ward, 1905). Thomas (1970) also reported that, at the time, only about 200 pieces of *Cycadeoidea marylandica* were known. Therefore, the cycadeoid discovery was considered to be quite rare and significant. The fossil discovery was additionally the subject of a newspaper article (Fig. 6) (Lague, 1970). After its discovery, this fossil specimen remained in National Park Service possession, although it was not formally accessioned. The specimen was later found in Dr. Thomas's office in Prince William Forest Park by Museum Tech Judy Volinoski. It was obtained by National Capital Parks-East Curator Mike Antonioni in September of 2005. The specimen was accessioned and cataloged in the park's collection under catalog number GREE-12, and is currently in storage at the NPS Museum Resource Center in Landover, Maryland. Ward (1905) had previously collected cycadeoid material in the same area within what is now GREE.

Cycadeoids, the order Bennettitales that includes the genus *Cycadeoidea*, are extinct. However, a few genera of cycad trees, which are morphologically similar to cycadeoids, but not directly related to them, are still extant in some subtropical and tropical regions of the world. This discovery illustrates the excellent potential for fossils to be discovered within the Potomac Group sediments of GREE, and possibly other NACE parks.

MONOCACY NATIONAL BATTLEFIELD PARK (MONO)

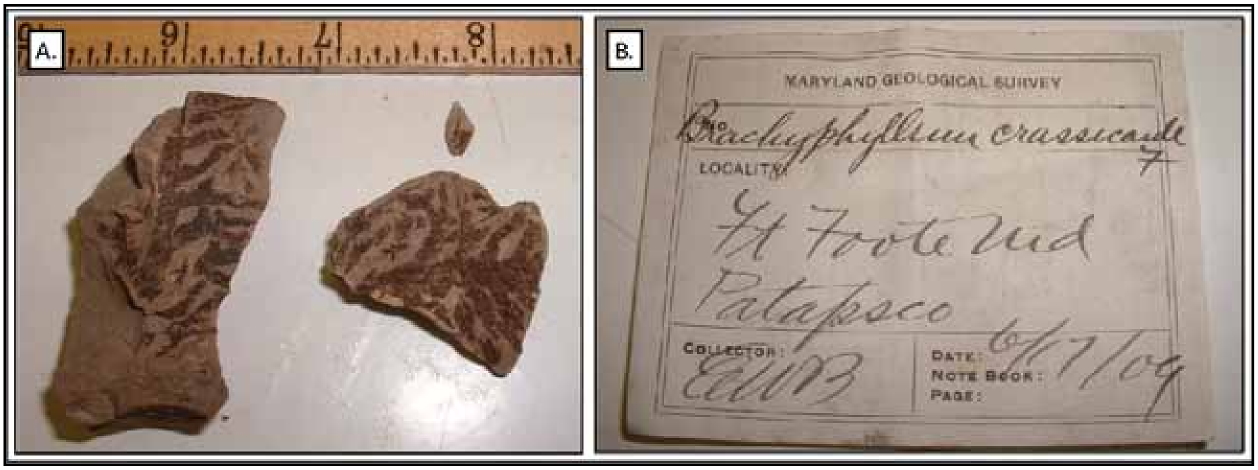

FIGURE 4. **A**. Fossil specimen of *Brachyphyllum crassicaule* from Fort Foote (USNM uncataloged). **B**, This specimen was identified by Edward Wilbur Berry (EWB), as noted on the specimen tag.

A single ex situ plant fossil specimen is reported from MONO, and is most likely a cone impression (Fig. 7). The specimen was discovered at the L'Hermitage (Best Farm) Slave Village site during archeological excavations in 2010–2011. The specimen has been accessioned and cataloged (MONO-33815) into the Monocacy Battlefield museum collection. The slaves at the village were collecting objects that they found of interest. The fossil specimen was found amongst prehistoric artifacts, several different minerals, glass beads, silver coins, and buttons (K. Birmingham, pers. comm., 2013). Because this fossil was a found and collected object, it is possible that it was transported a great distance. The lithology of this specimen does not match any rock units that occur within MONO boundaries. Further study to identify the provenance of this specimen and better taxonomic identification of the cone impression is needed. This will offer insight into both the plant fossil record for the region the cone was found in, and the history of the family who collected it.

PRESIDENT'S PARK (WHITE HOUSE, WHHO)

Fleming et al. (1994) mapped areas of middle and late Pleistocene-aged gravel, sand, silt, and clay deposits in a narrow band immediately south of the White House and north and east of Lafayette Park. These sediments likely represent fluvial and estuarine swamp deposits. Carr (1950) describes fossils from within the swamp deposits of these gravels in Washington, D.C. Two discoveries were located just north of Lafayette Park, and indicate the potential for finds in other late Pleistocene gravels in and around Washington, D.C.

Petrified bald cypress tree trunks were discovered during hotel excavations at Connecticut Avenue and DeSales Street and at 16th and K streets (Carr, 1950) (Fig. 8). The DeSales Street excavation for the Walker Hotel (now the Marriot Renaissance Mayflower Hotel) was a significant Pleistocene paleontological locality in 1922 and 1923 (Wentworth, 1924). Many specimens from over 19 families of plants were discovered during the excavations, although the large (up to 2.4 m [8 ft] in diameter) bald cypress trunks and associated material dominated the assemblage (Wentworth, 1924; Berry, 1924). There are 28 plant species represented in this assemblage, mostly represented by fruits or seeds. These belong to the genera *Taxodium*, *Vitis*, *Sambucus*, *Rhus*, *Sparganium*, *Naias*, *Polygonum*, *Chenopodium*, *Phytolacca*, *Castalia*, *Ceratophyllum*, *Ranunculus*, *Rubus*, *Prunus*, *Acalypha*, *Ilex*, *Ampelopsis*, *Cornus*, *Leucothoë*, *Galium*, *Viburnum*, *Carex*, *Scirpus*, *Cladium*, *Dulichium*, and *Cyperus*. Seventy-eight species of diatoms were also reported from the deposit (Mann, 1924). The age of the deposit has been a source of debate (Hay, 1924), although is it generally considered middle to late Pleistocene. Similar deposits have also been found near Union Station at the excavation for the Government Printing Office and the Bellevue Hotel (now Hotel George) and are described by Berry (1933).

PRINCE WILLIAM FOREST PARK (PRWI)

The Potomac Group of Early Cretaceous age is a well-known sequence of fossiliferous formations found throughout Maryland, Virginia, and Washington, D.C. The geology and paleontology of the Potomac Group at PRWI and other parks of the National Capital Region are described in Kenworthy and Santucci (2004). As mapped by Mixon et al. (1972), Anonymous (1985), Mixon (1990), National Park Service (n.d.) and Jett (n.d.) in and around PRWI, the Potomac Group has variable lithologies including light-gray to pink-gray medium to very coarse grained quartz sand, a green clay-sand, and a dark yellow-brown sandy soft clay. Found within these sands and clays are abundant, but generally poorly preserved, leaf and stem impressions of ferns, cycads, and gymnosperms along with rare silicified (or petrified) tree trunks (Mixon et al., 1972). Upchurch et al. (1994) report on a fossil floral assemblage from Potomac Group sediments found in a gravel pit along Engineers Road, parallel to Chopawamsic Creek south

FIGURE 5. Greenbelt Park fossil cycadeoid specimen (GREE-12), collected by Dr. L.K. Thomas in 1970.

of the U.S. Marine Corps Air Station. This assemblage contains 22 different plant species, including one species each of horsetail (*Equisetum lyellii*) and cycadophyte (D*ichotozamites cycadopsis*), eight species of conifers and 12 species of angiosperms (Upchurch et al., 1994). The conifer species include *Pseudofrenelopsis parceramosa*, *Araucarites aquiensis*, *Athrotaxopsis* sp. and *Sphenolepis sternbergiana*, indeterminate leaves (*cf. Abietites longifolius*) and *Brachyphyllum crassicaule*. The species of angiosperms present are aff. *Pabiania* sp., *Landonia cf. L. calophylla*, *Dicotylophyllum ovatodecurrens*, *Nelumbites extenuinervis, Nelumbites cf. N. minimus*, *Sapindopsis magnifolia/variabilis*, *Sapindopsis minutifolia*, and four species of *Dicotylophyllum* sp.

The only paleontological specimens cataloged within PRWI collections are various pieces and chips of petrified wood collected from Potomac Group sediments (PRWI-488-502, 2431, 7560, 7561, and 15796). Two large petrified logs are on display at the park, one outside the visitor center that is nearly 2 m (6 ft) long (Fig. 9), and one outside the Turkey Run Education Center (TREC) (C. Carmouche, pers. comm., 2013). Two smaller (<0.61 m [2 ft]) specimens of petrified wood are currently on display within the visitor center. Approximately seven of the smaller petrified wood pieces were discovered by a visitor during construction of the park's central drive. These specimens were turned over to a curator at another park, who, in turn, transferred the specimens over to PRWI (J. Lavelle, pers. comm., 1999). The largest specimens were unearthed by bulldozers in 1992 and 1993. The largest piece was discovered during construction of the Brittany Subdivision to the northeast of the park on land originally authorized for PRWI, but not included before development (J. Volonoski, pers. comm., 2004). The other piece was found west of PRWI during bridge construction over Quantico Creek. Both of these large pieces of wood were acquired by the park maintenance staff after corresponding with the respective developers (J. Volonoski, pers. comm., 2004). All of the petrified wood samples have been classified as *Taxodium distichum* (PRWI collections records).

WITH NAMES LIKE THIS, THEY DESERVE EACH OTHER

Fauna + Flora WASH. DAILY NEWS OCT 8 1970

Hey! A paleobiologist finds a cycadeoidea marylandica here

By LOUISE LAGUE

Long, long ago when Washington was a low fresh water swamp with dinosaurs roaming around on it, and Greenbelt Park was a large stream and delta, there lived a plant called cycadeoidea marylandica.

The plant was about three feet tall in the shape of a large pineapple with a crown of leaves resembling palm fronds. The cycadeoidea had scales and hair, much like a pineapple, but it bore no fruit or flowers.

Fruit-bearing plants were very much in demand in those days, some 110 million years ago, because dinosaurs ate them. All the cycadeoidea did to justify its existence was give off oxygen and hold down the soil.

DIED OUT

The fruit-bearers became stronger and more numerous. The cycadeoidea couldn't compete and died away. Some of its cousins lived on—the cycads that grow in tropical regions and the gingko trees that grow along some Washington streets—but the cycadeoidea marylandica had no direct descendants.

Large fossils of the plant began turning up in the early 18th century when the colonial farmers in a 15-mile wide corridor between Washington and Baltimore started clearing the land. They piled them up, thinking they were petrified beehives. The first identification of the fossils was made in 1860, and almost 300 fossils are now on display at the Museum of Natural History.

On Sept. 25, Dr. Leo Hickey, a paleobiologist (specialist in ancient life) from the Smithsonian, and L. K. Thomas Jr., a National Park Service research biologist, found a small cycadeoidea marylandica fossil in a streambed in Greenbelt Park.

NOT EARTHSHAKING

It is the size of a hand, and it looks, in the words of Mr. Thomas, "like a rock with holes in it."

Dr. Hickey, who brought the fossil back to the Smithsonian said: "It's interesting, it's rare, and it's exciting, but it's not earthshaking. The common fern, which dates from the same era has stayed alive like a small business—just marginally.

"But the cycadeoidea marylandica didn't even make it that far."

—Photo by Geoffrey Gilbert

Dr. Nickey and the fossile.

FIGURE 6. The article that was published in the Washington Daily News on the Greenbelt Park cycadeiod fossil discovered by Hickey and Thomas in 1970.

FIGURE 7. The Monocacy National Battlefield Park specimen (MONO-33815), which is likely a fossil cone impression. This specimen was collected during an archeological survey at the park in 2012 (Katherine Birmingham). Scale bar is 1 cm (0.4 in).

FIGURE 8. Wentworth (1924)'s figure 5, showing a petrified stump partially exposed during Walker Hotel excavations (center right of the photograph).

These specimens are most likely from the Cupressaceae family, in the fossil wood genus *Cupressoxylon*, closely related to modern sequoia and bald cypress (P. Kranz, pers. comm., 2004). *Cupressoxylon* is the most common Early Cretaceous-aged fossil wood in the National Capital region.

ROCK CREEK PARK (ROCR)

One large fossil, discovered outside of the park, is on display at the ROCR Nature Center and Planetarium (S. Berger, pers. comm., 2004). The three-foot (1 m) tall specimen of petrified wood was discovered during excavation for the Ronald Reagan Building and International Trade Center, located in the Federal Triangle just north of the National Mall. According to its label, the specimen has been identified as a 100-million year old cypress tree. Cypress tree fossils are common in Early Cretaceous Potomac Group sediments (approximately 100 million years old) throughout Washington D.C. and the surrounding area. Petrified logs, specifically cypress, have also been found in younger Pleistocene swamp deposits in Washington, D.C. as described in the Presidents Park section of this report.

Additionally, ROCR has a fossil fern, *Pecopteris* sp. in their collections (catalogued as ROCR-464). This specimen comes from the lower Pennsylvanian Kerbs Group in Wagoner Co., Oklahoma. The catalog records for this specimen does not provide any information regarding how or why this fossil plant was added to the park collection. The assumption is that the fossil plant was part of a teaching collection available for education at the Nature Center

WASHINGTON MONUMENT (WAMO)

The 193 commemorative stones within WAMO serve as a virtual geologic tour of the United States, as each state, and many organizations, contributed unique stones from their respective states. A number of these stones are fossiliferous. Sonya Berger (National Mall Ranger), Vincent Santucci, and Jason Kenworthy performed an initial inventory of fossils within the commemorative stones in July of 2004. The Arizona Memorial Stone was identified by Berger, Santucci, and Kenworthy as the single memorial stone to contain plant fossils. Future observations may identify additional memorial stones that contain paleobotanical material. The WAMO website (National Park Service, 2003) contains basic information about all 193 stones.

Arizona's state stone is located on the 98-m (320-ft) level and is the most dramatic of the fossil-bearing commemorative stones. The stone consists of three large sections of one petrified log with the state's name engraved across them (Fig. 10). The log, weighing approximately 2,722 kg (6,000 pounds) when installed in the monument, was originally collected near Chalcedony Forest around Holbrook, Arizona (National Park Service, 2003). Numerous outstanding examples of the same type of Triassic-aged petrified wood (*Araucarioxylon arizonicum*) in the Holbrook area led to the creation of Petrified Forest National Monument (PEFO; now a national park) in 1906. The log that is now the commemorative stone was collected outside of PEFO some time prior to 1920, and

FIGURE 9. **A**, Petrified bald cypress log found in Prince William Forest Park (PRWI) outside the Visitor Center, with a modern bald cypress tree planted next to it (at left). **B**, Close up view of the petrified wood.

was dedicated by President Calvin Coolidge at WAMO on April 15, 1924 (National Park Service, 2003; Author unknown, 1924a, 1924b). A copy of paleontologist Frank H. Knowlton's publication on the petrified wood of Arizona (likely Knowlton, 1889) is incorporated within the stone, as is a photograph of petrified trees near Holbrook (Author unknown, 1924a). Petrified logs like those from PEFO rarely have any original woody material. It has been replaced by minerals such as quartz, with various iron-rich minerals creating the rainbow of colors. Examples of *Araucarioxylon arizonicum* petrified wood are visible outside at the National Mall entrance to the Smithsonian National Museum of Natural History.

FIGURE 10. Arizona State Stone in the wall of the Washington Monument which contains specimens of *Araucarioxylon* from the famous Petrified Forest of Arizona.

ACKNOWLEDGEMENTS

We are grateful to a number of individuals who contributed to our research involving paleobotanical resources from the national parks of the National Capital Region. For nearly a decade, G. Mora-Bourgeoise (Center for Urban Ecology) has been a strong advocate for the paleontological resources in National Capital Region and has been instrumental in sponsoring several paleontology interns and guest scientists in the region. Three outstanding GeoCorps paleontologists, E. Clites, K. Loughney, and I. Carabajal, supported paleontological inventory and management at Chesapeake and Ohio Canal National Historical Park. Many thanks to M. Carter, C. Stubbs, S. Bell, and B. Carlstrom for their tremendous support of paleontology at CHOH. A number of individuals at Prince William Forest Park including: P. Petersen, L. Cohen, J. LaVelle, and J. Volonski, have assisted our work on the petrified wood from the park. Thanks to K. Birmingham from NACE for sharing information on the fossil cone impression discovered during an archeological project at Monocacy National Battlefield. Additional thanks are extended to S. Berger for providing a tour of the State Stones of the Washington Monument. We extend our appreciation to J. Winegarth and A. Telfer from the Smithsonian National Museum of Natural History for assistance with viewing fossil collections from Fort Foote. Finally, we extend a special thanks to J. Kenworthy (NPS Geologic Resources Division) for his important and valuable paleontological resource inventory work for the parks in the National Capital Region.

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ARTICLE

ARROYO DEL VIZCAÍNO SITE, SAUCE, URUGUAY: FIELDWORK, RESEARCH, CONSERVATION, EXHIBITION, EDUCATION

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ABSTRAT—Discovered in 1997 during a severe drought, the Arroyo del Vizcaíno site is a richly fossiliferous Pleistocene locality usually covered by waters in a stream near the town of Sauce, Uruguay. Some of the bones show marks with features consistent with those made by human tools. Radiocarbon dates yielded an unexpectedly old age, ca. 30,000 years before present, which makes it the oldest date for a site with human evidence in the Americas. Apart from its scientific importance, several activities are in progress or planned to share this knowledge of the site with the general public. These plans include the creation of a museum where the recovered material will be kept and exhibited, which will also serve as a place for research and cultural events. Additionally, a project is being developed to involve the local high school students (and, through them, also their families) to expand community awareness of the value of the discovery, both in terms of its contribution to scientific knowledge, and as an important part of their cultural heritage.

INTRODUCTION

The Arroyo del Vizcaíno site (Fariña et al., 2014; www.arroyodelvizcaino.org) is located near the town of Sauce, Canelones, Uruguay (Fig. 1). In 1997, the Vizcaíno stream, used by the local farmers to irrigate their crops, dried up due to a severe drought. As a result, numerous remains of the Pleistocene South American megafauna (Fariña et al., 2013) were exposed in its bed. Most of the bones belong to the gigantic sloth *Lestodon*, but a few remains of the South American ungulate *Toxodon* and scutes of three genera of glyptodonts (*Glyptodon*, *Doedicurus*, and *Panochthus*) were also found (Fig. 2). Many of these remains were gathered by students of the local high school (then Liceo de Sauce, now Liceo Nº 1 de Sauce) under the guidance of some of their teachers.

Fourteen years passed before formal excavations were initiated. In 2011 and 2012 professional excavations were undertaken by our team, composed of palaeontologists, geologists, and archaeologists. Our work confirmed that this is a most important paleontological site, in which fossil bones are counted by the thousands. Additionally, some of the bones show marks with interesting features suggesting human tool use while the age is unexpectedly old (see below). Several projects, including research, exhibition plans, and outreach were developed.

FIELDWORK

In June 2009, the Intendencia de Canelones (i.e., the regional authority, equivalent to that of a province or a state in federal countries) provided the machinery to build a bypass and divert the course of the stream (Fig. 3). In March 2011 weather conditions were finally suitable for excavations to start at the site. With the help of members of the 14th Battalion of the Uruguayan Army, the stream was dammed with bags of soil and the water was pumped out (Fig. 4).

A 30 m2 (320 ft2) area containing fossils was exposed and this area was divided with rope grid into areas of 1 m2 (11 ft2) (Fig. 5). Collections, restricted only to those remains that looked more vulnerable, were then mapped for each square.

In the campsite, the material that was removed was provisionally classified and catalogued. The elements were saved with tags in plastic bags (Fig. 6). Over 200 remains were then cleaned along with other lab treatments. When the excavation finished, the outcrop, with its thousands of remains still in place, was carefully covered with geocloth (Fig. 7), to protect the bones from natural damage as well as possible (although unlikely) pillage.

In January 2012, a second more systematic excavation was carried out by the team. Given the great number of fossils on site, an area of only 12 m2 (130 ft2) was opened. A rope grid was built again and collecting started. This area of the site had a great density of bones (Fig. 8), rendering their excavation and extraction very difficult. After 12 days in the field, due to weather conditions the available time ran short, and again many bones could not be removed from that area. However, over 500 fossils were extracted in 2012, and again they were primarily catalogued in the field. As in 2011, after the excavation, the site was covered in geocloth and the water was let in again to cover the site.

RESEARCH

Arribas et al. (2001) first published a description of a marked clavicle. A surprisingly old age of about 30,000 years was found for that clavicle and an associated rib (Fariña and Castilla, 2007). A general account on the South American megafauna (Fariña et al., 2013) devotes several pages to the site, while the biogeochemistry of some of the bones shed light on the fauna's ecological preferences (Czerwonogora et al., 2011).

Fariña et al. (2014) fully described the site and its exceptional character was stressed. More than a thousand bones have been documented, belonging to 27 individuals. The fauna includes three species of ground sloths

FIGURE 1. Map of Uruguay with the location of the town of Sauce indicated by the square marker.

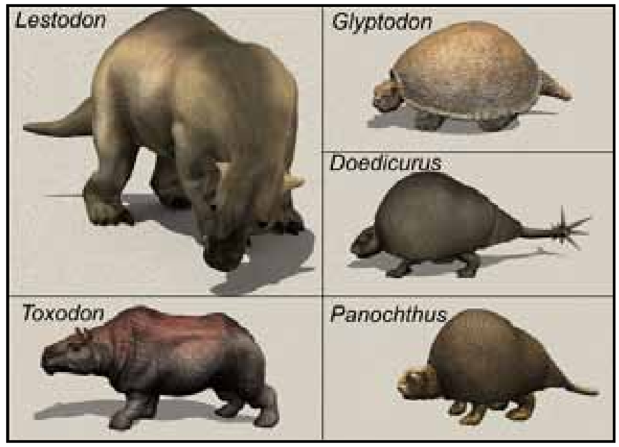

FIGURE 2. Reconstruction of animals belonging to the Pleistocene South American megafauna found in the site of Arroyo del Vizcaíno. Based on 3D reconstructions by Mauro Muyano.

(the vast majority of the remains belong to *Lestodon*, but there are some elements of *Glossotherium* and *Mylodon*), three species of glyptodonts (*Glyptodon*, *Doedicurus* and *Panochthus*), the South American ungulate *Toxodon*, a horse, a deer, a proboscidean, and a sabertoothed felid. The taphonomy of the site and its possible geological origin were also described by Fariña et al. (2014), and many new radiocarbon dates were reported that corroborate the previous age findings. Several aspects of the bone distribution, of the anatomical regions represented, and the mortality profile of the individuals found suggest potential human activity—a surprising possibility most strongly supported by the marks studied on 15 of the bones.

CONSERVATION

The authorities of the town of Sauce allowed the team to use a small room in one of the facilities, the local Casa de la Cultura (Fig. 9), to serve as a fossil repository for the bones collected in 1997 that had been previously housed in the local high school. After the excavation of 2011, the bones were moved to a larger room within the building (Fig. 10). The current lab/collection is only a temporary storage solution, because the 20 m2 (220 ft2) room is rather small for our current needs for housing the collection (let alone those that will derive from further collections) and the lack of controlled environmental conditions include severe humidity and structural issues in the storage room. Despite those substandard conditions, systematic efforts have been made in order to guarantee the conservation of the fossils (Shelton, 1994).

Originally, the remains were kept in and on the available furniture in plastic crates, using polyfoam beneath them and plastic to isolate them from the polyfoam (Fig. 11). After the 2012 excavation, the number of bones had grown so dramatically that the original furniture was replaced by more appropriate metal shelves and cupboards donated by the Facultad de Ciencias of the Universidad de la República as part of an agreement between that institution and the local government. Bones were placed in the shelves and cupboards with no specific order until the cataloguing of the whole collection was finished (Fig. 12).

In July 2012, a research and exhibition activity was held in a local venue, called Escaparate (see Exhibition and Figure 13). This event provided an opportunity to address the conservation issues of the collection and to help develop new strategies to improve the state of the specimens. The bones were classified in color categories according to their conservation urgency: black (destroyed specimen, in more than 4–5 pieces, difficult to restore), red (broken specimen, 1 to 4–5 pieces, fixable), yellow (cracked specimen, consolidation needed) and green (no superficial damage). This activity also allowed for more efficient use of the shelves and crates, leaving smaller, more resistant pieces in the crates and larger, unique, rare and fragile pieces on the shelves. Moreover, a specific shelf was used to store a composite complete skeleton of *Lestodon* armatus (as said, by far the most abundant species in the site represented by over 90% of the total remains), to be used for comparison to aid in the identification of broken pieces and research in general. A closed metal cupboard was chosen for cranial and mandible remains (including teeth and ear ossicles). The remaining cupboard was used for storage of laboratory supplies such as chemicals, glassware and books. When the fossils went back to the collection/lab, the space was better distributed and a dehumidifier was bought in order to address some of the relative humidity issues of the room.

All the specimens from the collection were properly catalogued and photographed. The digital catalogue includes taxonomic and anatomical information, location on

FIGURE 3. Heavy machinery opens a secondary course of the Vizcaíno stream to divert water away from the bone bed for the 2011 excavation.

FIGURE 4. Members of the 14th Battalion of the Uruguayan Army pose on top of the dam they built for the 2011 excavation.

the field, the date and time it was extracted, the number of photographs of each specimen, and other relevant information such as its integrity, presence of marks (see Research) and whether it was glued to another piece or was found next to an adjacent bone.

Consolidant Paraloid B-72 was imported and different concentrations were prepared in order to address the conservation needs identified in Escaparate (following Shelton and Chaney, 1994). Currently, the preparators are working on the new catalogue numbers to be painted in the bones, using both Paraloid and India ink. In addition, several of the specimens marked ‘black’ in Escaparate are being restored.

EXHIBITION

In Sauce, the fossils were exhibited in a local venue called Escaparate for one week in July 2012. There, a skeleton of *Lestodon* was mounted on the floor so the visitors could appreciate its size (Fig. 14). In addition, every December, the fossils are exhibited in the annual’s Casa de la Cultura showcase. Currently, some of the specimens are exhibited at a museum in Montevideo, the MAPI (Museo de Arte Precolombino e Indígena).

Plans for a future Paleontological Museum in Sauce are currently being developed. This institution will house these valuable remains, and we hope will develop into a center for research and cultural influence that will contribute to the spread of scientific knowledge. Some plans have been made to utilize a building near the old train station (Fig. 15). The Victorian-style building is a 20-m (66-ft) long, 7-m (23-ft) wide storage facility belonging to the train station. This structure, which is available to repurpose, now belongs to AFE (the Uruguayan state railway company), which has given its preliminary agreement, although the official resolution is still pending. Additionally, authorities have expressed their intention to develop an on-site museum at the Arroyo del Vizcaíno itself. We are presently looking for funding with which to undertake the work necessary to exhibit this material in the most professional way.

EDUCATION

Since the early excavations took place, the team has been concerned with the exhibition of the fossils from the site and the development of educational activities related to them. Initially, the bones were exhibited at the local high school and were used in several projects generated by the teachers, and in many talks given to the students by the team. After the lab/collection was installed in the Casa de la Cultura, many groups of students from local and surrounding elementary and high schools have visited it and received a short presentation about the findings. This has made the site and its fossils better known to the local population.

In 2012 the team created an organized activity to involve local high school students in science and research. Funded by ProCiencia (a state-driven educational program in charge of engaging high school students in science), it involved the teaching of paleontology, palynology, and the increased awareness of the important heritage found at the locality.

FIGURE 5. Grid of 1 m2 (11 ft2) laid over the site to map the excavated fossils.

FIGURE 6. Specimens from the 2011 excavation stored in tagged plastic bags.

FIGURE 7. Covering the fossils left in the site with geocloth after the 2011 excavation.

FIGURE 8. Detail of the site showing how the bones were intermingled.

FIGURE 9. View into the first room assigned to house the material in the Casa de la Cultura de Sauce prior to 2011.

FIGURE 10. Second slightly larger room assigned in 2011 to store the fossils in the Casa de la Cultura de Sauce.

During 2013, eight groups of 15–25 students became 'paleontologists' for a few days through several activities: digging out fossils, specimen identification, interpretation of the fossils, a visit to the lab/collection, and the presentation of a final student-made project. The students excavated replicas of the bones found at Arroyo del Vizcaíno and also from living animals. Each larger group of students was subdivided in 6 groups and each had to extract the material with the techniques used by paleontologists in the field (Fig. 16). The replicas were placed within two wooden boxes filled with sand and a rope grid was created using the sides of the boxes. Each box represented a different fossil locality. One box contained only fossil material, and the other box contained remains of extinct and extant taxa.

In order for the students to identify the bones they collected, the team created large sheets with information about the animals, pictures of their bones, life reconstructions, and a size comparison with humans. The team helped the students with the identification but made sure they came to their own conclusions with logic (Fig. 17).

Two different pollen samples were also analysed by the students, each belonging to one of the wooden boxes in order to make comparisons about the vegetation present in each 'site'. The samples were created using autochthonous trees, bushes, and grasses, keeping in mind the possible environments that could have dominated the area in the past 30,000 years. Informative sheets were also created to aid the identification of the pollen grains.

The students that worked in the 'oldest' box had only replicas of the bones from Arroyo del Vizcaíno and pollen indicative of an open environment, whereas the others had a 'younger site' with several smaller taxa and pollen evidence of a forest-like environment. They discussed their findings and came to these conclusions by themselves. They also created hypothesis explaining what could have happened between those times for the vegetation and animals to have changed so drastically.

The trip to the lab/collection was a good way to teach the students how we work in the field and how we store the fossils recovered. After watching a video of the excavations, they were shown the collection and all the improvements made in the last few months (Fig. 18). The goals of showing the fossils to the students were to make them realize how important the site is for science, and also to help foster pride in their community.

The students, working in groups, then elaborated projects of their choice that conveyed what they had learned. Projects included two theatrical plays, scale models, different types of souvenirs to give to the visitors, information sheets and two actual-scale silhouettes of a glyptodont and a giant sloth for people to compare themselves with and take photographs (Fig. 19). The projects created by the students were presented to the local community in an event attended by over 100 people in a local club (Sauce Basketball Club), and the students were given certificates of 'amateur palaeontologists'.

The response from the teachers and the students was very positive. Both groups expressed their interest in activities like these and wanted to do more. Another interesting outcome was the positive reaction from the parents and other relatives after seeing their children's projects – they showed gratitude towards the team and were excited about their children's enthusiasm. The team plans to continue developing other educational activities with local students as well as with students from other cities and towns of the country.

FINAL REMARKS

Even though the great quantity of fossils already extracted—and those still lying in the depths of the Vizcaíno stream—ensure there will be work for many years ahead (thus the enormous importance of the site), there are also signs that lead us to propose humans left their imprint on some of them—such as human-made marks found on a collarbone, a rib and other bones. As if this were not enough, radiocarbon dating in several labs, with diverse procedures and on varied remains (bone as well as wood) shows the fossils to be surprisingly old for human-modified bone, going back nearly 30,000 years. These results would double the accepted time of peopling of the Americas, excluding Alaska.

FIGURE 11. Fossils being identified. They were set on polyfoam with its tag and plastic bag in between.

FIGURE 12. One of us (MDG) reconstructs a broken femur of the giant sloth *Lestodon*. Shelves with fossils in the background.

FIGURE 13. Escaparate, a venue in Sauce where musical and theatre shows take place. During a week in July 2012, all the fossils collected in the Arroyo del Vizcaíno site were displayed there.

FIGURE 14. Team member Sebastián Tambusso lies besides a reconstructed composite skeleton of the giant sloth *Lestodon*.

FIGURE 15. Building associated with the train station in Sauce, planned to be used for the future museum.

FIGURE 16. Students of the Sauce high school digging for fossils in a sand box.

FIGURE 17. Team member Sebastián Tambusso helping the students with the identification of the fossil replicas they collected from the sand boxes.

FIGURE 18. Team member Luciano Varela showing the fossils in the current lab/collection.

FIGURE 19. A group of proud Sauce high school students show their project, a diorama of the Arroyo del Vizcaíno site as they conceived it.

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ARTICLE

PRESERVING THE FALLS OF THE OHIO'S FOSSIL BEDS: A SUCCESSFUL INTER-GOVERNMENTAL EFFORT

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ABSTRACT—The Falls of the Ohio State Park was established as a partnership with the U. S. Army Corps of Engineers and other community organizations to preserve, protect and interpret the Devonian fossil beds, the largest of its type in North America with easy public access. It is located in the midst of a major metropolitan area and is used as an educational resource by schools and the public at large.

THE SIGNIFICANCE OF THE FALLS FOSSIL BEDS

The fossil beds at the Falls of the Ohio (Fig. 1) have been known since the first European explorers came down the Ohio River. Evidence of fossil collection by earlier Native Peoples is documented by specimens in the Guernsey collection collected in a 1939–1940 excavation (Guernsey, 1942). The original "Falls" were a rapids dropping 8 m over 4 km (26 ft over 2.5 miles) through fossiliferous bedrock. Before engineering changes to accommodate a large system of locks and hydroelectric power plant (Lock and Dam 41, now called the McAlpine Locks and Dam), the exposed fossil beds covered nearly 809 hectares (2,000 acres). Today, under low water conditions, about 89 hectares (220 acres) of rich fossil-bearing rock may be seen.

The rock strata include the top of the Louisville Limestone (Wenlockian, Silurian) in the middle of the channel, but dominantly the Jeffersonville Limestone (Emsian and Eifelian, Devonian). Exposures of Sellersburg (North Vernon) Limestone (Givetian, Devonian) were present on the western side, with only minor exposures visible today. More than 600 species of Devonian marine invertebrates have been identified at the Falls of the Ohio and many are type specimens.

Perkins (1963) divided the Jeffersonville Limestone into five faunal zones, from lowest to highest the coral zone, *Amphipora* zone, *Brevispirifer* zone, bryozoan–brachiopod zone, and *Paraspirifer* zone. The coral zone was divided by Conkin and Conkin (1976, 1980) into the lower and upper coral zone. Oliver (1958) recognized typical Emsian (Lower Devonian) corals in the lower coral zone and Eifelian (Middle Devonian) corals in the upper coral zone.

The earliest published studies of fossils at the Falls include Rafinesque and Clifford (1820) and Lesueur (1821). Other significant studies include d'Orbigny (1850), Edwards and Haime (1850), James Hall (1876, 1882, 1884), Rominger (1876), Davis (1887), Nettelroth (1889), and Kindle (1901). The list is long, but little paleontological research has been published since Stumm (1964). Most recent work has focused on stratigraphy, primarily Perkins (1963) and a series of publications by Conkin and Conkin (1976, 1979, 1980, 1984) and Conkin et al (1998). For the general public, the Kentucky Geological Survey published Fossil Beds at the Falls of the Ohio (Greb et al, 1993). A substantially revised version will be published soon. Figure 2 is a map from Greb et al. (1993) and is used with permission.

Kissling and Lineback (1967) published the first distribution study of the largest corals and stromatoporoids. The coral beds at the Falls are one of the few places in the world where visitors can "dry snorkel" and see fossils preserved in a contemporaneous multi-acre bedding plane deposit of an extremely short timeframe. The Ohio River covers the coral beds (also called the lower fossil beds) from December through April in a typical year. May through July have intermittent exposure, while August through November they are usually accessible. The upper fossil beds (above the *Amphipora* zone) may be explored except in times of highest water, which is intermittent from December through June depending on precipitation in the middle and upper Ohio Valley.

A BRIEF HISTORY OF PRESERVATION EFFORTS

Establishing the Falls of the Ohio National Wildlife Conservation Area

The designation of the Falls of the Ohio as a Wildlife Conservation Area (Fig. 3) was preceded by many years of interest in formulating a means for protection and management of the resources there. Although the Falls was designated a National Natural Landmark by the United States Department of the Interior in 1966, the action provided no protective measures and fossils continued to be chipped off and taken by the public with no repercussions. In 1968, the National Park Service recommended the establishment of a commission composed of members from Kentucky and Indiana that would administer the area, but this proposal was not fully implemented. After further studies by the U.S. Department of Fish & Wildlife and the National Park Service, and continued strong public interest in providing for the protection and management of the area, federal legislation (Public Law 97-137) was passed in December 1981 designating the area as the Falls of the Ohio National Wildlife Conservation Area (WCA) and placing responsibility for administration of the area

FIGURE 1. View of the Falls of the Ohio fossil beds and Interpretive Center, facing west (United States Army Corps of Engineers photo).

with the United States Army Corps of Engineers (USACE) in consultation with the Department of the Interior. The USACE was chosen as the managing agency due to their long involvement in the area (U.S. Army Corps of Engineers, Louisville District, 1984).

In the river's natural state, boats could only traverse the falls during periods of high water, so the area became a stopping point while goods were unloaded and portaged. When there was enough water, boats could attempt to run one of three chutes, or passages, through the Falls, but this required expertise and boats often wrecked during the attempt. In 1830, the 3.1 km (1.9 mile) privately owned and operated Portland Canal with a three flight lock at the lower end was finished. The Corps of Engineers was given responsibility of the existing navigation facilities at the Falls in 1874. This was the first navigation lock that the Corps of Engineers operated. The first dam constructed in the area was built of timber and completed in 1879 in order to improve navigation through the canal. It included wicket gates that could be raised to increase the pool, or lowered to allow boats to cross over and avoid the locks during periods of high water. Over the years many additions and improvements have been made to the McAlpine Lock and Dam structure, giving it the look it has today (Johnson and Parrish, 2007). At normal pools, there is a drop of 11 m (37 ft) between the upper, McAlpine pool, and the lower, Cannelton pool. The exposed fossil beds are located in the Cannelton pool below McAlpine Dam.

After passage of PL 97-137, the Department of the Interior was given one year to establish and publish a boundary for the WCA; the final boundary was published on August 12, 1982 in the Federal Register.

The USACE then had to decide how much land within the boundary needed to be purchased as fee simple property (as opposed to merely placing a conservation easement, for example, on the property). The concept of 'Navigational Servitude'—rights of the U.S. Government to regulate navigational waters for the purpose of interstate or foreign commerce—was discussed. It was proposed to use this means to protect the area of the Falls that lies below the ordinary high water line, but since PL 97-137 deals with wildlife conservation and protection of the fossil beds and not navigation, it was decided that the government needed to acquire fee simple title to the area so as to ensure authority over the area (U.S. Army Corps of Engineers, Louisville District, 1984).

The WCA covers approximately 570 hectares (1,400 acres) of land and water, and is located in the Ohio River immediately downstream of the Pennsylvania Central Railroad Bridge (now the Louisville & Indiana RR Bridge) and the upper Tainter gates and dam of McAlpine Locks and Dam. The downstream boundary is located at the Kentucky and Indiana Railroad Bridge. The WCA is an oasis in the middle of the metropolitan areas of Louisville, Ken-

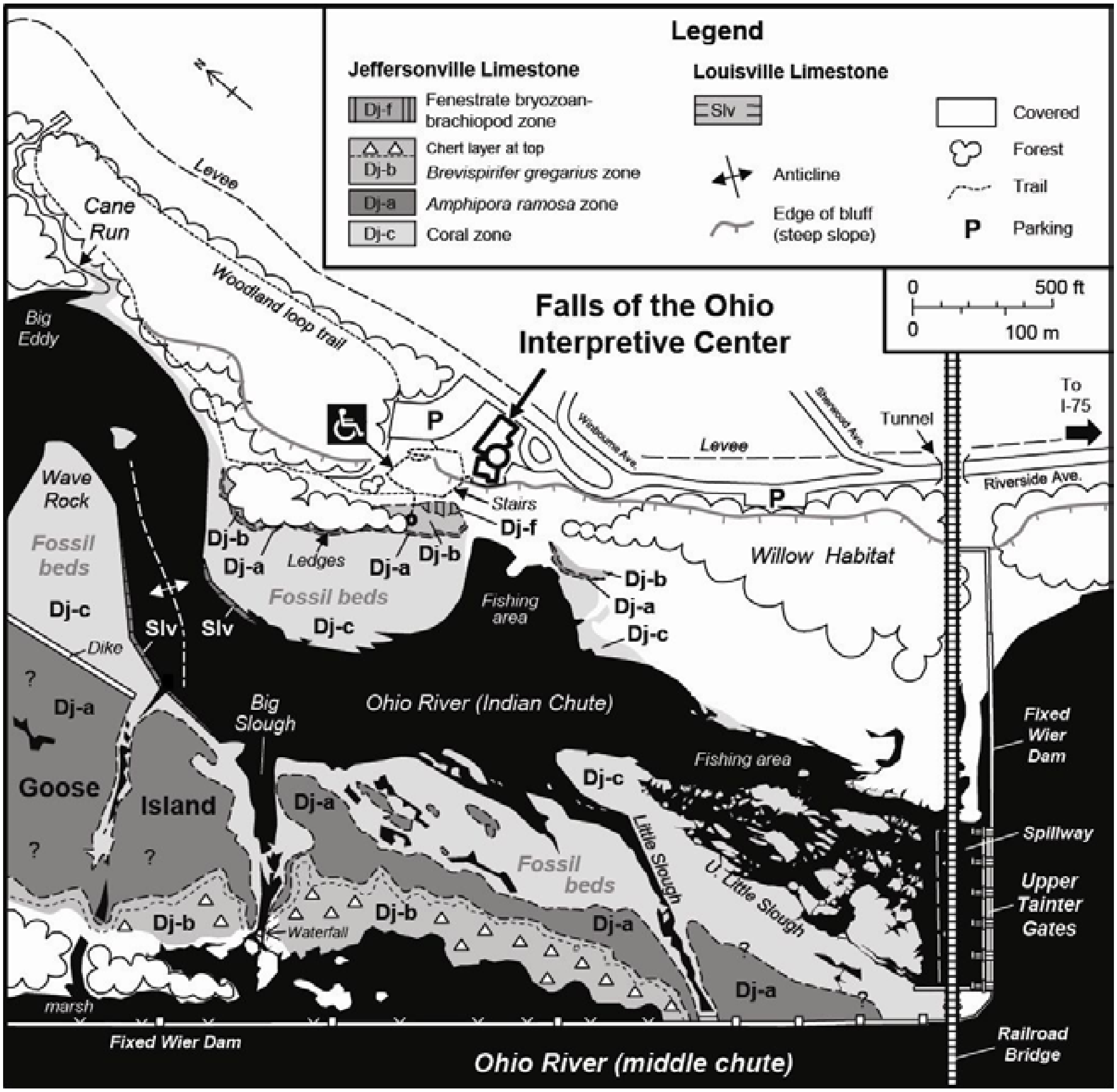

FIGURE 2. A geological map of the Falls of the Ohio fossil beds (from Greb et al., 1993).

tucky, and Jeffersonville, Clarksville, and New Albany, Indiana. The fossil bed covers approximately 89 hectares (220 acres) when the river is at normal pool elevation. The Indiana boundary of the project was set at 1.5 m (5 ft) above the Ordinary High Water mark (elevation 126 m [413 ft]). The boundary on the Kentucky side follows the existing Government boundary for the McAlpine Locks and Dam project. The normal pool elevation of Cannelton Dam is 117 m (383 ft) above sea level or 9 m (30 ft) below the ordinary high water elevation.

The Corps of Engineers then formulated regulations to govern the protection, use, and management of the WCA, which were initially published in the December 28, 1982 Federal Register. Final regulations were published in the Sept. 9, 1983 Federal Register (Title 36 CFR Part 331, Regulations Governing the Protection, Use and Management of the Falls of the Ohio National Wildlife Conservation Area, Kentucky and Indiana, as published as a final rule in the Federal Register, Vol. 48, No. 176, Sept. 9, 1983). The Corps obtains only proprietary (ownership) interests when purchasing the land, so individual state and local laws still apply as well.

Section 203 of Public Law 97-137 (U.S. Army Corps of Engineers, Louisville District, 1984) states the purposes of the Falls of the Ohio National Wildlife Conservation Area are:

“1. to protect wildlife populations and habitats in their natural diversity including, but not limited to, bald eagle,

FIGURE 3. Boundaries of the National Wildlife Conservation Area (United States Army Corps of Engineers photo).

peregrine falcon, Canada geese, mallard, gadwall, blue-winged teal, black duck, American widgeon, and wood duck;

2. to conserve fish populations in their natural diversity including, but not limited to, shad, shiner, crappie, large-mouth bass, striped bass and channel catfish;

3. to ensure, to the maximum extent practicable and in a manner consistent with paragraphs 1 and 2 and compatible with navigation on the Ohio River and operation of the McAlpine locks and dam, the necessary water quantity within the wildlife conservation area;

4. to protect the fossilized coral reef as a unique paleontological feature; and

5. to provide opportunities for scientific research and interpretive and environmental uses and fish and wildlife oriented recreational uses."

A Master Plan was developed in 1984 to "describe how project lands, waters and other resources could be developed, managed and used in the best public interest while maintaining the goals for which the project was established" (US Army Corps of Engineers, Louisville District, 1984:3). In an effort to best manage and allow for interpretation of the rich natural resources of the area, the USACE and the Indiana Department of Natural Resources (IDNR) have formed a partnership at the Falls. The USACE entered into a lease agreement with the IDNR in 1990 to allow for creation of the Falls of the Ohio Indiana State Park. The park is comprised of 24 hectares (60 acres) leased from the Corps, along with 34 additional hectares (85 acres) acquired by the IDNR for the interpretive center, hiking trails, picnicking, and so forth.

The Corps coordinates with IDNR to allow an annual period for foot access to the outer fossil beds. Each year from August 15 to October 15, river conditions permitting, all the upper Tainter gates are closed, allowing people to walk from the Indiana shoreline across the sill of the gates

FIGURE 4. Falls of the Ohio State Park Interpretive Center (Indiana Department of Natural Resources photo).

and out onto the outer fossil beds. Throughout the year, signage and warning sirens alert the public to imminent gate operations.

The Falls of the Ohio State Park's First 20 Years

Although the Falls of the Ohio has been historically associated with Louisville, Kentucky by virtue of the commonwealth border established in 1792, access has been primarily from Indiana due to the construction of the Portland Canal in 1830 and the Z-shaped Dam 41 in the 1920s. In the early 1960s, the McAlpine Dam replaced the old wicket system described in the proceeding section. Access to the Falls of the Ohio from the Indiana shoreline has been the norm since the early 19th century.

The Falls of the Ohio State Park was established in 1990 after a community effort led by the Clarksville Riverfront Foundation, a group established for that purpose. Through fundraising and much hard work by many volunteers and staff, a 1,486 m2 (16,000 ft2) Interpretive Center was built, featuring a 93 m2 (1,000 ft2) rotunda, 279 m2 (3,000 ft2) exhibit gallery, with a classroom/library accommodating 30 students at a time, an indoor river observation room, wildlife observation room, and small gift shop (Fig. 4). The exterior observation deck has a commanding view of the Ohio River: fossil beds or rapids are visible, depending on the water level. This is Indiana's smallest state park, with very little land actually owned by the state. Most is owned by the USACE, the Town of Clarksville, and the Levee Authority.

After the Interpretive Center was opened in 1994, two full-time naturalists began presenting programs, freeing teachers and staff at the science and history museum from this task. Since 1994, about 300,000 students (K–16) have visited and most had programs led by an interpretive naturalist (Fig. 5). They are on the fossil beds (hikes or fossil labs) May through mid-November and indoors (fossil labs) from mid-November through April.

Four 'Museum to Go' loaner kits were created to provide hands-on resources for classrooms in the area. They include: (1) fossils; (2) rocks; (3) minerals and rocks; and (4) prehistoric tools. They are not designed to be shipped; educators must pick them up and return to the Interpretive Center. The loan period is two weeks and is renewable.

The exhibits were largely 'hands-off' with dioramas, interpretive panels, videos, and copious amounts of text. In 1997 two 2,800 L (750 gal) marine aquariums allowing visitors to compare the Devonian sea with modern life and a 7,600 L (2,000 gal) Ohio River life aquarium were added. The marine aquariums were taken offline in 2010 and the Ohio River fish aquarium in 2014 due to maintenance issues. In 2002, 'Kid's Corner' was created to allow younger children to enjoy their visit, because the main

FIGURE 5. High school students scrub the coral zone to remove sediment buildup from regular flooding and thus re-expose the corals to view (Indiana Department of Natural Resources photo).

gallery was ‘over their heads’ literally and figuratively. The supporting foundation changed its name to Falls of the Ohio Foundation and has been working towards replacing the exhibits since 2007. The original lobby exhibits were replaced with glass sculptures suspended from the ceiling in 2011. New exhibits in our main gallery are in the final design stage with installation planned for 2015.

Temporary exhibits, mostly assembled in-house, were set up every four months from 1995 through 2009. Most involved loans from other museums and individuals, some with components from park collections. Paleontology-themed exhibits included dinosaurs, history of land plants, trace fossils, and focus on various animal groups (cnidarians, echinoderms, arthropods, sharks, animals with tentacles, etc.). Some included marine aquariums. Today, two display cases are used for year-long exhibits and another pair of smaller cases travel to libraries in the Louisville metro region.

An earth-science-themed special event has been held at the park annually since 1995. The largest was the two-day Falls Fossil Festival held from 1995 to 2011 with vendors, guest speakers, collecting piles, hikes, children's craft activities, and participation of local amateur geology clubs. In 2012 and 2013 it was replaced by Earth Discovery Day, a one-day event without vendors. In 2014 that will be combined with Archaeology Day as ‘Digging the Past’ as we have reduced special events in preparation for the Interpretive Center shutdown. The Interpretive Center will have to be shut down in 2015 for a period of several months to enable the removal of old exhibits and subsequent installation of new ones. In 2012 an annual fossil symposium was established, geared for serious amateur paleontologists.

To reduce the collecting urge of visitors (visitors have collected at the site for 200+ years), we have brought in two collecting piles: one with Middle Silurian Waldron Shale fossils from a quarry located several miles from the park; the second is a mineral pile from the fluorite mines of southern Illinois containing four mineral types, two of which are very colorful. The collecting piles are turned periodically, restocked annually, and are currently free. However, plans are to make the piles larger and change a nominal daily fee. Both of the original source areas of the imported rock are inaccessible to collectors, so the collecting piles are very popular with visitors and school groups. Plans are underway to develop an educational program for schools involving Waldron Shale material sent to the classroom. Students will collect specimens from the material and then identify, analyze, and upload data about the specimens to a website created to facilitate the project.

The Falls of the Ohio State Park website (www.fallsoftheohio.org) was created through the Falls of the Ohio Foundation in 1998. It is separate from the website for the Indiana Department of Natural Resources, Division of State Parks and Reservoirs, which supports all 32 properties. This website contains over 500 pages and more than 3,000 images (and growing) with resources for visitors, educators, children, amateur naturalists, and geologists. It averages more than 200,000 page views per year.

The George Rogers Clark home site became part of the National Register of Historic Places in 1974 and a small parcel of state land became the George Rogers Clark State Historic Site a decade later. It was incorporated into the Falls of the Ohio State Park in 1990. A boat ramp was placed adjacent to the home site in 1990 to provide access to the river and is used by fishermen and teams practicing swift water rescue. A log cabin (ca. 1830) of the approximate dimensions of Clark's cabin was erected in 2001. It is designated as a ‘representation’ of Clark's cabin. George Rogers Clark, a captain/general in the Revolutionary War, retired to this site 1803–1809. In 2003, the eastern legacy of the Meriwether Lewis and William Clark bicentennial commemoration was held through a National Signature Event. Lewis, Clark, and the “nine young men from Kentucky” departed from the Falls at Mill Creek on October 23, 1803 and returned four years later.

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APPENDIX 1: PHOTOS OF ACTIVITIES AND FOSSILS

Falls Fossil Festival collecting piles looking for Silurian and Devonian fossils from local quarries and minerals from Cave in Rock, Illinois.

Thamnopora limitaris Rominger, a well-preserved branching tabulate coral in the coral zone.

Eridophyllum seriale Edwards & Haime, a colonial rugose coral on the upper fossil beds.

A complete trilobite (*Odontocephalus*) found by a fourth-grade student visiting on a field trip.

Family Paleontology Camp at the on-site quarry collecting Waldron Shale fossils as part of a three-day in-depth experience in the life of a paleontologist.

Exploring the fossil beds in 1920, before the dam flooded most of the Devonian outcrop.

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ARTICLE

LATE PLEISTOCENE FOSSILS AND PUBLIC OUTREACH IN NORTHWEST ALASKA

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ABSTRACT—For thousands of years Native peoples of northwest Alaska have utilized the remains of prehistoric fauna (primarily bone and ivory from Late Pleistocene mammals), as sources of raw material for an array of domestic items, hunting implements, and pieces of art, as well as for trade. This practice of fossil collecting continues to the present and can play a role in the local mixed subsistence/cash-based economy. Unfortunately, these are essentially non-renewable resources and collecting on the scale to satisfy national and international demand can result in damage to the materials and loss of valuable information that is part of our national heritage. That is why collecting from the federal public lands is prohibited by law. Signed into law in 1980, the Alaska National Interest Lands Conservation Act (ANILCA) created a number of new national parklands, including those now covering the fossil-rich northwest portion of the state. ANILCA, along with the earlier Alaska Native Claims Settlement Act (ANCSA), grants Alaska Natives continued subsistence use rights on these public lands, but use rights exclude paleontological specimens. Though local uses center on hunting and fishing activities, it is also not uncommon for bones and ivory to be collected (from public and private lands) and put up for sale, either in their original form or after having been fashioned into objects of art. National Park Service resource managers are taking steps toward bringing more local public awareness to these non-renewable resources through a variety of educational mediums, including public presentations, workshops, and blogs, as well as offering an open door policy in which previously collected items can be brought in and local scientists afforded an opportunity to conduct rudimentary recordation prior to specimens being lost to the market.

A TRADITION OF COLLECTING

Native inhabitants of Alaska have long utilized animal remains discovered on the landscape as sources of raw material for a variety of household items, hunting implements, and pieces of art. It is not unheard of for the remains of a 500 year old pit house in northwest Alaska to contain sections of a 10,000 year old mammoth tusk. The ivory was likely collected from a nearby beach and then taken to the home with portions put to use in a myriad of ways. This tradition of fossil collecting continues to the present with bones and ivory collected (from public and private lands) and put up for sale, either in their original form or after having been fashioned into objects of art. This common activity plays a critical role in the local subsistence, cash based economy (Hardes, in press).

The National Park Service, charged with the stewardship of paleontological remains, seeks an ethical balance between the preservation of all prehistoric finds and particularly those rights of long-term native inhabitants, whose very livelihoods (often for many generations) have involved the collection of these very remains.

Federal regulations are clear about not disturbing or damaging paleontological finds on federal lands. Appropriate management involves federal land managing agencies conducting condition assessments leading to management actions that preserve paleontological resources where possible, or permanently captures and documents the information these resources contain where preservation is not possible.

THE PALEONTOLOGICAL RESOURCES PRESERVATION ACT

For federal managers, the Paleontological Resources Preservation Act (PRPA) provides the authority for the preservation and management of ancient remains. The act also reminds us that collecting these resources from federal lands without the appropriate permits is prohibited. In fact, damage or removal of paleontological resources can lead to conviction and a felony charge. State, federal and Alaska Native corporation land managers each have their own set of rules designed to protect these resources.

GEOLOGIC CONTEXT AND HISTORY

The bedrock geology of the Cape Deceit and Elephant Point localities is characterized by sedimentary rocks, consisting specifically of frost-rived regolith and colluvium. The geologic setting of the Trail Creek Caves locality is more complex because it lies at the intersection of several types of metamorphic rocks, including a chlorite schist and marble with local relict bedding and a York slate which is a very fine grained carbonaceous quartz siltite, slate, graywacke and phyllite (Robinson and Stevens, 1984).

Maximum glaciation in northwest Alaska occurred during the Illinoian period as glaciers engulfed the Noatak and Kobuk River valleys to the east of the Baldwin Peninsula and Kotzebue Sound. These were likely the largest glaciers ever to have existed in northern Alaska. To the south of the valley glaciers and just east of Kotzebue Sound was a vast ice field, covering much of the lowlands around present day Selawik Lake and reaching some 65 m (210 ft) in thickness (Hopkins, 1967). It was the subsequent retreat

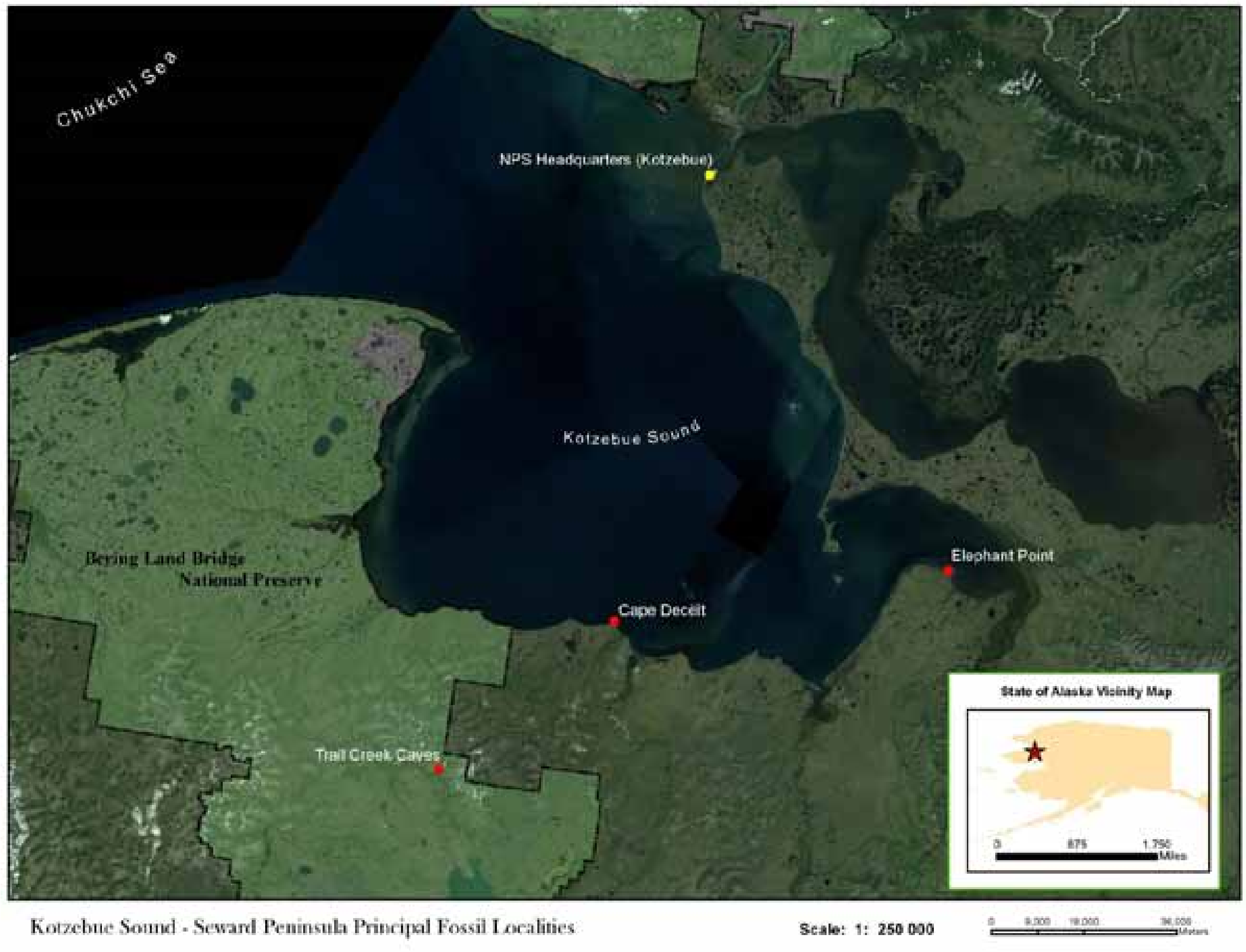

FIGURE 1. Fossil localities mentioned in the text.

of this ice field and the valley glaciers that resulted in widespread eolian loess deposition throughout the region.

During the Sangamon interglacial the climate eased and the accumulation of loess subsided. Subsurface ice wedges began to disappear and sea level rose to some 12 m (40 ft) higher than the present day. Fossiliferous marine deposits exposed along the shores of Kotzebue Sound speak to the irregularity of sea level rise and the multiple transgressions that occurred throughout this period of interglacial climate change.

The Wisconsinan glaciation in the area resulted in lower sea levels, increased occurrences of thaw lakes, and deposition of loess. Loess deposits on the Baldwin Peninsula reached some 10 m (33 ft) in thickness and the Chukchi Sea floor was exposed in its entirety until approximately 14,000–12,000 years ago, subjecting previously submerged sediments to wind erosion (Hopkins, 1967).

The past 10,000 years have brought increasingly warmer temperatures, coinciding with rising sea levels. The landscape, similar to today, was characterized by treeless tundra. “The permafrost table lay near the surface, ice wedges were actively growing and thaw lakes existed in areas underlain by fine-grained sediments” (McCulloch, 1967:111). These conditions of shallow permafrost capped by peat layers create a nearly ideal setting for the preservation of osteological remains.

THE SEWARD PENINSULA/KOTZEBUE SOUND FOSSIL LOCALITY

Pleistocene fossil remains are bountiful in northwest Alaska, with Kotzebue Sound and the Seward Peninsula being particularly rich with bones of this age. Located approximately 68 km (42 miles) south-southeast of the village of Kotzebue in the southeastern corner of Kotzebue Sound and within Eschscholtz Bay is Elephant Point (Fig. 1). The location was named by Captain Beechey in 1826, in order to “mark its vicinity to the place where the fossils were found” (Orth, 1967). First visited in 1816 by Otto von Kotzebue during his exploration of the area, he named the bay for his ship’s physician Dr. Johann Friedrich von Eschscholtz (von Kotzebue, 2013). The location was revisited in 1907 and 1908 by a party from the American Museum of Natural History, who explored the immediate area as well as miles of shoreline and a number of river drainages of the northeastern Seward Peninsula (Quackenbush, 1909). These field examinations resulted in the discovery and recording of osteological remains of woolly mammoth (*Mammuthus primigenius*), horse (*Equus* sp.), steppe bison (*Bison latifrons*), caribou (*Rangifer tarandus*), muskox (*Ovibos moschatus*) helmeted or woodland muskox (*Symbos cavifrons*, now *Bootherium bombifrons*), short-faced bear (*Arctodus simus*), brown bear (*Ursus arctos*), moose (*Alces alces*), beaver (*Castor canadensis*), and wolf (*Canis lupus*) (Quackenbush, 1909; Lent, 1999). All fauna was late Pleistocene or Wisconsin in age (approximately 85,000–11,000 years ago). Woolly mammoth (*Mammuthus primigenius*), horse (*Equus* sp.), and steppe bison (*Bison latifrons*) continue to represent the most commonly found Pleistocene species from the region.

Trail Creek Caves, on the Seward Peninsula, consists of four primary caves and a number of smaller cavities located in limestone cliffs, stretching for some 0.8 km (0.5 miles) along Trail Creek (Fig. 1). The first scientist to visit the location was U.S. Geological Survey and well known Bering Land Bridge geologist David Hopkins, in the summer of 1947. The presence of animal bones along with cultural artifacts prompted archaeological investigations of the site in 1949 (Larsen, 1968). These examinations resulted in the documentation of osteological remains of caribou (*Rangifer tarandus*), moose (*Alces alces*), Dall sheep (*Ovis dalli*), horse (*Equus* sp.), bison (*Bison* sp.), woolly mammoth (*Mammuthus primigenius*) and what Larsen thought were the canine teeth of domestic dog, later reanalyzed by Dixon and colleagues and determined to be deciduous teeth of brown bear (*Ursus arctos*) (Dixon and Smith, 1986; Vinson, 1988). Radiocarbon analysis of bones of bison (*Bison* sp.) and horse (*Equus* sp.) returned dates of 12,070 ± 280 years and 15,750 ± 350 years, respectively, while two mammoth bones were dated to 14,270 ± 950 and 11,360 ± 100 years before present (Larsen, 1968; Vinson, 1988). The faunal assemblage also included a variety of smaller taxa, such as fox (*Vulpes* sp.), hare (*Lepus* sp.), ptarmigan (*Lagopus lagopus*), and an array of small rodents.

Another key fossil locality is Cape Deceit, located near the village of Deering along the southern margin of Kotzebue Sound. As reported by Guthrie and Matthews, the locality consists of a 200–300 m (660–980 ft) stretch of early–late Pleistocene fossil-bearing deposits (Guthrie and Matthews, 1971) (Fig. 1). Identified taxa include wolf (*Canis lupus*), caribou (*Rangifer tarandus*), elk (*Cervus cf. elaphus*), horse (*Equus* sp.), as well as the diminutive forest vole (*Pliomys* sp.), "meadow" vole (*Microtus* sp.) and Hopkins's lemming (*Predicrostonyx hopkinsi*).

Nearly 200 years since the first scientific exploration at Elephant Point, these localities continue to produce fossil remains. However, the region has lacked the level of attention and scientific study of other northern areas such as the Klondike and the Yukon, and is therefore lesser known (Kurten and Anderson, 1980).

WESTERN ARCTIC NATIONAL PARKLANDS OUTREACH EFFORTS

Staff from the National Park Service's Western Arctic National Parklands (WEAR) have begun employing a variety of educational outreach tools in their efforts to bring more attention to local fossil finds and paleontological history, as well as the broader issues related to the significance of fossils on public lands. WEAR is based in Kotzebue, Alaska, and includes Bering Land Bridge National Preserve, Cape Krusenstern National Monument, Kobuk Valley National Park, and Noatak National Preserve.

A number of public osteological workshops have been held at WEAR's Northwest Arctic Heritage Center in Kotzebue. The most recent of these events, Animal Bone Show & Tell in 2013, included bone matching games for children, owl pellet dissection stations, a PowerPoint presentation, and an open house (including snacks and refreshments) geared for residents to bring in their finds and have them identified by our NPS archeologist. This program was staffed by an NPS archeologist, an interpretive ranger, and a wildlife biologist, and though not limited to just 'old' bones, it was considered a success, with several dozen attendees. It is worth noting that advertising posters for this event made it clear that it was "not an opportunity to have items appraised for their potential monetary value".

In September 2013, WEAR cultural resources staff (specifically the author), launched a new blog series, entitled Ice Age Mammals Bones of Northwest Alaska. New monthly posts highlight late Pleistocene bones found in the immediate area, often by local residents. The intent is to share local finds and local knowledge of paleontology in an informal way with all who have internet access, while stressing the importance of not collecting, particularly on Federal lands. These resources are incredibly limited in numbers and once they are damaged or removed from their original locations, much of their educational and scientific data is lost. Documentation of a find is often the most important aspect of fossil related research and collection. Appropriate recordation of a paleontological specimen includes information about the specimen (taxonomic identification, measurements, taphonomy), its location on the landscape (geographic coordinates, stratigraphic position), and the geology of the immediate area. Without this baseline data, the specimen has lost the vast majority of its potential to inform us about the prehistoric past. However, the blog urges individuals to bring in finds already in their possession, even with this lack of provenience, in order that some scientific data may yet be gleaned that will help to further reconstruct the local paleontological past, prior to them entering the market. The blog also resulted in a front page feature story in the Arctic Sounder, the local weekly newspaper.

In January of 2014, the village of Kotzebue hosted its first Community Science Night. Sponsors and presenters included National Geographic, NASA, University of Alaska, Fairbanks, US Fish & Wildlife Service, Alaska Sea

Life Center, and the National Park Service, among others. The night included exhibits with sea creature dissection, DNA extraction, a planetarium, and skull casts and furs of local wildlife. With several hundred in attendance, approximately 150 people participated in the National Park Service's vertebrate osteology-themed booth.

WEAR interpretive staff take part in a weekly morning radio show. Cultural resources managers use this forum to either join in the show directly or supply others in attendance with fossil-related information to be passed along to the public during the broadcast. Radio is a popular means of informal communication in the village of Kotzebue, with informal messages being relayed daily.

In an ongoing effort to educate people about fossil resources, NPS cultural resources staff members maintain an 'open door' policy with the hopes of increasing informal visitation from local residents. This policy, though instituted only about one year ago, has resulted in a slow but steady increase of phone calls and in person visits to the NPS archeologist. Visits have been extremely upbeat with very positive exchanges between NPS and the public. Occasionally an osteological item is brought in and it becomes necessary to address the fact that NPS is not there to assess monetary value of items nor do they condone the collection of paleontological for non-scientific reasons. It is important to note that the NPS headquarters in Kotzebue is surrounded by vast, remote, and open country that includes a patchwork of native allotments as well as 5.6 million ha (13 million acres) administered by the NPS. This landscape holds innumerable Pleistocene age fossils, with only a handful of formal localities currently recorded (Fig. 1). In this light, it would be nearly impossible for local NPS staff to determine the origins of paleontological specimens seen in town, short of those in possession of the finds directly divulging the location.

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ARTICLE

USING GEOGRAPHIC INFORMATION SYSTEM (GIS) TO UPDATE MONTANA GEOLOGY MAPS AND FACILITATE FOSSIL POTENTIAL DATA ANALYSES

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INTRODUCTION

The Bureau of Land Management (BLM) is one of several federal agencies that manage public lands of the United States. Part of active management includes overseeing the fossil resources. With the passage of the Paleontological Resources Preservation Act (PRPA) agencies were directed to manage and protect paleontological resources using scientific principles and expertise. A tool that the BLM uses to do this is the Potential Fossil Yield Classification (PFYC) system. The PFYC is a numerical rank from 1 (low potential) to 5 (very high potential) applied to geologic units, most often at the formation level. These ranks are assigned by BLM personnel with input from other knowledgeable individuals.

In its practical application, the PFYC is intended to help land managers plan where to focus resources during the planning or execution of ground-disturbing activities. The system can also be used by researchers in helping them to focus attention on fossil-bearing rock units. Perhaps more importantly, it can also highlight formations whose fossil potential is little known, pointing toward gaps in our paleontological knowledge.

METHODS

Management plans used by the BLM to inform the actions of resource managers include the PFYC. The PFYC is also important for providing guidance to consulting paleontologists who work for project proponents involving public lands. The system can be used to inform the project proponents of areas of high likelihood for fossil resources so adequate planning can be done to mitigate the irreversible destruction of valued heritage resources. For all these reasons the best quality information is sought.

The BLM amassed Geographic Information System (GIS) geology data for the state of Montana from a variety of sources of varying reliability and provenance. The intent of this project was to locate and integrate the best available GIS data from trusted sources in a user-friendly format. It was also critical that sources provided sufficient metadata to allow users to understand the data's intended uses.

Conceptually it seemed that a simple join between a geodatabase geology feature class that contained rock unit codes and a table, text file, or spreadsheet that also contained rock unit codes (and their respective PFYC values) would be effective. Joining these two data sources—one geospatial, one tabular—would enable map representation and geospatial analyses of features in a particular location in reference to the PFYC rating of the formation(s) in that area of interest. A similar approach was published by Smeins and Grenard (2009).

In compiling all of the maps into a single data set it quickly became clear that different geologists mapped geologic units in a variety of ways, and that was reflected in non-standard codes for rock units. For example, the standard code on one map might include Kb for a rock unit intending to specify Cretaceous (K) Bearpaw Formation (b), while on another map it may have designated Cretaceous (K) basalt (b). In geological terms, these rock types are significantly different and would be given different PFYC ranks.

The Montana Bureau of Mines and Geology (MBMG) is the primary data provider for digital Montana geology data and related reports. The source data were only available in ArcInfo export (.e00) format downloaded in zip files from http://www.mbmg.mtech.edu/gis/gis-datalinks.asp. This format is an older and somewhat cumbersome GIS product to use, but it contained a wealth of very valuable information. The MBMG website also provided links to United States Geological Survey (USGS) .e00 files for areas not covered by MBMG sources. Complete geology data for the state of Montana was spread over 149 individual ArcInfo map coverages. At the start of this project this appeared to be the only reliable data source available—daunting to integrate, but ultimately worth the effort.

The source maps ranged in scale from 1:24,000 for special focus areas to broad sweep 1:250,000 surveys. There were many gaps and overlaps of GIS features within and between these maps when reviewed individually and side-by-side. Some regions had multiple surveys of different scales that had been completed at different times. From a GIS perspective all these data needed to be integrated into a single, contiguous feature class with consistent geology codes if it was going to be effective.

Given that the rock codes in the various maps could indicate very different rock types, we needed to establish a standardized code for every mapped rock unit. In some cases, the original codes from the source data could be used, but in most cases new codes had to be created in order to maintain consistency across the whole data set. For example, one map may show the Woodside Formation, and another map may combine the Woodside and the Dinwoody formations. Similarly, one geologist may have mapped a single formation, whereas another mapped each of its members separately, and a third mapped the units by lithologic character. For all these cases unique codes for

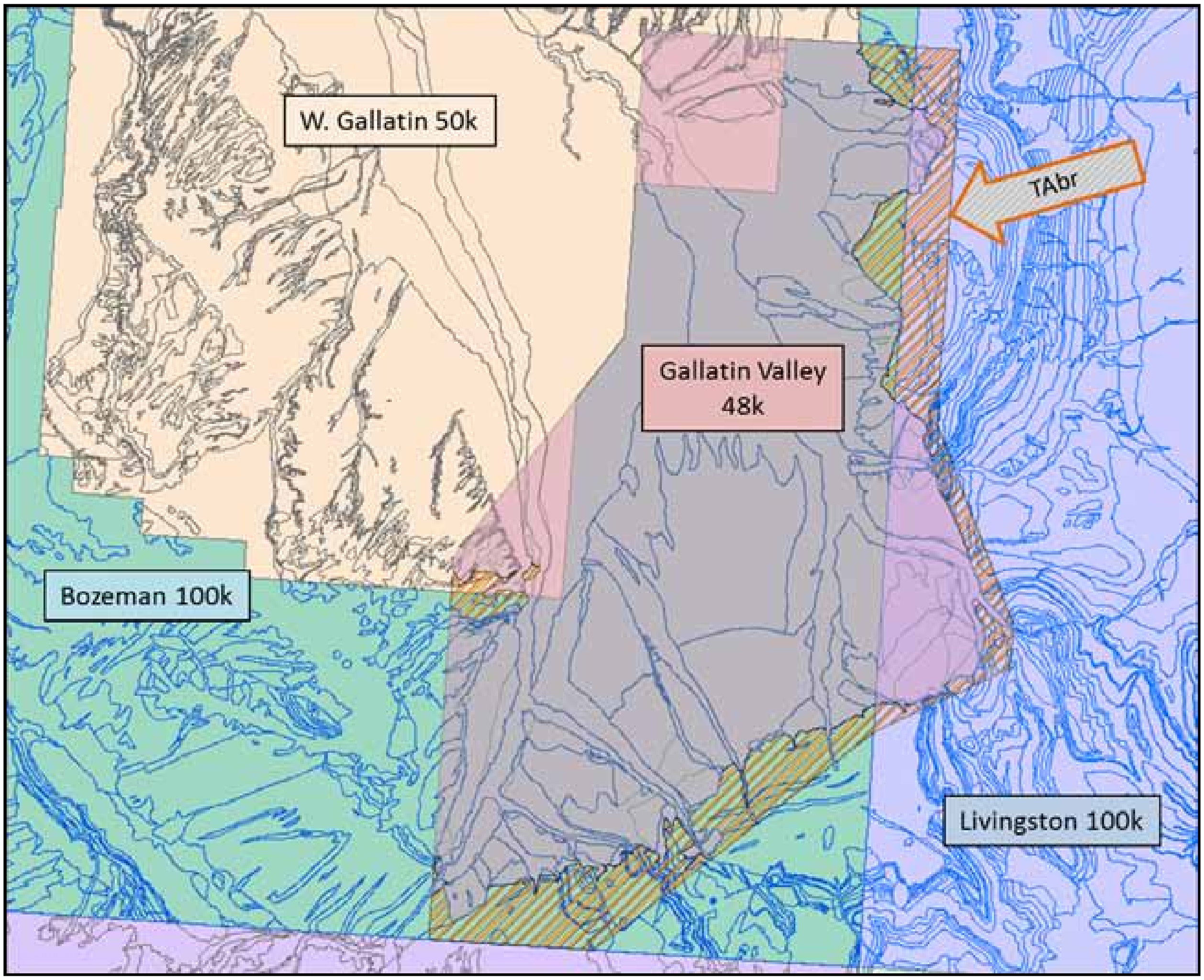

FIGURE 1. Integrating multiple GIS data sources of varying scale and currency required subject matter expert decisions. In this example a preferred 1:48,000 map of Gallatin Valley contained a TAbr (Tertiary to Archean bedrock) polygon that overlapped more detailed information in 1:100,000 scale maps. The TAbr polygon was removed from the overlapping areas.

the geologic units needed to be applied for consistency across the data. In the end, over 1,400 unique rock unit codes were assigned.

The first GIS task was to bring the older ArcInfo coverages into a geodatabase for use with the current version of ArcGIS available at the BLM Montana/Dakotas State Office (MTSO), ArcGIS 10.1. The downloaded files contained information on contacts, faults, folds, strikes, dips, other geologic lines, annotation, etc. It also provided metadata in various forms identifying key points of information about each data source, such as publication date, sources, constraints and caveats for use. The contact data became the basis of the new format GIS polygons, in tandem with the very extensive metadata that was provided. All other data in these files are considered useful for future efforts.

An individual geodatabase feature class was created for each of the survey maps using the contact data from the ArcInfo coverage. These feature classes were named using the map name and the survey scale, i.e. 'alzada_100k.' All attributes that were included in these data were kept and a new field ("NEW_POLY") was added and populated to accommodate the standardized rock unit code to be incorporated into all of the maps. All of these features were reprojected into a custom North American Datum (NAD) 1983 Albers projection used for GIS data in the BLM MTSO. Federal Geographic Data Committee (FGCD) metadata was fully populated for some of these feature classes—the effort to finish them all is still ongoing.

In areas where there were multiple sources available, primacy was given to the largest scale (smallest area) map data. For example, if both a 1:24,000 map and a 1:100,000 map were available, the 1:100,000 map data would be copied and the area of the 1:100,000 data would be cut out and replaced by the 1:24,000 polygons. Similarly, if one map

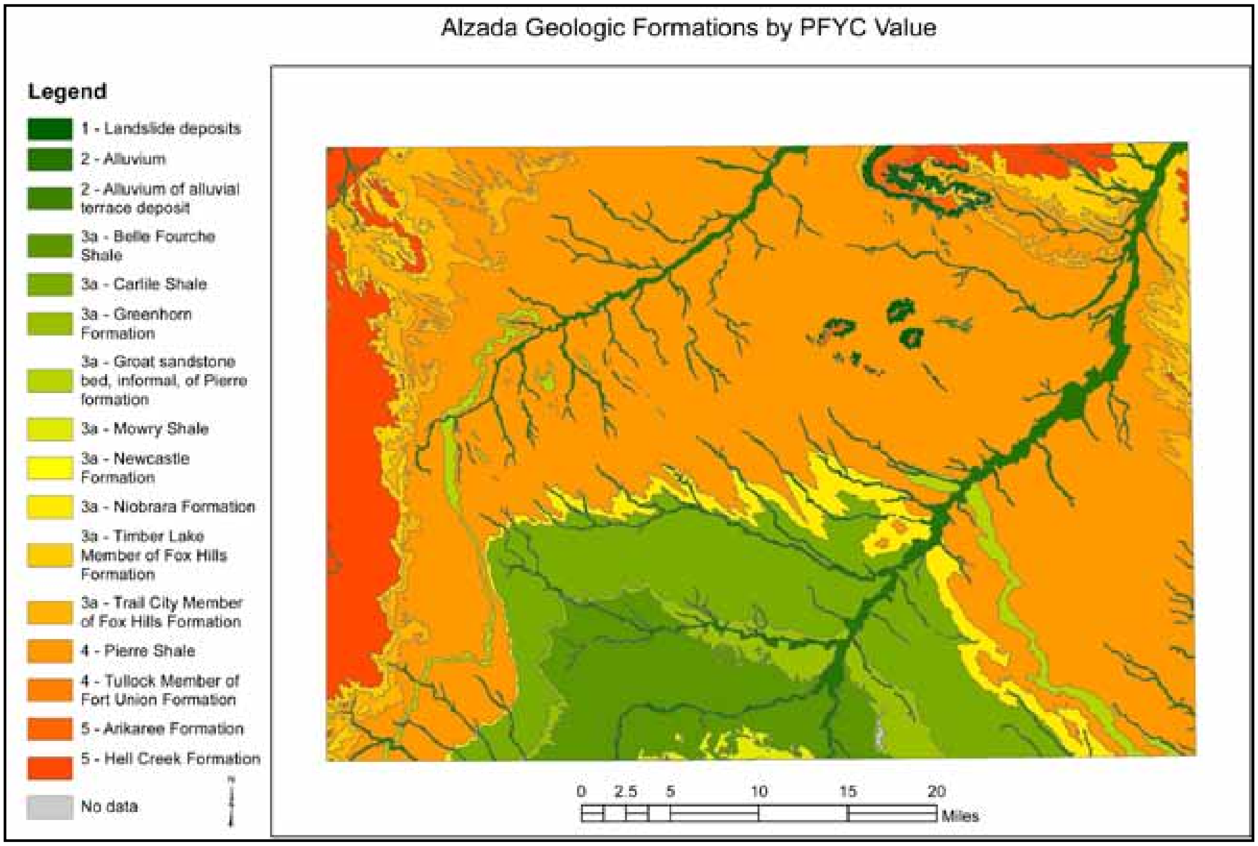

FIGURE 2. The Alzada 1:100,000 scale geology mapped with the Potential Fossil Yield Classification (PFYC) values as an example of visualizing the new composite data set.

of an area included blank or 'no data' areas that were identified with a geology code in an overlapping source, the blank areas were removed regardless of the mapping scale preference. In certain rare circumstances polygons with geology codes from larger scale surveys were removed in favor of more detailed data in overlapping sources (Fig. 1).

The 'jigsaw' of the individual maps of differing scales that had been cut out to fit together were merged into a single feature class. Only the NEW_POLY, original map scale, and calculated acreage attributes were included in this new feature class. This feature class contains approximately 126,500 individual polygons.

After merging the individual maps into a single feature class, a map topology was set up to identify the areas of gaps and overlaps in the feature class. For these data to be most effective in geospatial queries it needs to be continuous. The initial topological error count was somewhere over 31,000; at present it is under 20,000, so edits are ongoing. Most of these gaps or overlaps are very small and do not significantly affect the visual or analytical utility of the data as they are generally used.

The merged data were then dissolved into another data set so that there is only one polygon for each NEW_POLYCODE (geologic code) value. A version which dissolved the features on both the geologic code and the map scale was initially created but the scale attribute was later considered to be unnecessary. The current dissolved feature class contains the NEW_POLY attribute and calculated acreage to facilitate area calculations and contains 1,226 polygons, approximately one-tenth the number of the merged polygon feature class. As the topology errors are corrected in the merged feature class the dissolved feature class will be regenerated for improved overall data quality.

A GIS layer was created showing the boundaries of the individual data sources that were going to be combined into a single feature class. This was done to preserve the ability of a user to go back to the original source to answer any questions about the information presented in the combined data. This will also facilitate ongoing maintenance and updates of this feature class as new maps become available and need to be integrated into the whole.

Metadata has been populated for all of these feature classes and will continue to be updated as the data are maintained and improved.

Establish Connectivity Between PFYC Data and GIS Data

ArcGIS offers multiple options for connecting to non-GIS data sources, as well as for importing such sources into a geodatabase table for use and maintenance wholly within the ArcGIS interface. In this instance, the PFYC ratings per rock unit table exists in an ArcSDE geodatabase which is edited and updated using MS Access through an open database connectivity (ODBC) connection. GIS users can access the table for joins and queries, but cannot modify its contents. Changes made to the table by approved users in Access will be immediately available to the GIS community.

RESULTS

The geospatial end product of most interest from this process is the dissolved feature class carrying standardized rock unit assignments which can be joined to the PFYC table for mapping and analysis. The merged geology polygon feature class will be used when updating the geology data to accommodate new map information. The source boundary polygon feature class provides a tie to specific details about the original map information incorporated into this dataset.

Each of the more than 1,400 uniquely identified geologic units needed to be given a PFYC rank. A related project was undertaken to make an extensive review of all the geologic units from Montana, North Dakota, and South Dakota. The PFYC for each formation was determined from a review of the literature and known fossil localities and occurrences, and for each unit a short summary justification of the assigned rank was provided. As a rule, the BLM assigns 1 rank to a formation for the entire state. However, on a case-by-case basis a formation may be ranked differently in another state if it is justified by fossil occurrence. This formation by formation review will be published separately.

The standardized table of geologic unit codes and PFYC ranks can easily be joined to the GIS polygon data, creating the most up-to-date PFYC map. This information is invaluable to anyone involved in potential surface-disturbing undertakings, land use plans, and research.

FUTURE EFFORTS

There are still GIS 'housekeeping' tasks to be completed for all of the data that support this process. This includes completing the topology error cleanup in the merged dataset, fully populating metadata for the original 149 converted coverage files, finding sources for any remaining 'no data' areas, and so on.

Another area of improvement will provide users with an easy way to access key reports about each of the original map surveys. Access methods may include hyperlinks in the metadata, a searchable online library, or a document management application. At a minimum we are looking to provide a comprehensive citations list for the maps used.

An ArcGIS layer file (.lyr) allows GIS users to create a consistent look and feel of the mapped data, including the source, symbology, definition queries, and so on, that can be shared with other GIS users who have access to the same data. A layer package (.lpk) can be made that includes both the layer and the supporting data so that other GIS users that do not have access to the primary data source can also use them (Fig. 2). Having users add a layer file to a map document (.mxd) instead of just adding the feature class saves them the effort of setting the specific parameters again when collaborating with others or in generating consistent map products, or of having to apply a data style to the feature class.

Presently, we are also exploring the best way to make the full dataset publicly available. After more refinement of the data we will post them on the Montana BLM website. Web based map access through an internet browser is also under consideration.

CONCLUSIONS

Creating a standardized geospatial geology data set and PFYC ratings table for the State of Montana was both a specific project and a process pilot. While there is still some work to be done the next logical step is to expand the area of incorporated geology maps using similar steps. Recently we found a USGS website that may modify and simplify the geology GIS data gathering and standardization part of this effort. Starting in 1997 the USGS Mineral Resources Program set out to create "Digital geologic maps of the US states with consistent lithology, age, GIS database structure, and format" as described on the USGS data access page for this project (http://tin.er.usgs.gov/geology/state/). Shape files for all 50 states and Puerto Rico, as well as a combined dataset for the continental US, are available, as is extensive documentation of the project approach, data sources, and so forth. Google Earth compatible files are also provided, as are ArcMap style sheets and csv files listing references, unit descriptions, age categories, and other parameters. It includes standardized data for faults, dikes, and the other geologic features that have not yet been addressed in the BLM project. We are hopeful that much of the groundwork in expanding this effort may already have been accomplished. The USGS data may serve as the basis of a national standardized GIS geology layer and PFYC rating tool which could be available relatively quickly. Research into how these data were created, what rationale was used to create standardized rock unit codes and integrate different map scale sources, how new data are/are not added, and so on needs to be completed, but the outlook is encouraging.

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ARTICLE

INVENTORY OF U.S. GEOLOGICAL SURVEY PALEONTOLOGY COLLECTIONS TO IDENTIFY FOSSIL LOCALITIES IN NATIONAL PARK SERVICE AREAS

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INTRODUCTION

Between the last quarter of the nineteenth century to nearly the end of the twentieth century, the United States Geological Survey assembled an extensive collection of fossils from the continental United States and Alaska. Collectively these collections represent the foundation for American biostratigraphy and paleontological taxonomy. The U.S. Geological Survey paleontological collections also represent many significant historical collections associated with early reconnaissance and mapping of the western United States. Fossils associated with the Hayden Survey exploration into Yellowstone are maintained in museum cabinets at the U.S. Geological Survey facilities at the Denver Federal Center in Denver, Colorado. The USGS also maintains the important Mesozoic ammonite reference collection of Bill Cobban (Cobban et al., 2006).

Paleontological resources were addressed in the act which established the U.S. Geological Survey (USGS) in 1879. Generations of USGS geologists and paleontologists acquired collections of fossils to support their research, mapping, and other work for the federal government. In 1900, a Division of Paleontology was created within the organization of the USGS, which later changed names several times throughout the following 90 years. USGS fossil collections were directed to facilities in Menlo Park, California; Denver, Colorado; and the Smithsonian National Museum of Natural History in Washington, D.C.

Beginning in 1889, the USGS documented paleontological specimens and locality information in informal reports known as Examination and Report on Referred Fossils or E&R Reports. These reports enabled field geologists and mappers to record detailed information about fossils which were discovered during field work. Often the E&R reports contain geologic and geographic information regarding fossil occurrences and collections which were obtained contemporaneous with field work. In some cases the locality data reported in the E&Rs are extremely limited. A near complete set of paper E&R reports are maintained at the USGS Headquarters in Reston, Virginia. USGS staff have scanned and organized the E&Rs into a searchable database.

During the early 1990s, the USGS Paleontology and Stratigraphy Branch was eliminated and the professional paleontology expertise for the bureau was greatly diminished. In 1997 the paleontological collections at Menlo Park were transferred to the Museum of Paleontology, at the University of California at Berkeley. The USGS paleontology collections in Denver have continued to be maintained at the Denver Federal Center. Estimates suggest that the USGS at one point maintained over 1.5 million fossils in the various collections. These collections were accompanied by extensive records including the E&R reports, field notes, sketches, maps, locality and taxonomic reference cards, photographs and other information.

USGS PALEONTOLOGY COLLECTIONS—DENVER

In an effort for the National Park Service (NPS) to obtain information about fossil and fossil localities maintained in USGS collections, a pilot project was initiated in 2009 to inventory all fossil collections and associated records for the state of Oklahoma held by the USGS at the Federal Center in Denver. Although the principle interest for the NPS was to obtain paleontological resource data for Chickasaw National Recreation Area, the statewide approach to the project was determined to be the most efficient inventory method based on the organization of the USGS collections in Denver. A drawer-by-drawer inventory was conducted for each of the sixty museum cabinets with Oklahoma fossil collections. This work identified over 13,500 specimens assigned to 1,250 paleontological localities throughout the state of Oklahoma. Information was incorporated initially into spreadsheets and then into a database. Locality data was entered into ArcGIS so the distribution of paleontological data could be mapped and evaluated (McKinney et al., 2009).

Between 2002 and 2012 the National Park Service conducted a servicewide inventory to establish baseline paleontological resource data for parks throughout the agency (Santucci et al., 2012). Through this inventory effort and subsequent work, 244 units of the National Park System have been identified with documented fossils. The ten- year inventory effort significantly increased awareness regarding the scope, significance, distribution and management issues associated with NPS paleontological resources. This information enhances the ability for NPS staff to manage, protect, interpret and research fossils from park lands. The servicewide paleontological resource inventory found that the USGS has collected fossils and maintains fossil locality records from nearly 50 NPS administered areas. Many of these fossil collections and locality data were not known until recently. This paleontological resource data maintained by the USGS is extremely valuable to the

NPS in developing plans for future resource management, site monitoring, research and other stewardship activities.

Starting in 2011, the NPS and USGS began to inventory fossil collections and compile associated records and E&R reports from the state of Utah. Approximately 50 museum cases with fossils from Utah were identified by USGS Paleontology Collections Manager K. C. McKinney. The E&R reports associated with the Utah fossil collections were located in a number of file cabinets at the back of the collection area in the Denver Federal Center facility, arranged by the USGS group who worked on the material, not by the geographic location of the material worked on. Ninety-five E&R reports associated with fossils collected from areas administered by the NPS were scanned, portions of the text transcribed, and information (stratigraphy, taxonomy, geospatial) was incorporated into a project database.

NPS Guest Scientist John Ghist conducted the drawer-by-drawer inventory of the Utah fossil collections at the USGS facility in Denver. John systematically examined the fossil collections in each drawer contained within each cabinet. Photographs were taken of the entire drawer and secondary photos were taken with each specimen or groupings of fossil specimens. All associated cards, notes or other records were photographed and/or scanned, along with any corresponding field notes and E&R reports. All of the photos and information were entered into a searchable database.

Several important fossil collections from NPS areas in Utah were discovered during the inventory. In most cases these fossil collections were not known to current NPS staff and were not documented in park or servicewide paleontological archives. Notable fossil collections and corresponding records from Arches National Park and Dinosaur National Monument were photographed and scanned.

The collections from Arches National Park include the remains of mammoth and bison bones (Fig. 1) and clasts

FIGURE 1. USGS cabinet drawer (K-29-a-4) with miscellaneous vertebrate remains including mammoth and bison from Arches National Park.

FIGURE 2. Planorbid gastropods from locality referred to as "snail rock" in Arches National Park, which Jack Oviatt (UGS) sent to John Hanley in 1984 from the base of 'Tertiary deposits.'

with Tertiary planorbid gastropods (Fig. 2). Associated records and E&R reports provide detailed information regarding field localities, collector, date of collection and other information. Several letters, dated from the early 1980s, between C. G. "Jack" Oviatt (Utah Geological Survey) and John Hanley (USGS) discuss the interesting occurrence of the freshwater Tertiary gastropods from blocks within the Salt Valley Anticline in Arches National Park. Madsen et al. (2012) provides further discussion regarding Hanley's archives and the implications for the occurrence of the gastropod fossils at Arches and the collapse of the Salt Valley Anticline.

Two collections of Carboniferous invertebrate fossils from Dinosaur National Monument were found in the USGS collections. One fossil collection was made by J. S. Williams in 1944. The other fossil collection was made by Barnum Brown and Gilbert Stucker (American Museum of Natural History) in 1953. The field collections from 1953 were supervised by Jess H. Lombard who was superintendent at Dinosaur National Monument between 1946 and 1960.

USGS PALEONTOLOGY COLLECTIONS—SMITHSONIAN

In 2011, the National Park Service requested assistance to evaluate the thick Silurian sequence preserved in Glacier Bay National Park and Preserve (GLBA), the thickest Silurian section known in North America. A team led by Robert B. Blodgett conducted field investigations of Silurian strata both within and in areas adjacent to GLBA. Paleontological specimens were collected and utilized to reconstruct the paleoenvironmental relationship of the Silurian geology. Part of this project involved the development of a comprehensive fossil locality database for GLBA and the surrounding area, which incorporated data from over 576 localities, most of which were documented by USGS field teams. The new information gained during

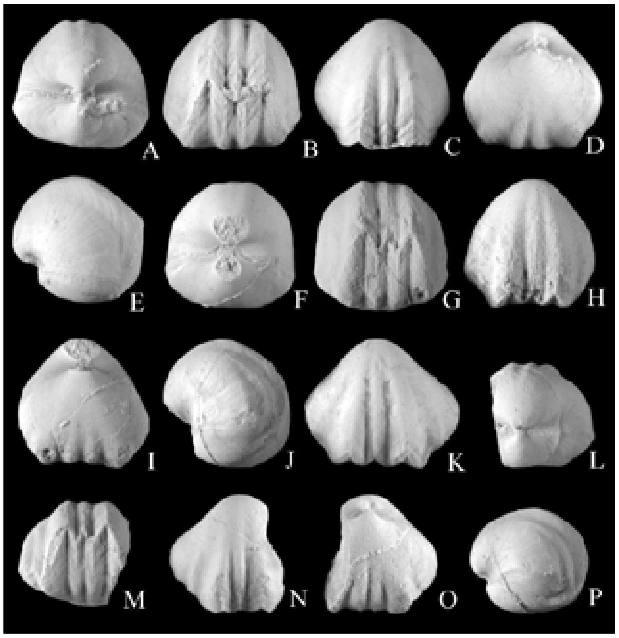

FIGURE 3. Holotypes and paratypes for *Sapelnikoviella santuccii* Blodgett et al. (2013), a Late Silurian gypidulinid brachiopod described from exposures of the Willoughby Limestone on the west side of Drake Island in at Glacier Bay National Park and Preserve, in southeast Alaska.

field activities in 2011, along with the large number of unstudied USGS collections, enabled a new interpretation for the Silurian stratigraphy and paleoenvironment (including massive reef complexes) for GLBA and surrounding areas in southeast Alaska (Rohr et al., 2013). The historic collections made by USGS staff from GLBA, now at the Smithsonian, were also inventoried and studied as part of this project. Several major taxonomic papers have been published on the Silurian brachiopods (including a new genus and species *Sapelnikoviella santuccii*, Blodgett et al., 2013) (Fig. 3) and gastropods. A manuscript is also in preparation redescribing the original type specimens of the bivalve genus *Pycinodesma* (formerly thought to be the largest Paleozoic bivalve), which was originally described from Glacier Bay in 1927.

While examining the USGS fossil collections from GLBA and other parks in Alaska now maintained by the Smithsonian, a collection of extraordinarily large Middle Devonian brachiopods (Family Stringocephalidae) from the northern flank of the Brooks Range were discovered. This particular collection is from Noatak National Preserve and was collected in 1968 by Augustus Armstrong from a monospecific coquinoid shell bed. Study of this forgotten collection conducted during the past year shows that the brachiopods are examples of the large stringocephalid genus *Chascothryis*, and are the first specimens of this Eurasian genus to be found in North America. A manuscript is in the final stages of completion, and this material is being described as a new species of the genus (Fig. 4). The species will be named in honor of Herbert Frost, the new Regional Director for the Alaska Region of the National Park Service. The occurrence of this genus in northern Alaska is of great interest to paleobiogeographers as it helps constrain the possible tectonic origins of the allochthonous terranes which comprise most of the state.

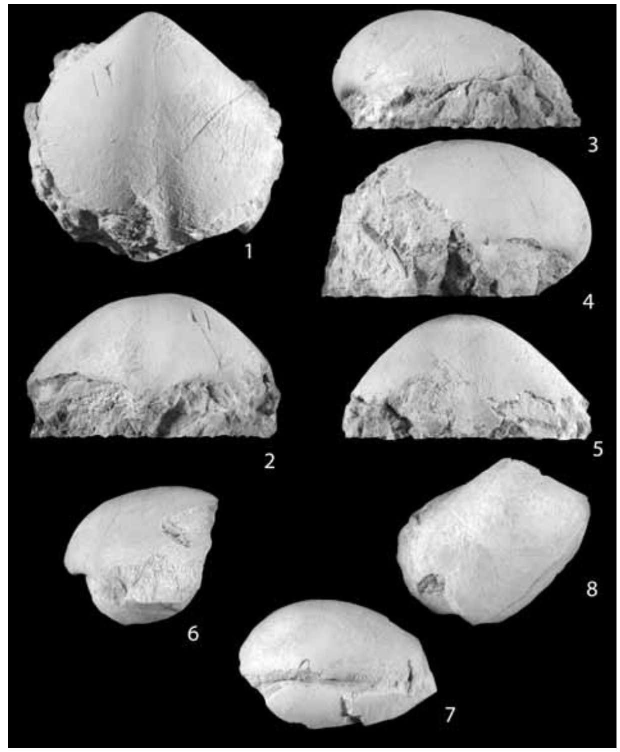

FIGURE 4. Various views of a new late Middle Devonian (Givetian) age stringocephalid brachiopod species being named in honor of Herbert Frost (NPS Alaska Regional Director). Specimens collected by A. K. "Gus" Armstrong (formerly USGS) in Noatak National Preserve (NOAT) in 1968, prior to the preserve being established as a unit of the NPS.

USGS PALEONTOLOGY COLLECTIONS–UCMP (MENLO PARK)

A cooperative venture between the NPS and the University of California Museum of Paleontology (UCMP) was initiated in 2013 to inventory the USGS Invertebrate Collection from Menlo Park for specimens associated with NPS areas. The Menlo Park collections were donated to the UCMP in 1997. Museum Specialist (Invertebrate Collection) Erica Clites is coordinating the project and is developing an online fossil locality portal for collections identified from NPS areas. Fossil collections from over 20 national parks have already been incorporated into the fossil locality portal, most of which are parks in California and the Pacific West Region of the NPS.

CONCLUSIONS

The USGS paleontology collections are the result of over a hundred years of scientific field work by teams of geologists, paleontologists and mappers. These collections held by the USGS in Denver, at the Smithsonian National Museum of Natural History, and at Menlo Park (now transferred to the Museum of Paleontology at the University of California), along with the associated data contained in the E&R reports, represent the foundation for North American stratigraphy and paleontology. It is difficult to imagine that such an extensive and representative fossil collection, dating back to the late 1800s, could ever be duplicated or replaced.

The paleontological collections of the USGS are a legacy and a reference collection (including thousands of holotype fossil specimens) that scientists today and in the future need to access for study and comparison. Through the authorities and mandates contained in the Paleontological Resources Preservation Act of 2009, the five federal agencies identified in this law will benefit from the century of work the USGS put forth to build the fossil collections. The care, maintenance, and continued access to the USGS fossil collections and associated data should be ensured in perpetuity in order to support the future work of the Bureau of Land Management, National Park Service, and U.S. Forest Service.

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ARTICLE

DANCING THROUGH DANTE'S TRACKSITE FROM THE GROUND AND AIR: THE USE OF AERIAL DATA COLLECTION AND PHOTOGRAMMETRY TO RECORD A DINOSAUR TRACKSITE IN ELK BASIN, WYOMING

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ABSTRACT—A track-bearing horizon occurs in the Upper Cretaceous Meeteetse Formation on the western limb of Elk Basin Anticline. Outcrops of the Meeteetse Formation occur in an arcuate belt approximately 12 km long offset by regional faulting. Dante's Tracksite is located approximately 31 kilometers north of Powell, Wyoming on public lands administered by the BLM. This is the first reported dinosaur tracksite from the Meeteetse Formation of Wyoming, and the first reported tracksite in Elk Basin, Wyoming. Since its discovery in 2000, nearly 300 dinosaur footprints have been documented in a well-indurated, heavily bioturbated, fine-grained sandstone. Tracks are preserved as natural depressions (true tracks and undertracks) in concave epirelief and natural casts in concave hyporelief. The tracks are formed as compressive and infill features in a key bed at the top of the Meeteetse Formation. Invertebrate traces associated with the dinosaur footprints include sea anemone resting traces (*Bergaueria* sp.), suggesting a near shore marginal marine environment with anastomosing channels, mudflats, lagoons, and tidal flats. Track morphologies consist of two distinct types of tridactyl prints, those with theropod and those with ornithopod affinities.

Extensive close-range photogrammetry was conducted during the summer of 2003 using a 35-mm tripod-based camera and low level photography from an aerial camera blimp system. Using aerial means to construct a photogrammetric mosaic of the dinosaur tracks provides a view of the tracksite possible in no other manner. The use of aerial photogrammetry allows for the accurate capture of spatial relationships of paleontological elements. Photogrammetry was used to measure the x, y and z components of the tracks. This form of study provides insights into the sedimentological conditions prevalent at the time of deposition of the tracks, as well as allowing accurate measurement of the tracks. This tracksite provides evidence for a group of dinosaurs moving through the vicinity of what is now Elk Basin in the Late Cretaceous during deposition of the Meeteetse Formation. The combination of the sedimentology and interpretation of the ichnofacies gives additional insight into the paleoecological conditions during the Campanian of northwestern Wyoming.

INTRODUCTION

Dinosaur footprints described herein come from the Meeteetse Formation (Upper Cretaceous, Campanian) and are found on a well-indurated sandstone outcrop nicknamed "Dante's Tracksite" (University of Wyoming locality yet to be assigned). Footprints were initially discovered during field work in 2000 and further investigation on the extent of the footprints and tracksite was carried out in the field seasons of 2001–2002. The footprints are located in the Elk Basin Anticline in the Bighorn Basin in Park County, Wyoming (Fig. 1) at the top of the Campanian Meeteetse Formation). This breached, doubly plunging anticline is nestled in the northwestern Bighorn Basin. The Meeteetse Formation crops out along an arcuate belt formed by anticlinal limbs of Elk Basin Anticline. It is Late Campanian in age. "Dante's Tracksite" is located east of the "This Side of Hell Quarry," on the western flank of Elk Basin Anticline in Park County, Wyoming. These localities are in the Elk Basin Anticline near Cody, Wyoming, northeast of Pitchfork, Montana, and northwest of Hell's Half-Acre, Wyoming, as well as southwest of Hellroaring Plateau, Montana. The intermountain Bighorn Basin is surrounded by the Bighorn Mountain to the east, the Beartooth Mountains to the west, and the Owl Creek Mountains to the south. The Elk Basin Oil Field is situated east of the tracksite, primarily in the center of the anticline. Distinctive signs liberally placed along oil field roads warn of hydrogen sulfide gas, and the ever-present smell of sulfur reminds one of a 'hellish inferno'.

METHODOLOGY

The Aerial Camera Blimp System (ACBS) is an excellent method for photographing paleontological subjects. This system combines a helium-filled blimp with on-board video and still cameras providing a bird's-eye view of objects below (Fig. 2). The 6-m (20-ft) long blimp is inflated by approximately 13 m3 (450 ft3) of helium and is capable of lifting the on-board cameras to a height of 80 m (260 ft) above the ground. A cable is used to control the camera height and connects the blimp to the operator on the ground. This system of data collection is quiet and non-invasive.

The ACBS operator wears a harness that holds a color-video display and remote camera controls. The on-board, color, micro-video camera provides the operator with a real-time image of the area being photographed. A swivel mount, equipped with pan and tilt motors suspended on the underside of the blimp camera, rotates the camera to align it with the targeted area. The swivel mount also allows the

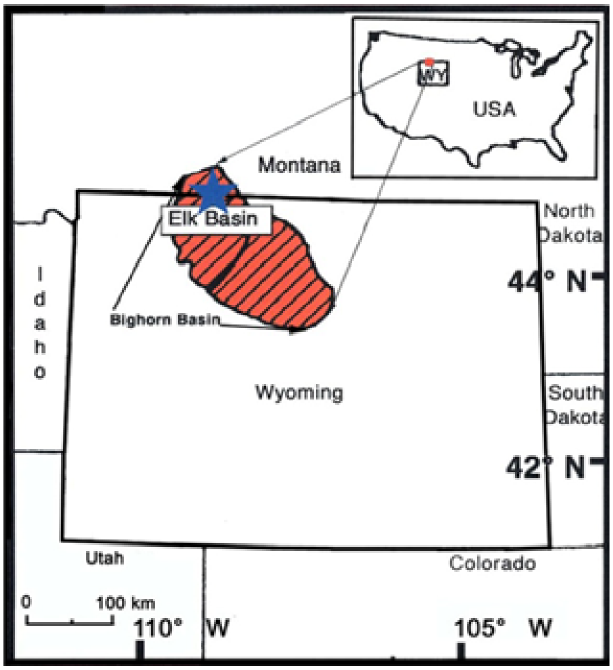

FIGURE 1. Generalized field locality map (after Wegweiser et al., 2004).

FIGURE 2. Aerial Camera Blimp System collecting data over Dante's Tracksite.

camera to hang plumb and offers a degree of self-leveling.

The on-board video monitor allows for predictable placement of each image. As a result, complete, systematic stereoscopic coverage of the study area was accomplished. The ACBS is ideal for photographing areas that are too large or too steep to be efficiently and systematically covered with a ground-based tripod system.

Large-format aerial photography of this area was used to define the field area for research, because it illustrates the form and extent of the Elk Basin Anticline. This photography was also helpful for location purposes in the field, tracing the extent of the outcrop, and for planning the Aerial Camera Blimp System (ACBS) photographic mission. Both natural color aerial photography and digital orthophoto quarter quads (DOQQ) were utilized for this purpose. The 1:24,000 scale natural color aerial photography was acquired from the Bureau of Land Management Aerial Archive in Denver and date from 1984. The DOQQ were produced by the United States Geological Survey in 1994 as 1:40,000 scale black and white aerial photographs. They were downloaded from the Internet.

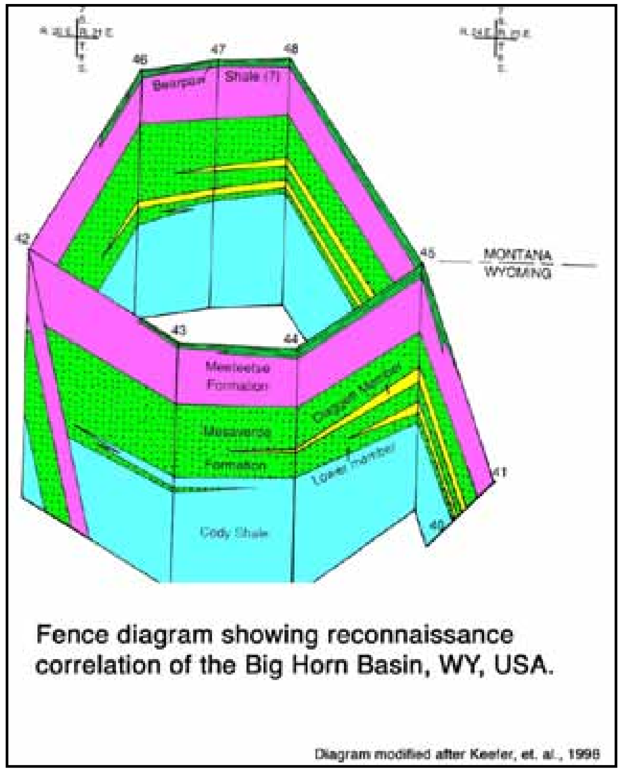

FIGURE 3. A fence diagram illustrates the spatial relationships of the Meeteetse–Bearpaw transition near the Wyoming–Montana border; from poster by Matthews et al. (2003).

STRATIGRAPHY AND SEDIMENTOLOGY

The Meeteetse Formation and Lewis and Bearpaw shales are intertonguing marine, marginal marine and nonmarine strata of latest Campanian and early Maastrichtian (Late Cretaceous) age. Johnson and Finn (2004) considered the Meeteetse/Bearpaw interval in the Bighorn Basin to be equivalent to the upper part of the Judith River Formation and overlying Bearpaw Shale in Montana. Marine strata in this interval in Elk Basin Wyoming are included in the Bearpaw Shale, and the marginal marine and nonmarine strata are associated with the Meeteetse Formation. The maximum combined thickness for the Meeteetse to Bearpaw interval ranges from more than 335 m (1,100 ft) in the northern and southwestern parts of the Bighorn Basin to about 150 m (500 ft) in the southeastern part (Finn et al., 2012).

The Meeteetse Formation is comprised of alternating thin beds of very fine to medium-grained sandstone, siltstone, carbonaceous shale, and coal that accumulated in poorly drained coastal plain environments along the western shore of the Cretaceous seaway (Keefer et al.,

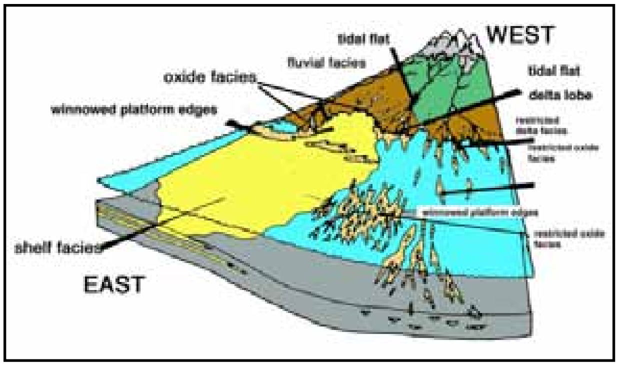

FIGURE 4. Depositional model for the Meeteetse-Lance Formation transition and related strata in the present-day Elk Basin, Wyoming (after Wegweiser et al., 2004).

1998). The Lewis Shale is a westward-thinning tongue of marine shale and sandy shale interbedded with thin sandstone beds, but it is not found in the Elk Basin. It is present in the eastern part of the Bighorn Basin, where it can be more than 90 m (300 ft) thick, and thins westward until it is non-existent, grading into the Meeteetse Formation (Keefer et al., 1998). In the northern part of the basin in the Elk Basin Anticline, the Bearpaw Shale overlies and intertongues with the Meeteetse Formation, representing the last stages of marine sedimentation in the Bighorn Basin. Where present, the Bearpaw Shale ranges in thickness from 24 to 60 m (80 to 200 ft) thick, and according to Keefer et al. (1998) is comprised of fissile gray shale, sandy shale, argillaceous sandstone, and thin beds of very fine grained sandstone.

The Meeteetse Formation is similar to the underlying Mesaverde Formation and overlying Lance Formation with respect to the principal types of lithologies that comprise it; however, the formation differs markedly in overall aspect. Large segments of the Meeteetse Formation present a distinctive banded appearance in outcrop, produced by the sharp alternation of light-and dark-colored strata unique among Cretaceous formations throughout the region. Meeteetse strata are also much less resistant than strata in either the Mesaverde or Lance formations, hence are commonly eroded into valleys with only a few exposures. The latter circumstance contributes to the fact that little surface information had been obtained and published in past years. Thin lenticular coal beds occur at several horizons, but are most common in the upper part of the formation, where Dante's Tracksite is located.

Approximately the upper 43 m (140 ft) of the Meeteetse Formation consists of fissile gray shale that is interpreted to be of marine origin. This shale unit is overlain by an 8-m (25-ft) thick sandstone that exhibits characteristics of a shoreface environment, and it is likely this sandstone contains Dante's Tracksite. The relationships suggest the shale unit is a part of the marine Bearpaw Shale, and the shoreface sandstone, identified in several wells in the northern part of the Bighorn Basin, is actually a basal por-

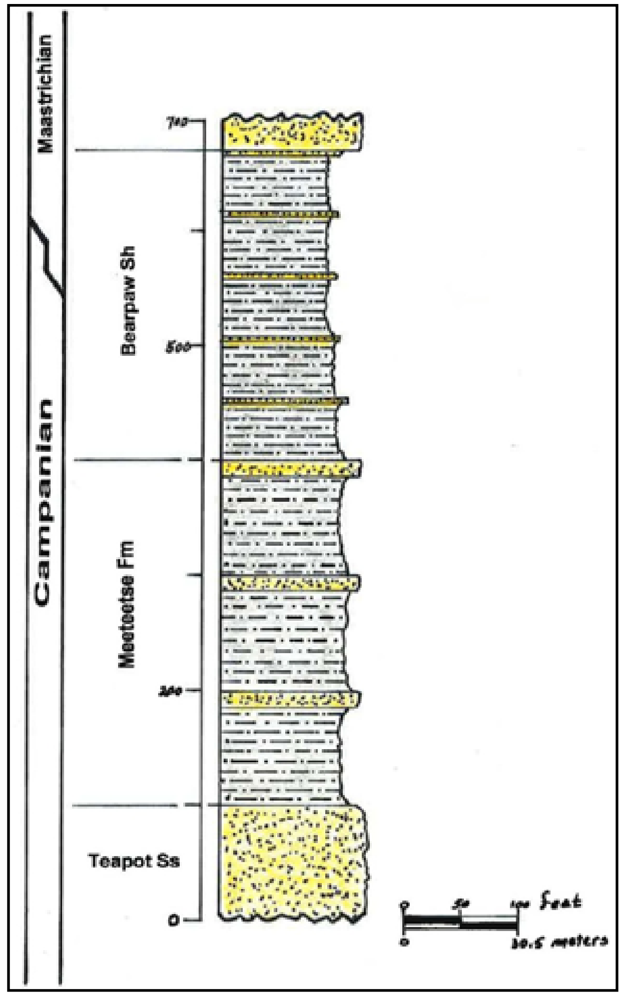

FIGURE 5. Generalized stratigraphic column indicating sedimentary responses to transgressive and regressive regional sea-level signals. Alternating layers of sandstones and silty shales are shown.

FIGURE 6. Dante's Tracksite and the field crew as seen from the air using the ACBS. Standard survey stadia rods and 2 m (6.5 ft) square wooded grids can also be seen for scale.

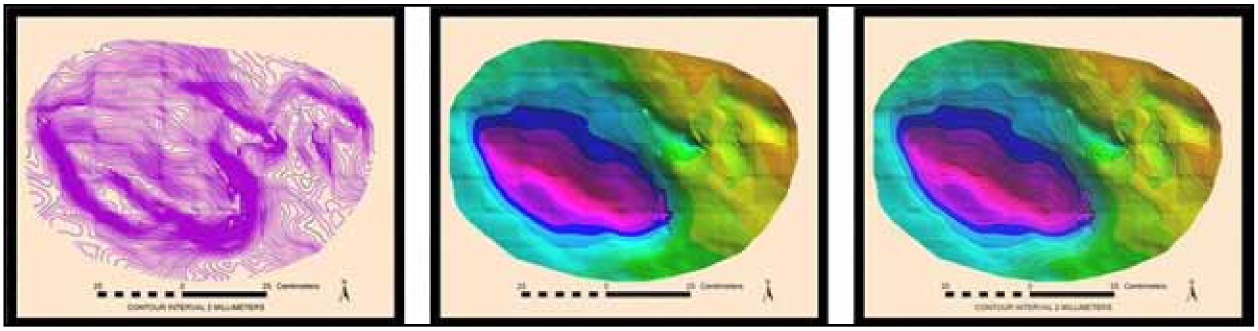

FIGURE 7. Photographs processed and analyzed in PhotoModeler Pro 5. First image shows dinosaur tracks with 2 mm (0.08 in) contour interval. Second image shows color contours of the tracks. Third image shows color contours and 2 mm (0.08 in) contour intervals.

tion of the Fox Hills Sandstone. It should be noted that the names Bearpaw Shale and Fox Hills Sandstone were used for strata equivalent to the Meeteetse Formation, Lewis Shale, and basal Lance Formation in the northeastern part of the Bighorn Basin (Keefer et al., 1998) (Fig. 3).

In general, sedimentologic information tends to imply deposition in a low topographic area on a delta lobe (Fig. 4). This deltaic system consisted of sandy braided plain fluvial deposits, interspersed with shallow intertidal bays, which were occasionally subjected to volcanic ash falls, channel abandonment, and episodic marine incursions. Flaser beds, reactivation surfaces, symmetrical ripples, and thin lenses of silty sandstone containing marine invertebrate trace fossils make up the cyclic repetition of upper Meeteetse stratigraphic intervals (Fig. 5). A number of uncorrelated tuffaceous and/or bentonitic strata units occur primarily in the lower portion of the Meeteetse Formation.

Variable paleocurrent directions were taken from troughs of cross-bedded sandstone; however, regional fluvial discharge was generally due east. In outcrop, the Meeteetse Formation presents a distinctive banded appearance that is produced by alternating light and dark colored strata. Average thickness of the Meeteetse Formation measured during this study is approximately 185 m (607 ft).

TIMING AND STYLE OF PRESERVATION

Immediately adjacent to the oil field, the track-bearing sandstone layer is exposed along a steeply dipping (~30°) ridge (Fig. 6). This intermittent ridge trends northwest/southeast and is occasionally displaced by faulting. The occurrence of tridactyl dinosaur tracks in Elk Basin is indicative of rapid burial of the tracks in the sediments shortly after formation of these tracks. Fossilization of non-biomineralized clues to the anatomy and behavior of terrestrial animals (such as tracks, trails, and traces) are of great importance to our understanding of the paleoecology of depositional settings. Preservation of ichnofacies begins to occur once the traces of physical activity are buried below the taphonomically active zone. The key bed located at the top of the Meeteetse Formation containing dinosaur tracks represents a true picture of Walther's Law. Laterally it ranges from cross-bedded sedimentary structures to a well-indurated sandstone, exhibiting no bedding laminae and everywhere having a heavily bioturbated upper surface. Occasional traces occur in the northwestern Elk Basin, where portions of the key bed contain trace fossils that are putatively assigned to sea anemone resting traces (*Bergaueria* sp.). Over 300 dinosaur tracks have been documented at Dante's Tracksite. The tracks are formed as compressive and infill features in a key bed at the top of the Meeteetse Formation. The footprints are preserved as natural depressions (true tracks and undertracks) in concave epirelief and natural casts in concave hyporelief in a well-indurated, heavily bioturbated, fine-grained sandstone. Track morphologies consist primarily of two distinct types of tridactyl tracks, those with ornithopod and those with theropod affinities. The majority of these are the pes tracks of hadrosaurian dinosaurs. In a number of cases, associated manus impressions have also been found.

Morphologic variability of the tracks reflects taxonomic differences, overprinting, and sediment consistency/saturation at the time of track formation, as well as later episodes of deformation and erosion. Footprint lengths range from 14 to 83 cm (6 to 33 in). Footprint widths range from 16 to 75 cm (6 to 30 in). Ichnites representing several taxa vary from relatively subtle, shallow impressions to footprints several cm deep. Distinctive sediment deformation around the tracks can be seen as a reflection of the thixotropic nature of the near-shore marine setting, as the dinosaurs walked across a water-saturated, coastal floodplain. The majority of the trackways show a preferred easterly orientation, although some tracks show a great degree of variability from this trend.

Identifications and analyses of the tracks and trackways are preliminary. However, Dante's Tracksite appears to represent another important, ornithopod-dominated dinosaur community along the humid, well-vegetated coastal plain of the Cretaceous Western Interior Seaway (see Currie et al., 1991; Lockley, 1991; Lockley and Hunt, 1995). Research on these dinosaur tracks are leading to

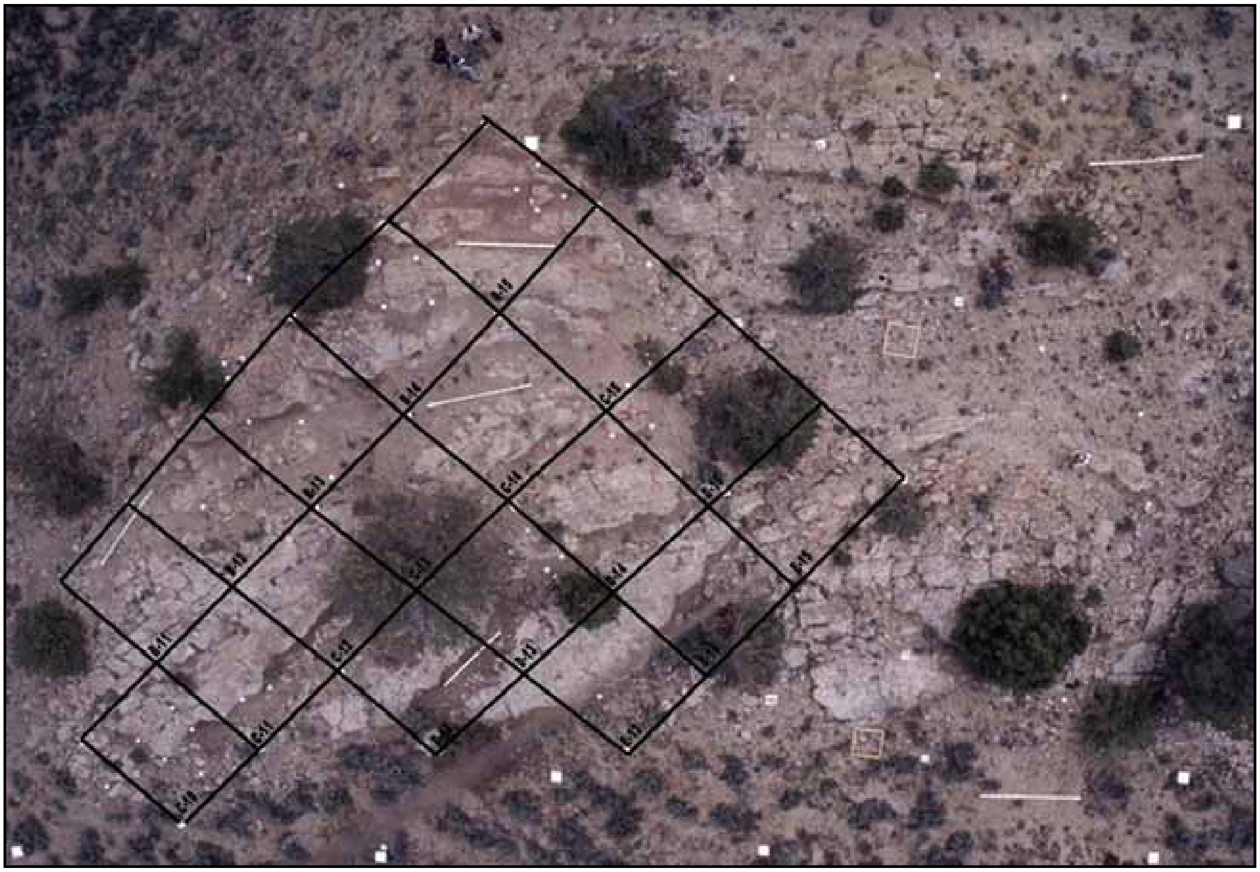

FIGURE 8. Grid created from the aerial photograph using the ACBS. Grids are 5 m (16 ft) squares. Large ornithopod track preserved as a natural cast (Fig. 12) can be seen in the upper right side of the uppermost grid (Grid B15). In addition five standard survey stadia rods and two wooden, two-meter square grids can be seen in this figure.

new interpretations of the regional ecology and depositional environments of northwestern Wyoming during the Campanian.

The preservation of the dinosaur tracks suggests that precise conditions existed for fossilization to occur, most likely immediately after burial. Paleosols in the Meeteetse Formation would have formed regionally during emergent conditions within deltaic complexes, which would have been enriched in Fe, Al, Mn, and CO_2 (Wegweiser et al., 2004), and these would have been conducive to fossilization.

DISCUSSION

Over the past 15 years close-range photogrammetry has been used by the authors to photo-document resources at a number of paleontological localities throughout the Rocky Mountain West (Breithaupt et al., 2004; Matthews et al., 2005, 2006; Matthews, 2008; Matthews and Breithaupt, 2001a; 2001b; 2009; Breithaupt and Matthews, 2011). The science of photogrammetry (making measurements from photographs) has allowed for the accurate capture of spatial relationships of paleontological elements at these localities.

An important aspect of photogrammetric data extraction is not only the precise measurement of horizontal (x and y) components, but also vertical (z) values. This ability to extract the third dimensional (z) component comes from stereoscopic analysis. Close-range photogrammetry has an object-to-camera distance of less than 300 m (984 ft) and has been successfully utilized in a variety of different fields (Matthews, 2008).

Reliable measurements can be taken from photographic images if the following conditions are met:

A) Stereoscopic images (two or more overlapping photographs) cover the object to be analyzed.

B) Accurate x, y, and z coordinates are known for at least three defined object points in the overlapping photographs.

To increase the accuracy of the measurements a metric camera is required. The advantages obtained by using a metric or calibrated camera are that the lens distortions have been measured and that a system of reseaux (reference points used for measurements or calculations, whose coordinates are known to the nearest micron) is imprinted on each frame (see Matthews, 2008).

The close-range photographs, as well as other scientific observations taken from paleontological sites can be integrated into a real-world, rectangular coordinate system

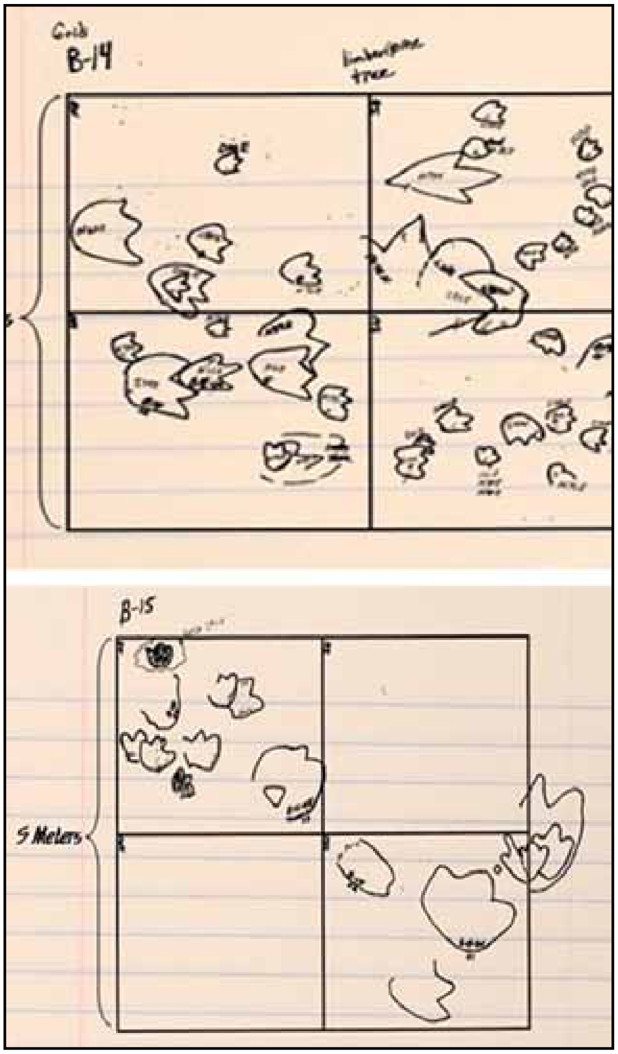

FIGURE 9. Samples of field notes sketch maps made from Grids B14 and B15 noted in Figure 8. Grids are 5 m (16 ft) squares.

FIGURE 10. Dinosaur footprint (natural cast) with lead author for scale. Footprint marked for aerial photogrammetric documentation with coded targets. Orange poker chip is 3.85 cm (1.52 in) in diameter.

that provides the framework for a Geographic Information System (GIS) of these sites. The GIS is used to analyze the relationships of the scientific data in 3-D space.

These different photographs can be taken at a variety of perspectives and scales and analyzed in relatively inexpensive software packages such as EOS Systems Inc. PhotoModeler Pro 5 (Matthews, 2008). The software not only allows for accurate measurements to be made from photos with relatively minimal set-up time, it also can be used to generate camera calibration reports for virtually any camera. More in-depth photogrammetric processing can also be done on these photographs, using traditional photogrammetric stereo-plotter systems for the production of digital terrain models and topographic 1 mm (0.04 in) contours (Fig. 7).

These techniques have many very important uses in the documentation, analysis, monitoring, protection and preservation of paleontological resources. Currently, a variety of Mesozoic Era sites (encompassing both tracks and bones) in the West are being documented utilizing this technology in conjunction with various other methodologies (Breithaupt and Matthews, 2011). Photogrammetric techniques provide permanent, three-dimensional, photographic record of fossil resources and are a non-disruptive/non-intrusive method of assessment and documentation.

Delineation of a coordinate grid and placement of coded targets prior to photography (Fig. 8) allows for highly accurate measurements to be made. Accurate field notes using the grids are an additional record of data location and in this case, footprint recordation for management and analysis purposes (Fig. 9). The coded targets (systematically placed at key locations) provide precise locations for tying a number of photographs together (Figs. 10 and 11).

In conjunction to using the ACBS, the field crews identified the locations of tracks using highly visible blaze orange poker chips (3.85 cm [1.52 in] in diameter; see Figs. 10 and 11). These, along with various coded targets, assisted in the on-the-ground grid system mapping of the dinosaur tracks. Having these maps allows the analysis of the over-printed tracks and trackways.

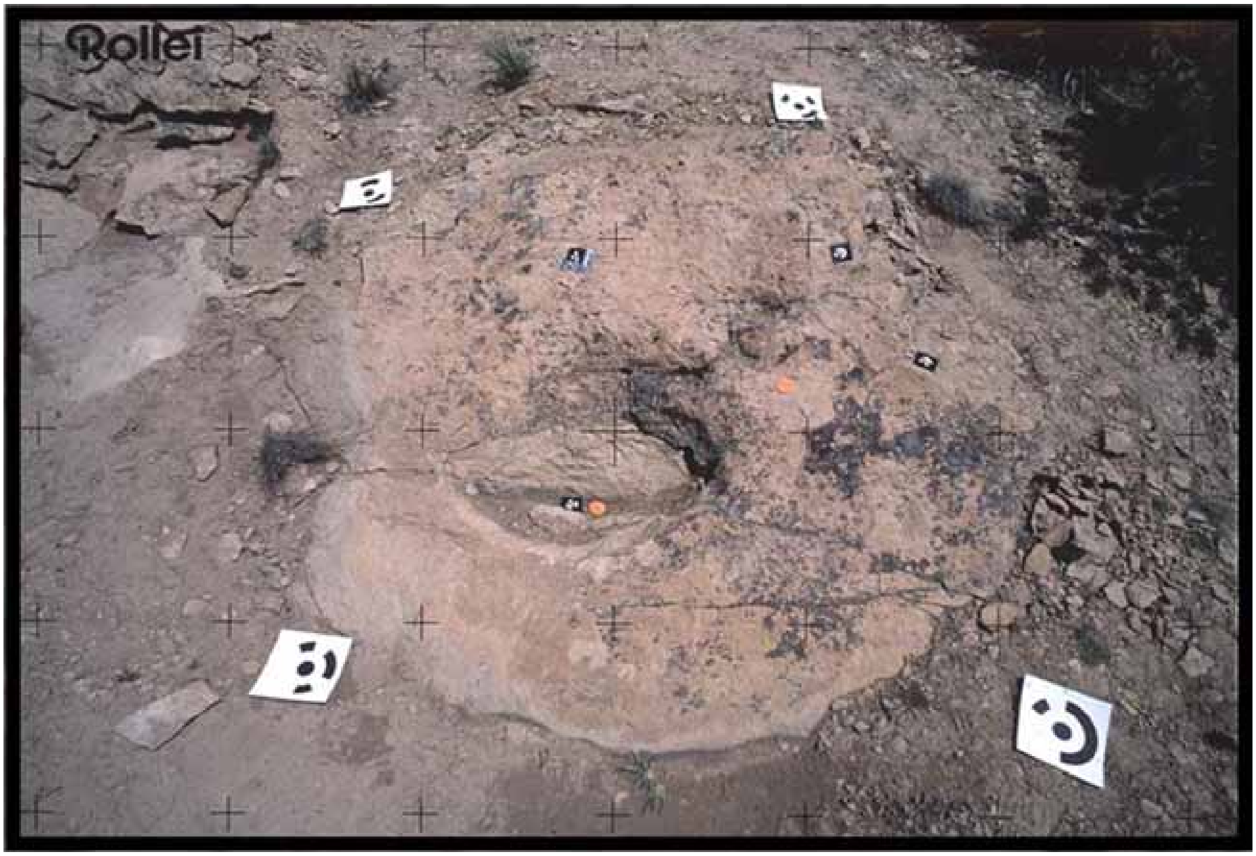

FIGURE 11. Ornithopod and theropod dinosaur footprints marked for aerial photogrammetric documentation with coded targets. Orange poker chips are 3.85 cm (1.52 in) in diameter.

FIGURE 12. A large ornithopod dinosaur track in Grid B15 preserved as a natural cast. Orange poker chip is 3.85 cm (1.52 in) in diameter.

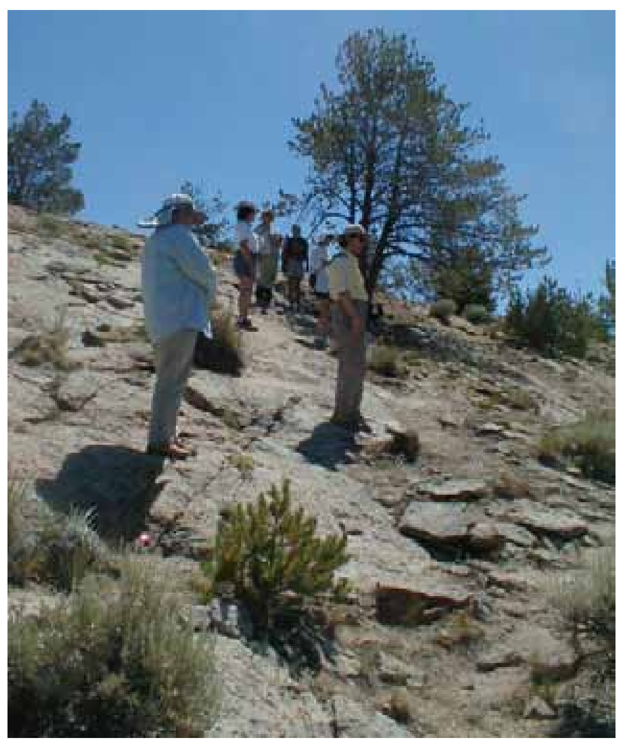

FIGURE 13. Volunteers from the field crew line up next to dinosaur tracks providing a visual of the steps of a large ornithopod dinosaur.

SUMMARY AND IMPLICATIONS

Dinosaur tracksites can be accurately mapped using both traditional and nontraditional methodologies. The use of an aerial blimp system is innovative and is non-invasive, making it a preferred method to be used on public lands. It is quiet and because it is hovering well above the people guiding it, it is unlikely to be noticed by any nearby wildlife. Thus, minimizing stress to the local inhabitants, as might be caused by the use of a drone or other mechanical device. Additionally, getting the 'bird's eye view' of a paleontological site allows resource managers to have a map that would otherwise be difficult to create—and provides a resource management tool where one can come back with the aerially created map and verify evidence of resource change or damage.

ACKNOWLEDGEMENTS

The Rocky Mountain West contains some of the most important vertebrate remains in North America, many of which are located on public lands managed by the federal government. To help facilitate the preservation and protection of these non-renewable scientific and educational resources, partnerships between institutions and land agencies are essential. The Dante's Tracksite Project is an example of this type of cooperative venture. To facilitate the thorough documentation of Dante's Tracksite in cooperation with the BLM, the authors utilized a diversity of volunteers (Fig. 13) to assist in the investigation of the site and the documentation of the paleontological resources. Appreciation is extended to all of the students and volunteers who devoted hundreds of hours of their time to assist us in this research. Their help in the documentation of Dante's Tracksite has led to the understanding of a previously unknown Late Cretaceous dinosaur community. We would like to thank T. Lumme of AeroArts for his excellent aerial photography. Gratitude is also extended to various BLM representatives for their help in arranging and participating in this project. The research on this project was done under Wyoming BLM Paleontological Resources Use Permit PA02-WY-061.

The dedicated volunteers were willing to 'swarm' the outcrop with whisk brooms, garden tools, and gloves to clean the surface in preparation for the aerial photography. These people worked diligently in hellish temperatures with a vitality that is unequalled. The success of this project is not possible without them. Thank you all: D. Boyd, A. Bredon, R. Davis, J. Davis, C. Edge, B. Finley, A. Gann, T. Grant, O. Haines, K. Hartung, T. King, S. Kramer, S. Marble, R. Mathison, K. Mathison, S. Maxwell, J. Meiloch, C. Nicholson, L. Presson, P. Seostrom, K. Solomon, P. Stern, G. Sill, B. Sill, K. Turley, E. Turner, R. Warner, D. S. Welsing, B. Wheeler, D. Williams, and R. Wood. A special thanks goes to V. Meyers for assistance in virtually every aspect of documentation of this site. A very special thanks goes to B. Bestram, retired BLM, for the drafting of some of the figures.

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ARTICLE

RAPID PROTOTYPING OF PALEONTOLOGICAL RESOURCES FACILITATES PRESERVATION AND REMOTE STUDY

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ABSTRACT—Fossil reproductions or replicas generated by rapid prototyping technology (3D printing) can aid public land managers achieve preservation, research, education and outreach goals. Replicas are a tool commonly used for remote study of scientifically important specimens. Specimens commonly rendered as reproductions include fossils or archeological artifacts. These specimens are generally susceptible to degradation or destruction if maintained in situ, whether through natural processes (e.g., weathering) or anthropogenic impacts. A reproduction is a viable substitute for the actual specimen, but traditional casting materials and procedures, such as plaster or latex molds, can lead to resource degradation. Photogrammetric methods to produce a digital record of two in situ fossils were utilized to create scale reproductions using a 3D printer.

INTRODUCTION

Photogrammetry, the science of using photographs to extract three-dimensional data through photo-documentation strategies, employs a non-contact method for acquiring resource information for monitoring and analysis (Matthews, 2008). Computer-aided photogrammetry generates digital information (virtual models) that when combined with recent advances in rapid prototyping technology, also known as 3-dimensional (3D) printing, allows for generation of accurate and precise reproductions with minimal or no physical contact to the original specimen. These 3D-printed reproductions can achieve sub-millimeter-scale resolution and rapidly provide models that will help facilitate the aforementioned goals of public land managers. We present two case studies where fragile and/or ephemeral fossil vertebrate tracks from National Park Service areas were photographed to create scientifically accurate replicas. This article emphasizes the methods used to generate scale reproductions via 3D-printing technology.

Fossil vertebrate tracks are a valuable scientific resource, are of great interest to the general public, and are present in at least 30 NPS managed areas (Santucci et al., 2006, 2009). Vertebrate tracks are sources of diagnostic information such as the morphologies of pes and manus impressions for extinct taxa. Because these types of fossils are valuable for the scientific information, they often represent challenges for preservation when maintained in situ, often at risk from weathering and anthropogenic impacts (Santucci et al., 2009). As such, these fossils are potential targets for vandalism, including poor attempts to make molds or casts, and loss from unauthorized collection (Santucci, 2002).

The two tracks photographed and prototyped for this study were from Gettysburg National Military Park (GETT) in Pennsylvania and White Sands National Monument (WHSA) in New Mexico. A single dinosaur track of the ichnospecies *Anchisauripus* was selected from GETT. The *Anchisauripus* track is one of three late-Triassic track morphotypes found on the stones quarried by the Civilian Conservation Corps (CCC) for the construction of a bridge during the 1930s (Santucci et al., 2006). This track was vandalized in the summer of 2013, highlighting the need for enhanced monitoring and preservation strategies for this resource. An unidentified carnivore track from WHSA is preserved in soft gypsiferous sediment, and is one of thousands of ichnofossils found in the late Pleistocene Otero Formation of the Tularosa Basin (Lucas and Hawley, 2002; Lucas et al. 2002). Further study of this significant track is hindered by the ephemeral nature of these tracks which rapidly weather once exposed at the surface. Utilizing standard model-making techniques would be impractical or ineffective for both of these examples and would result in damage to the resource. Instead, we collected photogrammetric data that in turn were used to create physical models of these fossils (Fig. 1A) using digital data and rapid prototyping technology.

METHODS

Rapid prototyping is used to generate 3D models of these valuable paleontological resources. The resolution and detail of a 3D model is dependent on several factors including photograph quality, software for model generation, and the rapid-prototyping hardware. Photograph quality is often described as proper geometry, and Matthews (2008) reports 66% overlap between adjacent images are critical to obtaining high-resolution results. Images of the selected specimens were obtained using a digital single-lens reflex camera with a 28 mm (1.1 in) lens; the focus and aperture settings were locked to ensure consistency between photographs. Scale was provided by a calibrated ruler and a stationary 12-bit photogrammetric target within each photograph series (Fig. 1B). Post-processing software such as Adobe® Bridge* was used to automatically adjust for the lens chromatic aberration but distortion was left in place. The processed images were rendered into a

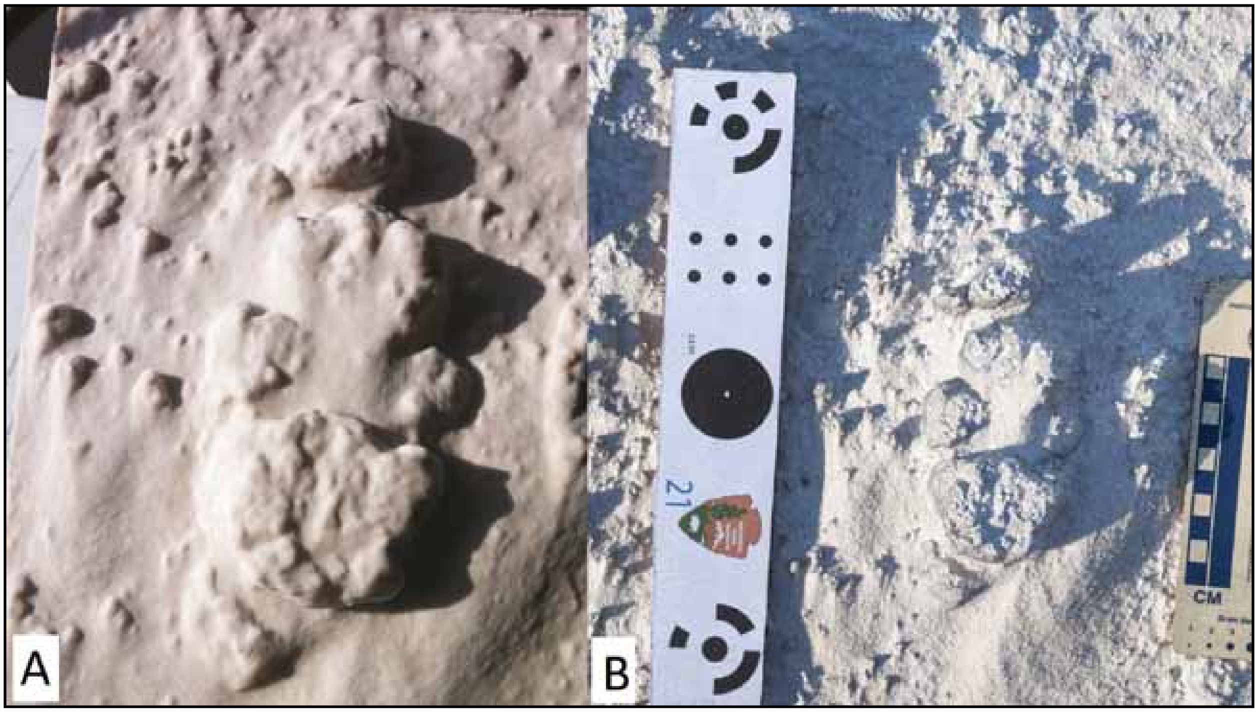

FIGURE 1. **A**, Full scale reproduction of an unknown ichnospecies track found in gypsiferous sediments at White Sands National Monument. This model was generated with photogrammetric data and 3D-printing technology; **B**, The track in situ, as digitally rendered by the software PhotoScan. Scale on right side is 10 cm (4 in); on the left side circular 12-bit targets on both ends of the scale bar aid the automatic photograph alignment process.

3-dimensional virtual surface model using the photogrammetric software PhotoScan Professional available from AgiSoft, LLC (http://www.agisoft.ru).

There are four principal steps to make a computer-generated surface model for creating a 3D-print. First, PhotoScan aligned the images by identifying and matching common pixels between the overlapping portions of photographs. These pixels were then used to generate a point cloud, and each dot was assigned a spatial reference with an X, Y, and Z coordinate. Second, the point cloud was refined using PhotoScan to eliminate poorly referenced pixels. The third step was the generation of a surface model, which was made by creating faces between the dots of a point cloud. The surface model was then exported to the open source software MeshLab version 1.3.2 (http://meshlab.sourceforge.net/), which was used to remove duplicated and null faces from the surface model. The fourth step was to transform the surface model into a 3D block model. The block model was created from open source software, and Blender for Windows, release 2.69 (http://www.blender.org) was used to add the base directly onto the surface model, to provide rigidity and support. The replica was printed using a Z Corp Z-310 3D-printer that employs gypsum powder and a binder, and constructs the model at a layer thickness of 0.076 to 0.254 mm (0.003 to 0.01 in).

RESULTS AND DISCUSSION

The processing time from collecting photographs until obtaining the replica in-hand was two weeks for both test cases. However, this length of time can be reduced: taking the photographs in the field required about 1 hour, processing time for the software was approximately 16 hours, and the actual printing took 4 to 6 hours to complete. With a concerted effort, one could photograph an object and have a replica delivered within a few days, depending on the scope of the project. It should be apparent that this time will increase with anything beyond hand specimens, such as the examples presented here.

The resolution of the printed replica tracks is correlated with image geometry and distance between the camera and the subject. The images of the *Anchisauripus* track were taken oblique (image angle was 40° to 60°) to the surface, creating inconsistent overlap within adjacent images. The images of the carnivore track were captured near parallel (angles between 85° and 90°) to the ground surface, providing a consistent overlap amongst adjacent images and thus provided a more uniform geometry between adjoining photographs. Furthermore, the replica of the *Anchisauripus* track was created using images that were taken 1 m (3.3 ft) above the actual track, whereas the unidentified carnivore track was photogrammetrically captured at a distance of 0.3 m (1 ft). As such, mm-scale features such as cracks in the *Anchisauripus* track are not apparent in the reproduction. In contrast, the quality of the carnivore track reproduction approaches the printer limitations. Submillimeter features are rendered in the replica, such as the mm-scale micro-dunes that are apparent on the surface of the track. Resolution is however restricted because sand-grain size features (~0.25 mm/0.01 in) in the digital model are not present in the 3D model.

High-resolution photogrammetry and associated 3D-prints of paleontological resources could be considered a form of preservation. The photogrammetric data can provide insights to degradation of resources using episodic photo-sets, thus monitoring can qualitatively assess change in resources (Matthews, 2008). The 3D-printing and digital data provide a means to record, collect, and study fossil tracks like those found within WHSA which are ephemeral and are otherwise too fragile to collect. Even when fossils are collected, they are quite often too sensitive for transportation because of the rarity or risk for loss. With photogrammetric data and the resulting digital information, a model can be prepared and shipped, or the fossils can be sent electronically, easily allowing others to print their own reproduction if desired. In the example of the Anchisauripus track, a 3D-print represents a mode to expand outreach and education for resource interpretive staff. A 3D-print will not compromise the security of the actual location, yet provides a tangible artifact to enhance the connection between the resource and the public beyond just a photograph.

CONCLUSIONS

The 3D models rendered from the photogrammetric information improve efforts for the protection, preservation and understanding of sensitive and easily disturbed or damaged resources. The photogrammetric data enhances documentation and long-term conservation efforts by providing a baseline 3D specimen to measure for subsequent photogrammetric analysis. Furthermore, photogrammetric data can be disseminated anywhere. Photogrammetry combined with the ability to generate a scale reproduction enhances public land managers' ability to share resources for remote study by researchers and can also provide material for visitor education and outreach.

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*Mention of trade names, businesses or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

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ARTICLE

UP, UP, AND AWAY: THE USE OF UNMANNED AIRCRAFT SYSTEMS FOR PALEONTOLOGICAL DOCUMENTATION

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ABSTRACT—The Bureau of Land Management (BLM) has pioneered the use of photogrammetry for capturing detailed three-dimensional information on paleontological resources, as well as a variety of other natural resources found on public lands. Not only has the BLM been at the forefront of this digital capture technology, but they have streamlined techniques for field use and have provided training in photogrammetric techniques to researchers around the world. While many subjects can be easily photographed from the ground, some sites require an elevated perspective, necessitating the use of a variety of different platforms to capture imagery for photogrammetric processes. The use of Unmanned Aircraft Systems (UAS) for paleontological resource documentation was first used by the BLM at the Red Gulch Dinosaur Tracksite (RGDT) in Wyoming in 1998. A remote controlled hobby aircraft equipped with a 35mm film camera was used to capture imagery over the main track-bearing surface at RGDT. These early flights provided unique imagery and a wealth of valuable experience. For any photogrammetric method, ground-based or aerial, guiding principles still apply and include capturing high-quality images with proper stereoscopic (66%) overlap, and accurately and completely controlling the subject.

Advancements, both in legislation (Paleontological Resources Preservation Act of 2009) and unparalleled advancements in technology provide new and creative ways to find, document, and study paleontological resources. While a Secretarial Order in 2003 placed limitations on the use of government (federal, state, and local) and university owned and operated UAS in the national air space, advantages can be gained from utilizing this technology. By looking back at the techniques utilized by BLM to document in situ paleontological resources, we can look forward to the efficiencies gained through emerging technologies. Advancements in science and instrumentation have improved the level to which resources can be documented and monitored to better preserve and interpret our paleontological resources for current and future generations.

INTRODUCTION

The Bureau of Land Management (BLM) has pioneered the use of photogrammetry for capturing detailed three-dimensional information on paleontological resources, as well as a variety of other natural resources found on public lands in the western United States. Photogrammetry is the science of making measurements from imagery, which utilize the principals of perspective viewing and stereoscopic images to produce accurate measurements. Through much of the mid- to late 20th century, photogrammetry was mainly used for aerial reconnaissance and topographic map making. However, BLM staff expanded the traditional aerial process, forming a hybrid method that combined photogrammetry and surveying. The hybrid method streamlined digital close-range photogrammetric capture techniques for field use (Breithaupt and Matthews, 2001; Breithaupt et al., 2004; Matthews et al., 2006; Matthews and Breithaupt, 2009). BLM Technical Note 428 (Matthews, 2008) provides documentation on the use of close-range photogrammetry and has been used to provide training in photogrammetric techniques to researchers around the world (Fig. 1B) (Breithaupt and Matthews, 2011).

Advances in digital cameras, computer architecture, graphic processors, multi-view matching software, and cloud computing provide great advantages for field processing. However, the best results are achieved by following five basic recommendations. First, an object of known dimension must be in the stereo overlap of at least two photos. Second, images should be in focus with good contrast to accentuate subject texture. Third, consistent focus and focal length should be maintained during image capture. Fourth, images should be taken with an ideal overlap of 66%. Fifth, a redundant set of images should be taken with the camera turned at 90° for camera calibration (Matthews and Breithaupt, 2011; Matthews et al., 2012).

While traditional aerial photogrammetric software predominantly derived measurements from a single stereoscopic pair (two adjacent photos which overlap each other), the new generation of photogrammetric software utilizes hundreds of digital photos and produces dense point clouds of 3D data in a matter of minutes. The resulting 3D surface data contain hundreds of thousands of very precise x,y,z coordinate locations (accurate to the subpixel level). Each data point can also carry an RGB (Red, Green, Blue Color Model) value depicting the natural color of the subject (Breithaupt et al., 2012).

While many subjects can be easily photographed from the ground, some sites require an elevated perspective. BLM has a history of utilizing a variety of different platforms to capture imagery for photogrammetric processes. These include both aerial and ground-based platforms. A nadir (or overhead) perspective can be achieved from the ground by using tripods of various heights (1 to 10 m [~3

FIGURE 1. **A**, preparation for low-level imagery collection using digital SLR camera mounted below Bell Ranger helicopter of the Moccasin Mountain Tracksite near Kanab, Utah, summer 2008; **B**, ultralight image collection over the Red Gulch Dinosaur Tracksite (RGDT), Wyoming, summer 1999; **C**, monopod mounted camera with remote trigger, Laetoli Hominid Tracksite, Tanzania, spring 2011; **D**, setting up the Gigapan robotic mount to collect high resolution imagery at RGDT, summer 2012; **E**, 10-meter tripod used to collect imagery at RGDT, summer 1999; **F**, 1.5-meter tripod used for imagery collection at RGDT from 1998 to 2001.

to 33 ft]) (Figs. 1E and 1F), or by utilizing a monopod (extended overhead up to 3 m [10 ft]) with remote trigger (Fig. 1C). Several applications for smart devices not only allow for remote triggering, but also provide real time viewing, making stereoscopic image acquisition from the monopod very efficient. Another ground-based option for getting very high resolution stereoscopic images is the use of telephoto lenses and tripod heads designed to capture panoramas (e.g., Gigapan robotic head). The resulting panoramas, captured with proper geometry in relation to each other, can be stitched into very large (several hundred megapixels, even gigapixels) images (Fig. 1D). Specialized software removes lens distortions and creates a virtual stereo image (Breithaupt and Matthews, 2011; Mudge, 2012).

In addition to ground-based camera platforms, a variety of aircraft have been used to capture nadir imagery at RGDT, as well as a variety of BLM managed paleontological resources. These platforms include manned aircraft, such as helicopters, ultralights, and single-engine fixed-wing aircraft; and unmanned platforms such as blimps and Unmanned Aircraft System (Figs. 1A and 1B) (Breithaupt et al., 2004; Matthews et al., 2006, 2010a, 2010b, 2011; Chapman et al., 2012).

BACKGROUND

Unmanned Aircraft Systems (UAS) were first used for paleontological resource documentation in 1998 by the BLM at the Red Gulch Dinosaur Tracksite (RGDT). The RGDT is a 1,600 m2 (17,000 ft2) area of public land administered by the Bureau of Land Management's Worland Field Office. The site lies on the eastern edge of the Bighorn Basin of northern Wyoming and is located between the towns of Greybull and Shell. Pat Shea, the BLM Director at that time, visited the site and recommended that the best science be used for documentation and management of the RGDT. This directive provided the opportunity to test and refine a variety of different documentation techniques, making the Red Gulch Dinosaur Tracksite one of the most thoroughly documented sites of its kind (Breithaupt et al., 2001, 2004, 2006). In addition, the close-range photogrammetric techniques developed and refined at RGDT have proven effective for documenting vertebrate ichnological sites around the world (Breithaupt and Matthews, 2011).

From the beginning, photography and photogrammetry played an important role in work at RGDT, with the acquisition of commercial, large format aerial photography from a manned aircraft. While suitable for developing management and recreation plans, this imagery did not provide the level of detail needed to illustrate track and trackway relationships. For a commercial aerial photography mission to resolve objects as small as 2.5 cm (1 in), photography at a scale of 1:1,000 would be needed, which necessitates a flying height of 154 m (500 ft). However, is not legal for a commercial plane, even in unpopulated areas, to fly below 228 m (750 ft). To fill the gap between the close-range photogrammetry taken from a ground-based tripod at a height of approximately 2 m (7 ft) and the minimum height for commercial aircraft, a variety of aerial systems were tested (Matthews et al., 2006).

REMOTE CONTROLLED AIRCRAFT

During the fall of 1998 and late summer of 1999, low-altitude, remote controlled airplanes (LARCA) were used to capture imagery at RGDT. The first LARCA consisted of an Olympus 35mm Single Lens Reflex (Model OM 2n) camera mounted, in a container, on the underside of a front engine Senior Telemaster aircraft. The plane had a 2.44 m (8 ft) wingspan and MVVS 1.44, 2-cylinder engine (Fig. 2A). The film camera was equipped with an automatic frame advance, although the roll size was limited to 36 exposures. Eight missions were flown during a 3-day period, seven in natural color and one in black and white. The flyovers were considered a success because the main track surface and important outlying exposures were photographed. At a flying height of 20 m (66 ft), using a 50 mm lens, an image resolution of 0.5 cm (0.2 in) was achieved. Because there was no through-the-lens viewing, alignment of the camera over the target area was done visually from the ground (Fig. 2B). This resulted in some misalignment of photos, but with the number of missions all of the areas were covered.

As a result of the October 1998 flyovers, several issues surfaced with respect to inefficiencies in the aircraft and camera mounting system. Steps were taken to improve the camera and aircraft. A utility styled, 3-wheeled aircraft with rear mounted, 32.5 cc, 2-cycle engine and 2.4 m (8 ft) wingspan provided a much more stable ride (Fig. 2C). Mission duration was increased to 120 minutes and a 250-exposure back was purchased, thus reducing the frequency of landings and takeoffs. The new platform and camera system were also tested at Chatfield State Park in the summer of 1999. In the late summer of 1999, this LARCA was used for flyovers at the RGDT (Fig. 2D). Although this aircraft itself performed better, problems with the 250-exposure film back occurred during flight. This necessitated the use of the 36-exposure film back, resulting in limited use of the LARCA at the RGDT.

Camera motion was a noticeable problem for all pictures taken from the LARCA. Aerial cameras take still pictures while the plane is moving, which may result in blurred images. For higher altitude aerial photography, this is of little consequence, or has been solved through the use of forward motion compensators on the aerial mapping cameras. However, when trying to obtain high levels of detail at very large scales this becomes a problem.

Through-the-lens viewing was not available with either of the remote controlled airplanes. Since the camera position could not be 'controlled,' complete, systematic stereoscopic coverage of the trackside did not occur with these systems. The unsystematic distortions in the images—due to the tip, tilt, and yaw, which changed from image to image—made systematic correction of this imagery virtually impossible with the tools and software of the time. However, the photographs taken from the LARCA did provide good reconnaissance coverage, and were made into a useful digital photomosaic.

AERIAL CAMERA BLIMP SYSTEM

In June 2000, an Aerial Camera Blimp System (ACBS) was used at the RGDT to photograph the 'dry wash' and

FIGURE 2. Low-altitude, remote controlled airplanes were used to capture imagery at the Red Gulch Dinosaur Tracksite, WY during 1998 and 1999. **A**, prepping the Senior Telemaster aircraft for flight; **B**, remote piloting of the Senior Telemaster aircraft (circled in the upper left of image); **C**, utility styled, aircraft with rear mounted engine; **D**, utility aircraft flying over them main track surface.

selected outliers. The ACBS combined a helium-filled blimp with on-board video and still cameras which provided a real time view of the subject. The 6 m (20 ft) long blimp was inflated by approximately 12.8 m3 (452 ft3) of helium and was capable of lifting the on-board cameras to a height of 80 m (260 ft) above the ground. A tether/control cable was used to control the camera height and connected the blimp to the operator on the ground. The operator wore a harness that held a color-video display and remote camera controls. The on-board, color-micro-video camera and still camera provided the operator with an image of the area to be photographed. A swivel mount (equipped with pan and tilt motors) suspended on the underside of the blimp rotated the camera to align it with the targeted area. This mount also allowed the camera to hang plumb and offered a degree of self-leveling (Fig. 3A) (Breithaupt et al., 2000; Matthews and Breithaupt, 2001; Matthews et al., 2001).

The on-board video monitor of the Aerial Camera Blimp System provided for 'controlled' placement of each image. Thus, complete, systematic stereoscopic coverage of the 'dry wash' was accomplished. The pan and tilt motors, and the self-leveling nature of the camera mount removed much of the distortions due to tip and tilt. However, yaw was still a factor when photography was attempted during windy conditions.

Systematic stereoscopic coverage of the 'dry wash' was taken in black and white with the medium format (45- x 60-mm) still camera. Several higher altitude views of the site were taken using 35-mm color film, with the camera set at an oblique angle in the swivel mount. Flight heights were determined based on desired scale and width to be covered. The camera was set on auto exposure, the focus preset, and a fast shutter speed used. The B&W film taken at the site was developed in a portable darkroom, allowing for in-the-field verification of stereoscopic coverage. The resulting improvement in systematic stereoscopic coverage resulted in better photogrammetric processing.

Between 2000 and 2004, the ACBS was used to capture low-level aerial coverage for photogrammetric docu-

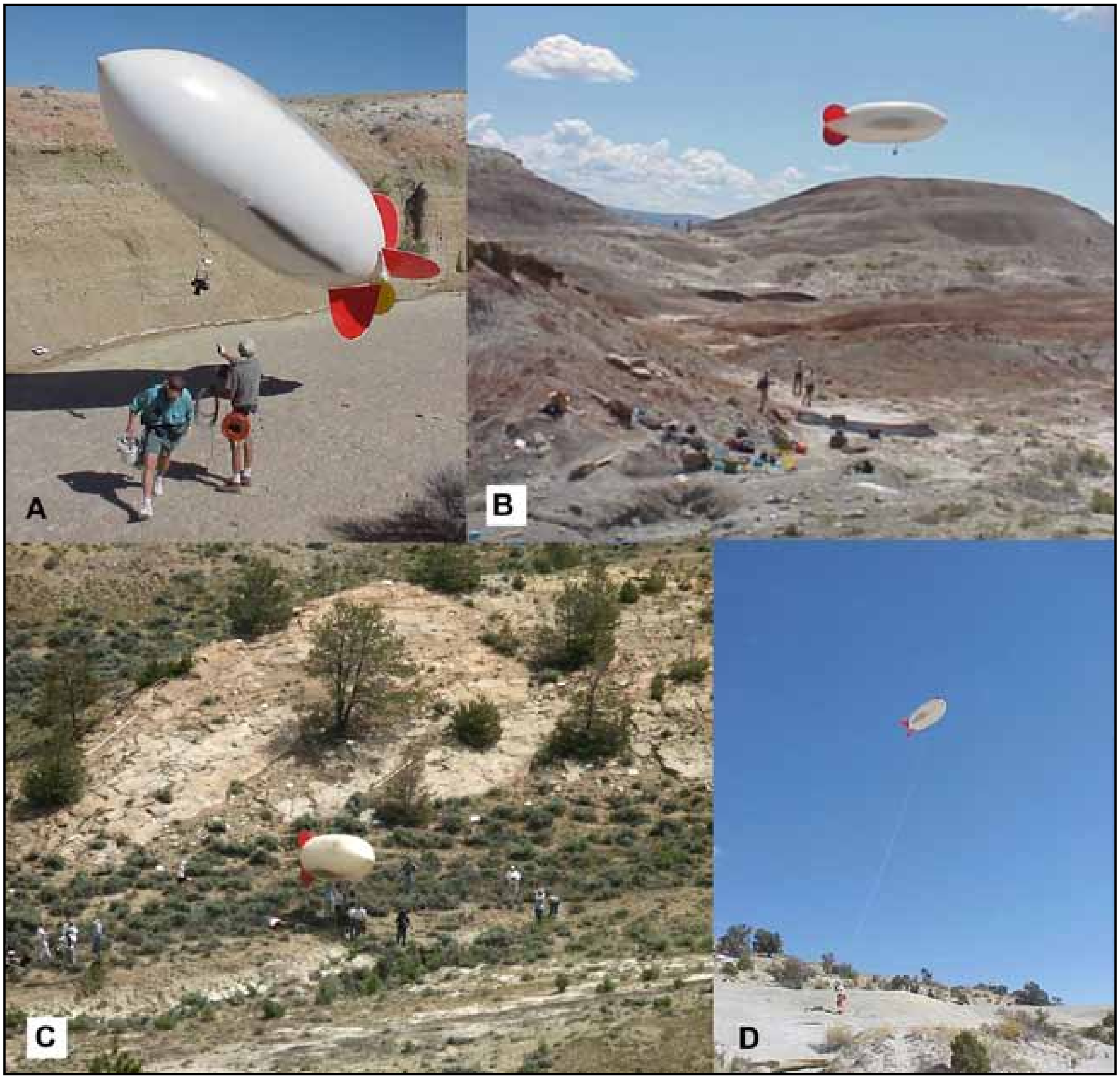

FIGURE 3. **A**, Details of the camera mount and tether to operator of the Aerial Camera Blimp System (ACBS) used at the Red Gulch Dinosaur Tracksite, Wyoming, summer 2000; **B**, ACBS over excavation of a Morrison Formation dinosaur bone bed near north of Red Gulch Dinosaur Tracksite, Wyoming, summer 2000; **C**, volunteers assist ground crew with ACBS operations at Dante's Tracksite near Cody, Wyoming; **D**, ACBS capturing stereoscopic imagery at the Twentymile Wash Dinosaur Tracksite, Grand Staircase Escalante National Monument, Utah.

mentation at a variety of BLM paleontology sites (Fig. 4). The excavation of a Morrison Formation dinosaur bone bed near Greybull, Wyoming was documented for successive seasons (Fig. 3B) (Breithaupt et al., 2000; Matthews and Breithaupt, 2001; Matthews et al., 2001). Two dinosaur tracksites, in addition to the RGDT, were documented using the ACBS: Dante's Tracksite near Cody, Wyoming, (Fig. 3C) (see Wegweiser, et al., this volume; Matthews et al., 2003) and Twentymile Wash Dinosaur Tracksite (TWDT) in Grand Staircase Escalante National Monument, Utah (Matthews et al., 2002, 2005; Matthews and Breithaupt, 2006).

The Twentymile Wash Dinosaur Tracksite (also known as Collett Wash Dinosaur Tracksite) is a 400 m (1,300 ft) long bench of the Middle Jurassic Entrada Sandstone. Due to the length, a topographically complex surface, and the spatial distribution of the tracks and traces, using traditional grid mapping methods at TWDT would have been very difficult and time consuming. Preliminary mapping of mapping of a portion of the site was conducted in 1998 (Foster et al., 2000; Hamblin and Foster, 2000). In addition, the somewhat friable nature of the sandstone, combined with public visitation of the site, made this a very good candidate for low-level, high-detail photogrammetric

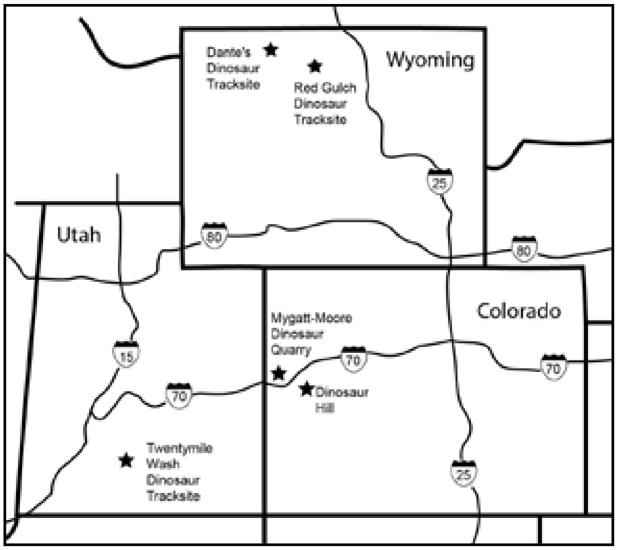

FIGURE 4. Bureau of Land Management paleontological localities documented using unmanned aircraft.

documentation. The ACBS was used to image the site in stereoscopic coverage, which was used for photogrammetric mapping (Fig. 3D), making TWDT the first dinosaur tracksite to be completely mapped using photogrammetry prior to complete documentation by traditional methods. As a result of the documentation, more than 1,000 tracks and related traces were identified and mapped in 3D space (Matthews et al., 2002, 2005; Matthews and Breithaupt, 2006).

MODERN UNMANNED AIRCRAFT SYSTEMS (UAS)

During the last 10 years, the use of UAS for military purposes has increased dramatically, resulting in an increase in technological capabilities of these system and use across the civilian sector. The term 'Unmanned Aircraft Systems' includes the unmanned aircraft and the support system necessary to operate the aircraft. This support system includes a computer-based control station, data links, telemetry, communications and navigation equipment, and a ground crew of pilots certified in safe and proper flight of the aircraft. The National Unmanned Aircraft Systems program within the Department of the Interior (DOI) utilizes retired military UAS to fly missions on public lands. Many state and local governments utilize commercially available UAS for assistance to law enforcement.

To ensure public safety, privacy, and airworthiness of UAS, Secretarial Order 3250 was signed on September 30, 2003. This order places limitations on the governmental use of UAS in the national air space and provides guidance on their operations and management. The Federal Aviation Administration (FAA) administers this guidance. At present there are only two methods of gaining FAA approval for flying UAS. Government (federal, state, and local) and university owned and operated UAS can fly under a Certificate of Authorization (COA). Civilian owned UAS for experimental purposes may fly under a Special Airworthiness Certificate—Experimental Category (SAC-EC). Currently, commercially operated UAS are not authorized to fly in the national air space. Privately owned model aircraft flown solely for hobby or recreational reasons on public lands do not require FAA approval.

In January 2014, the FAA and the DOI signed a new document that will allow the BLM and other DOI agencies to fly with a simplified COA. This will streamline the processing of scientific applications, wildlife surveys, and search and rescue operations over DOI lands. While guidance is yet to come from the DOI-Office of Aviation Services and the BLM National Aviation Office, it is anticipated the simplified process will significantly reduce standard wait times of 3 to 6 months for FAA review.

The BLM has been proactive in the use of UAS by partnering under the National Unmanned Aircraft Systems program and with local government entities to image a variety of resources. Current systems have been utilized for wildlife counts, land slide and hazard monitoring, hazardous materials remediation, and paleontological resources mapping. The Museum of Western Colorado and BLM partnered with Mesa County to obtain low-level imagery of two paleontology sites within the McInnis Canyons National Conservation Area near Grand Junction, Colorado. Dinosaur Hill (also known as Riggs Hill) was imaged in 2011 and in 2013 the Mygatt-Moore Dinosaur Quarry was imaged (Fig. 5). Both of these sites are on BLM-administered lands and are open and interpreted to the public. The stereoscopic aerial imagery collected over the Mygatt-Moore Dinosaur Quarry will be used for geologic mapping and fossil location.

SITE PREPARATION SECTION

There are other factors which can affect the success of a photogrammetric mission that are not directly related to the aerial platform or the camera system. It is often advisable to address these factors during mission planning prior to arrival at the site. The areas to be photographed should be identified and prioritized in advance. These areas should then be delineated by bounding geographic coordinates (e.g., GPS data points). Visual delineation on the ground is also useful and can be accomplished by laying out large round objects (e.g., orange, plastic 5-gallon bucket lids) that will be visible to the remote pilot and/or camera operator. It is also useful to mark features of interest in some way, so that they are easily distinguishable in the resulting imagery. When appropriate, the area to be imaged should be cleaned and extraneous material should be removed.

Another component of site preparation is providing a method to incorporate real-world units to the final products. In some cases, the accurate geographic location of the final data set may be required. In this case, a high order ground control survey using Real Time Kinematic GPS should be conducted and those points monumented prior

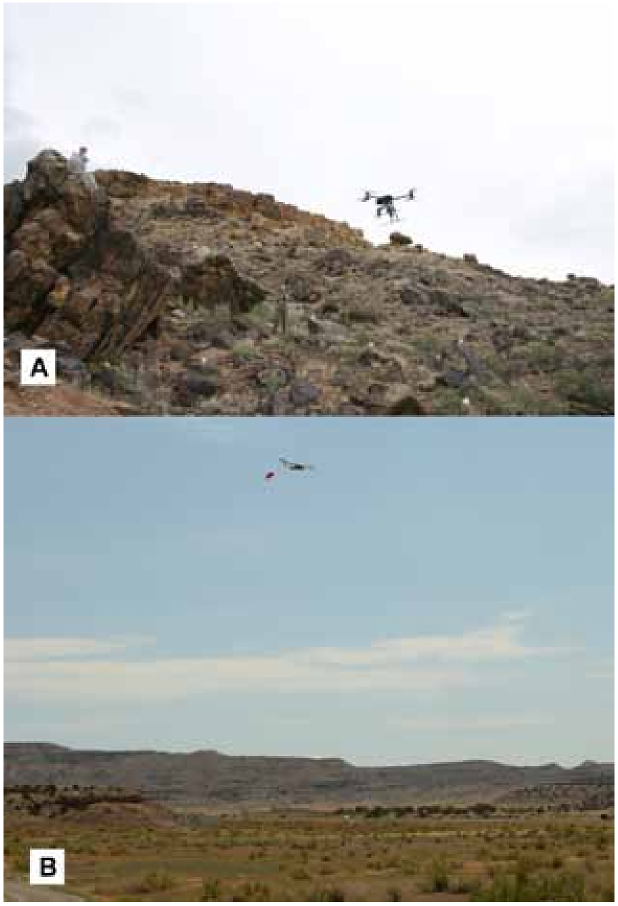

FIGURE 5. **A**, multicopter type Unmanned Aircraft System (UAS) imaging paleontological features at Dinosaur Hill in the McInnis Canyons National Conservation Area (MCNCA) near Grand Junction, Colorado, spring 2011; **B**, fixed wing UAS preparing to land after successful imaging of the Mygatt-Moore Dinosaur Quarry, MCNCA, Colorado, summer 2013.

to collecting the imagery. To aid in identifying these points in the final imagery, these should be emphasized on the ground by adding some type of visible target around then. In some cases, the precision of the surface is of higher priority than precise geographic location. In these cases, the onboard GPS may be sufficient, but must be supplemented by objects of known length placed at multiple locations within the mission area. Objects of known length help with the calculation of scale and provide an internal check after photogrammetric processing. In order for either control points or objects of known length to be the most useful, they must be visible in two or more properly overlapping photographs. Complete records about camera setup, ground control markings, weather, date, and time of day are also extremely important to document.

An enthusiastic group of volunteers are invaluable for assistance with site preparation. Such groups have been successfully utilized at the RGDT, TWDT, and Dante's Tracksite to assist in cleaning and preparing the main track surface. Not only is the use of volunteers effective from a perspective of site preparation, but it is very valuable in engaging the general public to better understand management decisions and the scientific and educational values of paleontological resources.

DISCUSSION

The opportunities to utilize UAS for the documentation of paleontological resources has proven very valuable; not only for the unique view that only low-level imagery can provide, but also the knowledge gained for the photogrammetric processing of unique imagery sets. The various aerial techniques utilized at the RGDT have been foundational in establishing current methods for the low-level aerial documentation of paleontological resources utilizing digital cameras and more advanced UAS systems used today.

The most paramount concept, however, is the need for good, blurry-free images with proper stereoscopic (66%) overlap. To obtain this imagery, several important items must be consistently considered. These are:

- Determination of aircraft speed, image capture speed, image download time, and camera battery life.
- Determination of the most effective way to control coverage, alignment, and stereoscopic overlap.
- Determination of aircraft payload, as well as the weight, shape, and size (length and width) of the camera.
- Isolation of the camera from aircraft vibration and minimization of the tip and tilt of the camera.
- Development of GPS or dimensional control of subject.
- Preparation of the site, including cleaning and appropriate marking of features of interest to distinguish them on the photos.
- Coordination of additional people to help with the cleaning of the site, the placing of ground control, and assistance to the aircraft pilot, as well as interacting with the public as necessary

CONCLUSIONS

Over 15 years ago, the BLM director instructed that the best science be used for documentation and management of paleontological resources at the RGDT. Since that time not only has the Omnibus Public Land Management Act, which includes the Paleontological Resources Preservation subtitle (PRPA), been put in place, but UAS and digital technology have seen unparalleled advancements. These changes should cause resource managers and researchers alike to take a new and more scientifically appropriate look at ways that paleontological resources can be found, documented, and studied. By looking back at the techniques utilized by BLM to document a number of its in situ paleontological resources, we can look forward to the efficiencies gained through emerging technologies, as advancements in science and instrumentation improve the level to which resources can be documented and monitored, thus better preserving and interpreting our paleontological resources for current and future generations.

ACKNOWLEDGEMENTS

PRPA mandates that paleontological resources be managed and preserved on public lands utilizing scientific principles and expertise. To that end, state-of-the-art UAS have been utilized by the BLM for the past 15 years for paleontological resource documentation and management. The management of these resources has emphasized interagency coordination and collaboration with various partners, the scientific community, and the general public. These projects were performed under various BLM Paleontological Resources Use permits. This work could not have been done without the assistance of scores of individuals. Appreciation is extended to all of the people involved with our many UAS projects performed throughout the Rocky Mountain West. In particular, B. Southwell, T. Adams, T. Lumme, N. Fraser, G. Fielder, L. Cunningham, A. Titus, J. Smith, K. Cayhill, V. Barkas, D. Kett, R. Baugh, R. Workman, J. Foster, R. Hunt-Foster, B. Miller, S. Gerwe, C. Miser, and A. Bell were invaluable to the success of these projects. In addition, thanks to the various volunteers from across the country who also assisted in these projects.

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ARTICLE

THE FEDERAL MANDATE FOR MITIGATION PALEONTOLOGY

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INTRODUCTION

Mitigation paleontology is a business and is the only subdiscipline of paleontology where employment is currently expanding (Fig. 1). However, mitigation paleontology also follows the same boom-bust cycle that is associated with the development of natural resources on America's public lands. Mitigation paleontologists develop technical reports for federal agencies to allow managers to make decisions using scientific principles and expertise. Work typically includes some combination of literature and geologic map reviews and museum record searches, pre-disturbance pedestrian surveys, construction monitoring and impact mitigation, and post-construction museum deposition of scientifically important fossils and associated data.

AUTHORITIES FOR MITIGATION PALEONTOLOGY

There are many laws and rules that apply to mitigation paleontology, and this partial list of federal mandates is not comprehensive. For example, paleontology is included in lesser known Acts that may or may not apply to proposed work, including the Cave Resources Protection Act, the Reservoir Salvage Act, and others. The following is a partial list that specifically applies to lands administered by the Bureau of Land Management:

Antiquities Act of 1906 (P.L. 59–209, 34 Stat. 225, 16 U.S.C. 431–433)—is often cited, but rarely presents a mandate for mitigation paleontology. However, the Antiquities Act represents some of the earliest legislation that applies to public lands calling for preservation of resources, in this case 'objects of antiquity.' The term 'object of antiquity' is vague and is no longer used as a primary authority for the management and preservation of paleontological resources, but the history and effect of the Antiquities Act should not be overlooked.

National Environmental Policy Act of 1969 (P.L. 91–190, 83 Stat. 852, 42 U.S.C. 4321–4347)—is the most cited authority for mitigation paleontology because of its wide-ranging call for all areas of significance to be considered prior to disturbing the land, and to "preserve important historical, cultural, and natural aspects of our national heritage."

Federal Land Policy and Management Act of 1976 (P.L. 94–579, 90 Stat. 2744, 43 U.S.C. 1701–1785)—applies two mandates to public lands. The first is to preserve for future generations the natural and cultural values found on the land. The second calls for the use, for the public benefit, of resources found on the land. The dual mandate of FLPMA only applies to lands administered by the Bureau of Land Management, but the U.S. Forest Service has similar multiple-use mandates.

FIGURE 1. Oil and gas development in the Uinta Basin, BLM Utah, 2007.

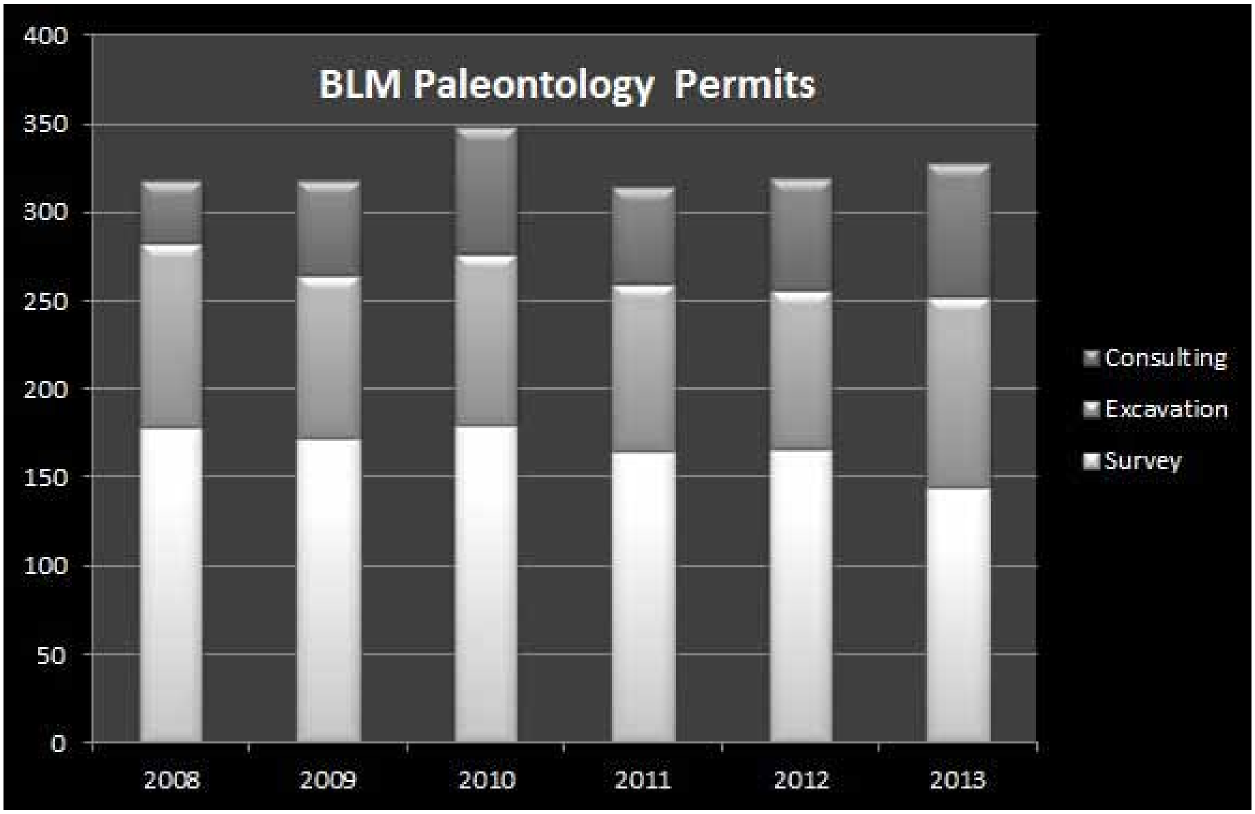

FIGURE 2. Paleontological resource use permits issued by the BLM between 2008 and 2013.

Paleontological Resources Preservation Act of 2009 (P.L. 111–11, 123 Stat. 991, H.R. 146)—calls for the preservation of paleontological resources. PRPA is not a mitigation law and does not specifically call for mitigation work, so federal agencies, mitigation paleontologists, and land use proponents should be careful when justifying mitigation activities solely on the mandates of the PRPA. PRPA also only applies to public lands and not to Indian, military, state or private lands. What the PRPA does do is state that federal land managers must preserve and protect paleontological resources on federal lands using scientific principles and expertise. The effect of PRPA has been the inclusion of paleontological considerations in NEPA analyses.

MITIGATION RESEARCH

The goal of mitigation paleontology is to preserve paleontological resources and associated data. This may, but often does not, lead to actually conducting research. Mitigation paleontologists, while highly qualified to conduct research, are normally subcontractors for environmental firms; construction, land development, and energy development companies; public utilities; and other entities. They are employed to conduct surveys and preserve resources, and maintain compliance with environmental laws. Basic research is rarely funded. However, when done correctly mitigation paleontology results in the long-term preservation of resources and associated data for future research.

It is occasionally stated that "oil and gas development is good for paleontology because new resources are discovered." This may or may not be true. If paleontological resources are not adequately preserved, and if subsequent research does not occur, then the benefit is minimal, and due to ground-disturbing activities context is lost forever. Mitigation paleontology, when done correctly, anticipates future research needs and successfully preserves some of the original context through technical reports, salvage of specimens, and pre-work photos and mapping.

PALEONTOLOGICAL RESOURCE USE PERMITS

Assessing the potential effects to paleontological resources prior to land disturbing activities and mitigating those effects during and after activities requires a combination of paleontological knowledge and field experience. Not all paleontologists are trained or prepared for this type of work, and non-paleontological specialists are rarely educated in recognizing both the identity and paleontological significance of fossils. This is why it is critical that all aspects of mitigation paleontology be carried out by experienced mitigation paleontologists and that evaluation of qualifications also be made by experienced paleontologists working for or on behalf of the land management agency.

Field methods and criteria for evaluation of paleontological resources are significantly different than those used in archeological evaluations, often called cultural resource management (CRM). While CRM specialists may understand many of the laws and bureaucratic procedures that apply to paleontological assessment and mitigation, the similarities end there. Few professional archeologists or geologists are adequately trained or experienced to do both types of field work and if they are, the methods and nature of work are sufficiently different as to make the mixing of CRM and paleontological mitigation crews impractical. Paleontology is a geological science that requires advanced understanding of stratigraphy, sedimentology, and paleobiology. Generally, archeological landscapes are confined to the surface of the ground or near-surface. Artifacts are rarely observed or collected out of solid bedrock. However, it is out of sedimentary bedrock that nearly all paleontological resources originate. The differences between CRM and paleontological assessment and mitigation cannot be overstated.

BLM typically issues between 320 and 350 permits in a given year. The number of consulting permits has been rising slightly in the past few years as work in the field has increased (Fig. 2). Note that mitigation paleontologists vary the size of their workforce in response to work (not captured in the above graph). It is the responsibility of the BLM permitting officer to ensure that all of the consultants that hold BLM consulting permits are qualified to do paleontological assessment and mitigation. There also needs to be a high level of scrutiny when issuing consulting permits. Work under BLM research permits normally includes having students in the field who will have variable levels of knowledge and experience with paleontological resources. All research field work should be supervised by an experienced paleontologist, normally the principal investigator on a survey or excavation permit. If a fossil is broken by a paleontologist during the course of research or excavation, the damage is normally limited to a single bone. Paleontological mitigation consultants (holding consulting permits) have a much greater responsibility. If an area is not identified correctly during scoping, entire localities or even entire geologic basins may be overlooked. If a paleontologist fails to identify an important paleontological resource during a monitoring assignment, full skeletons or entire paleontological localities will be destroyed forever without notice. A single 'windshield' survey of an area may result in a paleontologist missing entire fossil exposures, causing the area to be 'cleared' for surface disturbance without ever evaluating important paleontological resources. With mitigation paleontology the cost of failure to both the bureau and the science of paleontology is extremely high, so it is imperative that permitted paleontological consultants and their field crews be fully qualified to do the work that they propose to do. Apprenticeship is acceptable and necessary, but a qualified paleontologist must also be present for all stages of work.

APPROVED REPOSITORIES

Repositories are approved on a permit-by-permit basis. This is a misconception that once a repository is found compliant with federal or professional standards that it becomes 'federally approved.' In fact, approval is on a case basis for each permit or project. A repository may state that it has been found to be 'federally compliant' but still may not be approved, even if it meets the minimum standards required to house and care for federal museum collections. Being approved includes additional factors such as possessing adequate knowledgeable staff and an appropriate scope of collections. These standards are generally similar to those put forward by professional organizations, such as the American Alliance of Museums (AAM). In the Department of the Interior, this would be similar to being compliant with departmental manual 411.

FEDERAL ORGANIZATION

The differences between archeological and paleontological sciences underscore the importance of agencies using qualified paleontologists to evaluate paleontological resource management decisions. Agency paleontology coordinators are often trained as archeologists or geologists and are effective at managing paleontological resources only when they consult frequently with professional paleontologists. In the BLM this role is normally filled by a regional paleontologist who will be assigned at least three regions which each cover more than 70 million acres. The regional paleontologist will then work with state paleontology program leads (often a collateral duty for the state archeologist and deputy preservation officer) and district and field office paleontology coordinators (normally a collateral duty of an archeologist or geologist). Because non-specialists are assigned the complex task of managing paleontological resources on public lands, is it important for the bureau to coordinate with non-federal partner paleontologists. Mitigation paleontologists offer information and advice to bureaus that is considered when making resource management decisions. When done correctly, the results of mitigation paleontology allow bureaus to successfully manage paleontological resources using scientific principles and expertise.

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ARTICLE

A FOUNDATION FOR BEST PRACTICES IN MITIGATION PALEONTOLOGY

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ABSTRACT—Mitigation paleontology focuses on the recovery and preservation of paleontological resources (fossils) that are threatened by ground disturbance associated with land and energy development projects. Mitigation includes the assessment of potential impacts and the development of measures to reduce or eliminate adverse impacts to scientifically important fossils, as well as the implementation of those measures. Despite several decades of steady progress with the development of standard procedures and regulatory guidelines for the assessment and mitigation of impacts, neither mitigation paleontologists nor the regulatory agencies that oversee their activities have been successful in developing industry-wide standard operating procedures. Best practices are methods and techniques that have consistently shown results superior to those achieved by other means, and are used as a benchmark for judging the adequacy of mitigation. They are a standard way of doing things that multiple organizations can adhere to, although they evolve and improve over time. In this paper we propose comprehensive and detailed best practices for the mitigation paleontology industry that fall into ten categories: 1) qualifications and permitting, 2) analyses of existing data, 3) research models and scientific context, 4) field data collection, 5) field surveys, 6) construction monitoring, 7) fossil salvage, 8) data management and reporting, 9) curation facilities, and 10) business ethics and scientific rigor. Our purpose, with input from the mitigation community, is to establish procedures that are successful in maintaining a rigorous scientific standard while promoting integrity in the industry in order to accomplish the common goal of paleontological resource preservation via impact mitigation.

INTRODUCTION

Since the 1970s, regulatory protections for scientifically important fossils in the western United States have resulted in the recovery of vast numbers of these nonrenewable resources – many of which have been literally plucked from the path of bulldozers. From city and county regulations designed to protect paleontological resources from earth moving operations at residential and commercial construction sites in southern California, to state and federal policies developed largely in response to the increasing use of public lands by large-scale energy development projects for oil, gas, wind and solar energy; the trend is clearly towards resource management policies that are in favor of impact mitigation. The efforts of those who have been involved with policy development and implementation are laudable. After all, the recognition that paleontological resources are worthy of preservation and protection is an acknowledgement of their scientific value as finite and irreplaceable evidence of the history of life. The many benefits to science are illustrated by the vast amount of research that has been based on fossils collected as the result of impact mitigation projects.

Not surprisingly, paleontological resource regulatory requirements in combination with private development projects have created a new niche for paleontologists. The growing demand for mitigation paleontologists has to date resulted in at least two generations of paleontologists who, in addition to their academic and field training in paleontology, have expertise in working with fossils and associated rock strata exposed under the incredibly challenging field conditions that exist on construction sites, some of which are vast and in remote locations.

The last twenty years has seen an increase in employ ment opportunities for mitigation paleontologists – this at a time when funding to higher education and public funding for natural history museums has been sharply declining. In light of this, it is useful to consider the value, purpose and goals of the emerging profession of mitigation paleontology. As applied scientists, mitigation paleontologists are typically hired by private companies or less frequently, by government agencies. Under contract to such a client, a specific service, or set of services (scope of work), is provided. These services are often required in order to achieve regulatory compliance for the client's project. A common work product is a final project report, which is often necessary for the project proponent to obtain an environmental clearance for their project in the form of a license or permit, and/or to prepare other supporting environmental documents. A paleontological technical report may include recommendations for additional work that is needed in order to adequately mitigate potential impacts to fossils that would be exposed, damaged, or displaced as the result of project construction. An additional common work product is a collection of fossils typically made either prior to or during construction, or both. The prepared and identified fossils, along with associated data, are ultimately transferred to an approved curation facility. Such facilities are typically museums that are approved by the government agency that issues the paleontological resource use permit and/or grading permit.

Mitigation paleontologists, as applied scientists, are in a unique position to ensure that significant paleontological resources threatened with destruction by proposed development projects have the contractual responsibility to achieve their client's objectives in a manner that complies with agency regulations and meets accepted scientific standards as well as the expectations of the institutions with which they hold curation agreements. It is the added, although regrettably more nebulous responsibility of mitigation paleontologists, to ensure that all paleontological work is done to an acceptable standard of scientific rigor so that detailed, reliable data accompanies every fossil. Unless specifically requested by a client, it is typically not the purview of the mitigation paleontologist to conduct research on the fossils they salvage under contract, but rather to ensure that the fossils and associated data are in a condition that is suitable for research upon arrival at the curation facility.

Despite legislative achievements such as the Paleontological Resources Preservation Act (PRPA) of 2009, and the many benefits to science resulting from paleontological resource impact mitigation, significant challenges related to scientific integrity and ethical business practices exist and must be addressed. Some examples of ethical issues include instructing paleontological monitors at a landfill project to sit in their vehicles so they do not find any fossils in order to avoid incurring additional costs, reporting that adequate field surveys have been completed via so-called 'windshield surveys' or 'drive-by surveys,' staffing projects with 'cross trained' archeological monitors who do not possess sufficient paleontological knowledge to properly document and collect fossils, or failing to curate fossils collected from mitigation projects in appropriate curation facilities– there are far more examples than can be listed here.

If left unchecked, these and many other unfortunate practices will continue to undermine regulatory intent and do a disservice to the resources that regulations were designed to protect. What's more, such practices are not consistent with preserving paleontological resources using scientific principles and expertise, which should be the goal of all paleontologists and involved agencies regardless of the jurisdictional applicability of the PRPA. The root of the problem is a compounding of three primary factors: 1) market forces that reward the lowest bidder with the most consulting contracts because of a lack of incentive to pay for quality; 2) an unwillingness or inability on the part of managing agencies due to lack of resources, knowledge, or authority to provide consistent and meaningful oversight and ensure compliance with regulations, leading to an environment where permittees are not held accountable for the quality and quantity of their work; and 3) a lack of proper training and/or ethical standards.

With recent industry growth and more paleontologists (and non-paleontologists) striving to work in the field of impact mitigation, it is our belief that a critical juncture has been reached. Paleontologists working in this field need to develop industry-wide standard operating procedures based on rigorous and scientifically defensible principles. The purpose and goal of this paper is therefore, with a degree of urgency, to articulate the problems and challenges that currently exist in the field of mitigation paleontology and to offer an effective path toward a solution. We present a preliminary set of detailed, comprehensive best practices in mitigation paleontology that are intended to be complimentary to other existing standards and procedural guidelines such as those of the Society of Vertebrate Paleontology (SVP) and those federal, state and local agencies that have already developed such standards and guidelines. This paper does not represent agency policy, which is a topic worthy of separate papers. Nor is it our purpose to convey paleontological and geological knowledge or field skills, which is also a required prerequisite for practicing mitigation paleontology. Rather, with a combined perspective gained from working on well over a thousand mitigation projects over a period of decades, our focus is on the day-to-day tasks of background research, field surveys, construction monitoring, fossil salvage, data management and reporting, business practices, scientific rigor, fossil preparation, and 'museum' curation. It is our hope that this paper will demonstrate that there is more to mitigation paleontology than simply finding fossils at construction sites.

METHODS

Much of the information in this paper was gathered and synthesized by the authors based on their own experiences in mitigation paleontology. Additional information and input was obtained from colleagues working as consultants, in museums, and for government agencies. Fact-checking with regard to the standard archeological procedures discussed in this paper was done in collaboration with cultural resource management professionals. Agency paleontologists were consulted for the purpose of fact-checking paleontological resource laws, regulations, and policies. Unpublished paleontological data obtained from the Department of PaleoServices at the San Diego Natural History Museum from projects completed in San Diego County, California; and from SWCA Environmental Consultants from projects completed in Uintah and Duchesne Counties, Utah, and Garfield County, Colorado, were analyzed for the purpose of providing real-world examples to illustrate mitigation concepts in this paper.

The best practices described in this paper are summarized in Appendix A, and for quick reference the text of the paper includes reference numbers that correspond to numbered best practices in the appendix.

Following publication of this initial document, the authors will solicit feedback from the mitigation paleontology community including those involved with mitigation work in museums and government agencies. Based on this feedback, these best practices will be modified as needed to best meet the goal of the project as defined herein. Although it is expected that the best practices will evolve to improve over time, this initial document will serve as a road map for elevating the practice of mitigation paleontology, thus increasing the potential of achieving scientific rigor with professional integrity for the preservation of paleontological resources.

HISTORY AND SCIENTIFIC CONTRIBUTIONS

Given the stereotypical image of paleontologists collecting fossils in remote, picturesque badlands, many people are surprised to learn just how many fossils have been discovered in mining and construction excavations, and how many of these discoveries have been made in areas with little or no opportunities for fossils to be found on in natural outcrops due to lack of exposed sedimentary bedrock. Classic examples of such discoveries include remains of the first formally named non-avian dinosaur, Megalosaurus bucklandii (recovered from the Stonesfield limestone quarry near Oxford, England), the first recognized fossil remains of the ornithopod dinosaur, *Iguanodon* (recovered from the Whitemans Green quarry, near Cuckfield, England), famous fossils of *Archaeopteryx lithographica* (recovered from the lithographic limestone quarries near Solnhofen, Germany), the spectacularly preserved Messel plant and vertebrate fossils (recovered from the Messel Pit bituminous shale quarry in Messel, Germany), and the renowned Rancho La Brea Pleistocene mammalian fossil assemblages (initially recovered from commercial asphalt quarry excavations in Los Angeles, California, USA), to name just a few. Today, excavations for natural gas and oil well pads, pipelines, electrical transmission lines, renewable energy generation facilities, coal mines, gravel pits, highway new and existing highways, railway alignments, above- and below-ground public transportation systems, housing developments, commercial developments, urban developments, and underground parking structures, all provide excellent and unique opportunities for paleontologists to access fossils and the strata in which they are preserved in settings which may not have been made available via natural processes of weathering and erosion. Most major natural history museums in the western United States house substantial collections of fossils recovered as a result of fossil salvage projects at construction sites.

Following the first formal gathering of mitigation paleontologists at an annual meeting of the SVP in 2013, a sub-set of the authors of this paper (Knauss, Fisk, and Murphey) posted an online survey, the purpose of which was to prepare a report on the demographics of mitigation paleontology (Knauss et al., 2014). In conjunction with the survey, an effort was launched to compile a comprehensive database of peer reviewed scientific publications, theses and dissertations that involve fossils collected as the result of mitigation paleontology. This database, while still under development, is complete enough to estimate that the total number of such publications is in the hundreds. Furthermore, based on the preliminary data from the published literature, combined with data obtained from museums and other curation facilities, we estimate the total number of curated fossil specimens from mitigation projects to be in the millions.

BRIEF HISTORY OF MITIGATION PALEONTOLOGY IN THE UNITED STATES

For more than a century, the importance of preserving the United States' cultural and natural heritage has been recognized and addressed by legislation, including the Antiquities Act of 1906, the National Environmental Policy Act (NEPA) of 1969, Federal Land Policy and Management Act (FLPMA) of 1976, and the California Environmental Quality Act (CEQA) of 1970. A primary goal of these legislative actions was to require agencies to address concerns about development and other land uses that might impact significant and nonrenewable natural resources, including paleontological resources. CEQA specifically requires California state and local agencies "to identify the significant environmental impacts of their actions and to avoid or mitigate those impacts, if feasible." Local agencies such as county and city planning departments are tasked with maintaining compliance with CEQA and NEPA, thereby reducing impacts on resources to a level less than significant.

Following the passage of CEQA in 1970, Orange County was the first county in California to require mitigation of impacts to paleontological resources. The urban development of Orange County accelerated rapidly in the early 1970s and concerned citizens and scientists, including John Cooper, Carol Stadum, Larry Barnes, Mark Roeder, and Rod Raschke, lobbied for regulations to protect paleontological resources in the county as development increased and more land was disturbed (Babilonia and others, 2013). In response to these lobbying efforts, in 1972 the Mission Viejo Company hired one of the first paleontological monitors, Paul Kirkland. In 1976, as part of the conditions of approval for development, the County of Orange passed the first paleontological mitigation guidelines; Resolution No. 1977-866, requiring monitoring and salvage of fossils as part of the development process. This was followed a decade later by passage of Resolution No. 1987-516, requiring donation of paleontological finds from sites in unincorporated parts of Orange County to a central county facility "for the purpose of promoting scientific study and for display for the education and enjoyment of the people of Orange County."

These municipal resolutions required pre-construction surveys, impact assessments, and construction mitigation measures to prevent the destruction of fossils. However, although thousands of fossils were salvaged and housed at an Orange County facility, there were no provisions for these fossils to be accompanied by adequate field data or to be prepared, stabilized, and professionally housed for perpetuity in a repository where they could be retrieved for study. Even today, Orange County does not require that developers provide funds for preparation and curation of salvaged specimens. Fortunately, in 2009 Orange County Parks and California State University, Fullerton entered into an agreement to provide funding for a staff to manage a curation facility that meets the modern standards of professional collection care. CSU Fullerton's John D. Cooper Archaeological and Paleontological Center ('Cooper Center') in Santa Ana now serves as Orange County's authorized curatorial facility, with a large and growing collection of paleobotanical, invertebrate, and vertebrate fossils that document the unique paleontological record preserved in the sedimentary rocks of Orange County. Although still largely unstudied, this collection is beginning to attract the attention of numerous research paleontologists, students, and interested members of the public.

When adjacent California counties - Los Angeles, Riverside, San Bernardino, and San Diego - began to rely on mitigation paleontologists from Orange County to mitigate impacts, established museums in those four counties began to feel the burden of receiving large volumes of unprepared specimens without compensation for preparation and cabinet/storage space. Starting in the late 1970s, Robert (Bob) Reynolds, Earth Science curator at the San Bernardino County Museum and member of the San Bernardino County Environmental Review Committee, arranged meetings with museum curators and fossil salvage contractors to discuss differing standards, methods of salvage, and the unsustainable practice of 'dumping' salvaged specimens at museums or in warehouses. Participants in these discussions sought to create standard guidelines that would make assessment and salvage programs, methods of recovery, preparation and stabilization, and funded curation of specimens and associated field data 'conformable.'

Discussions focused on the necessity for advanced scoping of potential impacts using sensitivity maps; the need for adequate preconstruction assessment (including record and literature searches and field surveys); the importance of adequate full-time monitoring and criteria for reducing monitoring effort to half-time or spot-checking; the scientific value of salvaging not only skulls, but also post-cranial remains, small and microscopic vertebrate fossils, and associated environmental and habitat indicators; the necessity of preparation of specimens to a point of identification (thereby concurrently reducing storage volume and costs); and the need for funding for the curation of specimens, field data, and reports into an established repository.

In 1980, the City of Chula Vista in San Diego County began requiring residential developers to implement paleontological resource mitigation programs during mass grading operations. Soon other cities in the county (i.e., San Diego, Vista, Carlsbad, Oceanside, National City, and La Mesa) followed suit. The result was that a wealth of fossils ranging from Cretaceous ammonites, mosasaurs, and dinosaurs to Pliocene scallops, walruses, and baleen whales began to be salvaged from the upper Cretaceous through Pleistocene stratigraphic sequences along the coastal plain of San Diego County. By the early 1990s, even the California Department of Transportation (Caltrans) began to realize the significance and benefits of paleontological mitigation in the District 11 region (San Diego and Imperial counties) and issued the first on-call paleontological resource mitigation contract in state history. Fossils salvaged from District 11 roadway projects, together with fossils from the rampant growth of residential and commercial development in San Diego County during the 1980s and 1990s were deposited at the San Diego Natural History Museum (SDNHM). From the very beginning, the staff of this regional education, research, and curation facility realized the importance of avoiding the problems faced by Orange County in terms of the impact on institutions of receiving large amounts of unprepared and uncurated fossils. Fortunately, city and state environmental planners based in San Diego County also realized these potential problems and required paleontological mitigation contracts in the region to include provisions for preparation, curation, and long-term storage of salvaged fossils.

However, other regions of southern California were not faring so well during this period and seeing what was happening, Michael Woodburne, then President of SVP and a member of its Government Liaison Committee, appointed Bob Reynolds to chair the SVP Committee for Conformable Impact Mitigation in 1990. The existing southern California guidelines, already field tested in the states of California, Nevada, and Arizona on utility projects crossing federally (Bureau of Land Management [BLM]) administered lands as well as lands managed by counties and municipalities, were used as a template for guidelines that could be applied to agency managed lands elsewhere in the western states. A draft of the SVP "Standard Measures" was distributed for review in 1991 (SVP, 1991). The revised SVP "Standard Guidelines" were published in 1995 (SVP, 1995) and to strengthen the position of museums receiving salvage collections, in 1996 the SVP "Impact Committee" issued Conditions of Receivership (SVP, 1996). During 2009 and 2010, the SVP "Standard Guidelines" were reviewed, revised, and expanded by a committee co-chaired by Lanny Fisk and Bob Reynolds. The revised "Standard Procedures" are available online (SVP, 2010).

In 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law by President Barack Obama as part of the Omnibus Public Land Management

Act. PRPA requires that coordinated policies and standards be developed that apply to fossils on federal public lands. Section 6302 of the PRPA mandates that federal agencies "manage and protect paleontological resources on Federal land using scientific principles and expertise." Thus, federal agencies began looking to the professional paleontological community to implement these PRPA-mandated policies and regulations. It was partially in anticipation of new regulations that in 2009 the SVP re-activated the Conformable Impact Mitigation Committee as the Impact Mitigation Guidelines Revision Committee and invited input from federal and state land management agencies.

With the presentation of impact mitigation measures/guidelines/procedures by the SVP in 1991, 1995, 1996, and 2010 respectively, western states, federal agencies, counties, and other municipalities were able to adopt guidelines that would support the preservation of paleontological resources and associated data. In California, southern counties and several in the Bay Area (thanks largely to the efforts of Bruce Hanson) adopted guidelines. Examples were developed for San Bernardino County (1985), the BLM's California Desert Conservation Area (1985), Riverside County (1990; updated 2003 and 2008), San Diego County (2007; updated 2009), and San Bernardino National Forest (1995). Updated versions of these mitigation guidelines were prepared for the Needles (2005) and Barstow BLM (2008) field offices. With agency-specific modifications, Caltrans (2012) adopted similar guidelines.

As use of public lands increased from the late 1980s into the 2000s, largely tied to a surge in energy development projects (especially oil and gas), there was an increase in demand for mitigation paleontologists in the intermountain west, particularly in parts of Colorado, Wyoming, and Utah. Initially, the demand was met by paleontologists who were employees or associates of museums including the Utah Field House of Natural History Museum, the University of Colorado Museum, the Museum of Western Colorado, the Idaho Museum of Natural History, and the University of Wyoming Geological Museum. Small firms and independent consultants were soon established, agency positions were added (including highway department paleontologists in Colorado and Nebraska and BLM and United States Forest Service [USFS] paleontologists in multiple states), other museums became involved, and at least two larger environmental firms established paleontological resource programs. The BLM developed procedural guidance for paleontological resource management (1998), which included assessment and mitigation procedures, permitting and reporting requirements, and a resource management classification system (Conditions 1-3). The USFS revised its Fossil Yield Potential Classification (FYPC) system (2005), and the BLM adopted its own version of the FYPC, the Potential Fossil Yield Classification System (PFYC) in 2007. In 2008, the BLM released revised procedural guidelines for the assessment and mitigation of potential impacts to paleontological resources. Regulations under the PRPA are presently undergoing development and revision at the Departments of the Interior and Agriculture. In recognition of the ongoing demand for trained mitigation paleontologists, the South Dakota School of Mines and Technology continues to develop a curriculum with a track that prepares students for positions in paleontological resource management and impact mitigation, the first institution of higher education to do so.

1. QUALIFICATIONS AND PERMITTING

As with field-based paleontological research projects, paleontological resource use permits for are required for mitigation work on public lands in order to ensure that those who perform the work are qualified to do so, that regulations are complied with, and that the results of work is adequately reported to the land managing agency. In this section, we describe the complex state of permitting, while avoiding discussion of specific agency stipulations for obtaining paleontological resource use permits. While we do point out some serious problems, our intent is not to judge the adequacy of current permitting requirements (where they exist), but rather to establish a baseline set of minimal qualifications for principal investigators, field supervisors, and field paleontologists (technicians/surveyors/monitors) that can serve as industry best practices (1.1).

Several federal and state agencies require persons proposing to conduct paleontological mitigation work on public lands to apply for paleontological resource use permits (1.2). Agency review of these applications is designed to ensure that only qualified paleontologists are issued such permits, which in turn helps to ensure that paleontological resources are properly protected. In the absence of such a permit process, some city and county jurisdictions in southern California have a vetting process by which resumes are reviewed and approved individuals are placed on lists of 'qualified' or 'certified' paleontologists. However, there are agencies and jurisdictions in California, where despite regulations including the California Environmental Quality Act (CEQA) (see Scott and Springer, 2003), there is no mechanism for permitting or vetting potential mitigation paleontologists. For this reason, it is fair to view California as the state with the strongest paleontological regulations on one hand, and the least oversight on the other. The result of this odd combination is ironic for the many California paleontologists who have been active in mitigation paleontology for decades, since the participation of non-paleontologists in mitigation paleontology has led to the preventable destruction and permanent loss of scientifically important fossils and associated data. Any agency with regulatory oversight for the protection for paleontological resources that has not developed minimal qualifications and a vetting process for prospective mitigation paleontologists will undoubtedly experience a similar result. This problem is most wide-spread in certain jurisdictions and agencies in California. But the problem is not unique to California. Over the last several decades, the fact that so many non-qualified paleontologists have obtained paleontological resource use permits (or worked without them) and then botched mitigation projects. This has contributed to the strict minimal qualifications for obtaining paleontological resource use permits that are now required by many federal and state agencies across the western U.S.A.

Most paleontological mitigation projects outside of California have taken place on federal, and to a much lesser extent, state lands in a handful of states, and are required by federal and state laws and regulations. In contrast, many mitigation projects located in California take place on privately owned lands and fall under the environmental requirements of state and local laws and regulations. Recently, mitigation requirements for privately owned lands in other western states have been adopted by state agencies for high profile projects with significant stakeholder concerns about paleontological resources, and even by the BLM if the project is a federal action. However, the bulk of mitigation work in states other than California takes place on BLM, and to a lesser extent, USFS administered lands. Both of these federal agencies have established processes and procedures that include a review of consultant qualifications to obtain or work under a paleontological resource use permit. BLM procedural guidelines (BLM, 1998, 2008), including minimal qualifications for permitting, are often consulted by other federal and even some tribal and state agencies that lack their own guidelines. We encourage this practice of standardizing permitting qualifications to the maximum extent possible.

Any consideration of minimal qualifications to work in mitigation paleontology must include justifications for why such qualifications are necessary, as well as consideration of the problems resulting from non-qualified paleontologists engaging in impact mitigation work. The obvious answer to why qualifications are necessary is to ensure that only a qualified mitigation paleontologist/permittee has the knowledge and experience needed to accomplish the goals of the mitigation program according to established professional standards (see SVP, 1991, 1995, 1996, 2010) including the best practices described herein, and in compliance with procedural guidelines, if any, of the overseeing lead agency (e.g. see BLM, 2008). To any paleontologist, the problems with non-qualified paleontologists doing paleontology are patently obvious. Would you hire a plumber to prescribe new glasses? Would you see a proctologist to clean your teeth? With no disrespect intended for the vast majority of highly knowledgeable and ethical archeologists, the fact is that many archeologists, and to a lesser extent geologists, without paleontological training have taken on mitigation paleontology projects presuming that their education and field experience renders them competent in mitigation paleontology.

Unfortunately, the seed for the confusion between paleontological and archeological resources was unknowingly planted by land managers and municipal planners who, several decades ago, programatically included paleontological resource management within cultural resources (and archeology). This confusion still permeates many agencies, municipal planning departments, and private firms in the environmental consulting industry. However, the confusion is not just the fault of land managers. The two disciplines are inextricably linked in our popular culture, much to the frustration of archeologists who often get questioned about dinosaurs, and paleontologists who often get questioned about projectile points. The fact is that in the Western Hemisphere, there is a clear distinction with relatively little temporal overlap between archeological and paleontological sciences. This distinction is fuzzier in the Old World due to the significantly more ancient record of pre-Holocene humans and associated cultural remains. Mitigation paleontologists need to do a better job of educating agency personnel and municipal planners with no background in paleontology about the differences between paleontology and archeology. The simplest way to convey the differences between paleontology and archeology is to emphasize the very few similarities between them: both disciplines work on old objects that sometimes needs to be excavated, even though the objects being excavated are different, and from distinct time periods. Virtually all of the research questions, field methods, and analytical techniques traditionally employed in each discipline are unique. Archeological testing methods are essentially useless for paleontology for reasons that will be discussed in Section 5.

Another manifestation of the confusion between paleontology and archeology is the notion that practitioners of either discipline are capable of doing the other, or can become capable with minimal training. 'Cross trained' is a term that applies to individuals who purportedly have sufficient expertise to work in both their own discipline and another, or even two or three others. The practice comes at the expense of the very resources that the laws and regulations are intended to preserve and demonstrates a lack of understanding of the complexity of paleontology, and the complexity of other resource disciplines. In the many years the authors have been involved with mitigation paleontology while working in universities, museums, and as consultants, we have known few individuals who are legitimately trained and sufficiently experienced to work as a 'cross trained' archeologist and paleontologist. The fact is that it is rare to come across an individual who is legitimately qualified to work as a cross trained scientist in any combination of disciplines. It is also a fact that there are few paleontologists (by training) who claim to have the expertise (or desire) to work as an archeologist, whereas many archeologists continue to profess expertise in both disciplines.

An example of a well-intentioned but largely ineffective effort to ensure that only qualified paleontologists work in mitigation paleontology is the currently unenforced attempt by the State of California's Board of Professional Engineers, Land Surveyors, and Geologists to equate paleontological mitigation work with professional geological work and in turn to imply that paleontological mitigation work should be supervised by either a California Professional Geologist (including California Certified Engineering Geologist, California Certified Hydrogeologist, or California Professional Geophysicist). However, the qualifications for being a Professional Geologist or other licensed geoscientist do not include an extensive knowledge of paleontology and paleontological methods and procedures and thus do not translate into qualifications for conducting paleontological mitigation work. While there are California paleontologists who are also licensed geoscientists, most are not, and a large percentage of those that are not licensed do not have the breadth of geological and engineering training that is required to pass the professional geologist exam, which largely focuses on engineering geology, hydrogeology, and geophysics and not on sedimentary geology, stratigraphy, paleontology, and taphonomy. A potential solution to this current confusion surrounding the issue of who is qualified to work as a mitigation paleontologist in California would be for the Board to develop a separate professional mitigation paleontologist licensing category and examination.

Paleontological mitigation work is generally conducted by three categories of personnel with different levels of expertise and responsibility (see Appendix A, 1.1 for a detailed list): 1) paleontological principal investigator, 2) paleontological field supervisor, and 3) field paleontologist. A paleontological principal investigator is someone with graduate level academic training (M.S. or Ph.D.) in paleontology and sedimentary geology or equivalent professional experience, in combination with demonstrated professional experience and competency with paleontological resource mitigation procedures and techniques. The principal investigator should also have a working knowledge of how paleontological resources and their associated data are used in conducting and publishing professional paleontological research (such as is demonstrated by having a peer-reviewed publication record). The principal investigator is responsible for obtaining all necessary federal and state agency permits, for submitting any and all required progress and final mitigation reports, and for ensuring compliance with all scientific and operational requirements of the project. Therefore, it is critical that the principal investigator have knowledge of federal, state, and local laws and procedures that apply to all aspects of mitigation paleontology.

A paleontological field supervisor is someone with academic training (B.S. or M.S.) in paleontology and sedimentary geology or equivalent professional experience, in combination with field experience in impact mitigation procedures (including fossil salvage/collection), stratigraphic competency, knowledge of fossil curation procedures, authorship experience with final mitigation reports, knowledge of resource management strategies and concerns, an understanding of the regulatory environment including knowledge of federal, state, and local laws and procedures that apply to mitigation paleontology, project management experience, and an understanding of the business of mitigation paleontology. The paleontological field supervisor typically manages the field paleontologists (on field survey and/or mitigation projects), supervises fossil salvage operations, communicates with construction foremen and superintendents, and assists with preparation of progress and final project reports.

The field paleontologist (paleontological technicians, surveyors, and monitors) is someone with academic training (B.S., B.A., or M.S.) in paleontology and sedimentary geology or equivalent professional experience, in combination with field experience in conducting field surveys, fossil salvages, and construction monitoring. The field paleontologist should be able to safely find, salvage, collect, identify to a basic level (taxon and element), and evaluate the scientific importance of fossils in undisturbed settings as well as in active cuts at construction sites, and accurately record data including site stratigraphy. Other recommended requirements include the ability to record field interpretations of the taphonomy of fossil assemblages and recognize and describe unusual depositional or preservational conditions and associations; the ability to interpret depositional environments based on site geology and paleontology; sufficient knowledge of geology to communicate with a registered professional geologist when necessary; the ability to properly complete field forms, operate a GPS, photograph fossils and localities, and plot localities on grading plans when applicable; and an understanding of safety requirements.

We recognize that few paleontologists have degrees in paleontology because few institutions offer degrees in it. Typically, paleontologists earn degrees in geology or biology with an emphasis in paleontology. Academic training and field experience in sedimentary geology is an important prerequisite to work in mitigation paleontology. The aforementioned three categories of paleontological mitigation personnel are not intended to correspond to paleontological mitigation personnel categories developed by agencies, but rather, to clearly represent the roles and responsibilities that have proven to achieve the best results across the spectrum of mitigation paleontological projects over several decades. Henceforth, we refer to paleontological principal investigators and field supervisors as 'professional mitigation paleontologists.' The field paleontologist is a technician level position for possible training to be a professional mitigation paleontologist.

The bottom line is that although there are archeologists and biologists who have sufficient expertise to work in more than one discipline, and registered professional geologists who have sufficient expertise in paleontology, it should never be assumed that any archeologist, biologist, or professional geologist is qualified to do so. Likewise it should not be assumed that all paleontologists have sufficient training and expertise to be considered professional mitigation paleontologists since there are paleontologists who specialize in morphology, taxonomy, or phylogeny of specific taxonomic groups, who may not have the knowledge needed in stratigraphy, taphonomy, or with other taxonomic groups. Thoroughly vetting all individuals in order to ensure their professional competency to work as mitigation paleontologists is a critical best practice. The proof is that this practice, when it has been well implemented, has been directly responsible for the successful recovery of countless scientifically significant fossils and associated data from construction sites in the last 30+ years, resulting in the preservation of large numbers of important fossil collections and the production of a vast body of published scientific research. Ultimately, a universally effective solution to the problem of ensuring professional competency may be a professional registration process that mirrors that of the 'Registered Professional Archeologist,' a process that was developed to ensure that only properly trained archeologists conduct archeological work.

2. ANALYSES OF EXISTING DATA

The purpose of an existing data analysis is to evaluate the potential of a geologic unit in a geographic area to produce fossils of scientific importance. This potential is commonly referred to as paleontological sensitivity and is determined from an analysis of existing paleontological and geological data. There are six elements of an analysis of existing paleontological data: 1) geologic map review, 2) literature search, 3) institutional/agency records search, 4) land ownership analysis, 5) aerial photo review, and 6) consultation with local paleontological experts. The analysis of existing data is typically a prerequisite to any mitigation action such as a field survey or construction monitoring, and may also provide the background information for a paleontological resource evaluation. Like all aspects of mitigation paleontology covered in this paper, analyses of existing paleontological and geologic data should be completed under the oversight of a professional mitigation paleontologist in possession of a valid paleontological resource use permit or certification/qualification when applicable (See Section 1).

For the purpose of conducting geologic map reviews and quantifying the size of a project and its disturbance area, the area of analysis is conceptually three-dimensional – it is a two-dimensional geographic area with a third dimension consisting of a stratigraphic interval that underlies or is laterally equivalent to the area of proposed ground disturbance. The geographic area or areal extent of disturbance is most commonly expressed in acres or linear miles. The stratigraphic interval or thickness/depth of the proposed disturbance is most commonly expressed as the volume of rock or sediment in cubic yards or cubic meters. The geographic and stratigraphic limits of the disturbance area are important considerations in evaluating paleontological sensitivity and the potential impacts on paleontological resources associated with ground disturbing projects. However, information regarding disturbance depth is often not available to the mitigation paleontologist at the time of preliminary data analysis, at least not with any meaningful level of precision.

Geologic Map Review

A thorough geologic map review is a necessary step to take in an analysis of existing data. Geologic map reviews should utilize published, and if necessary, unpublished but reputable sources. The highest precision maps available should be used. Because electronic geologic map data are often not available at the same scale as hard copy maps, it may be necessary to scan, georeference, and digitize portions of hard copy maps in order to utilize them in Geographic Information Systems (GIS). A geologic map review is especially important for stratigraphically and/or structurally complex project areas containing multiple geologic units. The purpose of the geologic map review is to determine which geologic units occur within a project area (especially fossiliferous units), and to determine their areal distribution. Soils maps may also assist in a determination of areas of potential fossiliferous bedrock or surficial deposits. However, it is the authors' experience that soils data are often inaccurate and should be used with caution, and only in combination with field verification.

While discussing geologic map reviews, it is useful to consider paleontological sensitivity classification systems because the most widely used systems, namely SVP's 'rock unit potential' classification system, the BLM's Potential Fossil Yield Classification System (PFYC), and the USFS's Fossil Yield Potential Classification System (FYPC), are all geospatially defined on the basis of geologic map units. It is important to distinguish between a project specific analysis of existing data done by a professional mitigation paleontologist and the assignment of PFY (FYP) class values. The latter is not the purview of the mitigation paleontologist, but is a resource management process undertaken by the agency to assess the general paleontological potential of a geologic unit (usually an entire formation) and inform agency personnel about recommended management approaches. The former, which is typically performed by a mitigation paleontologist on behalf of a client, is based on a more detailed dataset that is synthesized to inform the client and the lead agency about the need, or lack thereof, for the development of paleontological impact mitigation measures. Depending upon the scale of the available maps, the geologic units shown on a given map may consist of groups, formations, members, submembers, or combinations thereof; and may consist of bedrock units and/or surficial deposits. While a critique of the aforementioned predictive classification systems is beyond the scope of this paper, it should be pointed out that paleontological sensitivity class rankings are often assigned based on 1:500,000 scale (state scale) geologic mapping, and in such cases the highest class ranking is assigned to combined map units. This is both a practical function of the available geologic maps, since more precise geologic mapping generally is not available for entire states, but also because the PFYC and FYPC systems were designed to function as a resource management step completed by the agency that triggers further analysis by a professional mitigation paleontologist. Higher precision geologic mapping is available in many states, and should be used to refine the analysis to the greatest extent feasible. Additionally, the scale of the map used to assign the PFY/FYP classes may not account for rare or isolated occurrences of significant fossils that may necessitate further consideration.

As mentioned above, PFYC (or FYPC) assignments should be completed by the applicable lead agency prior to the start of a specific project. Exceptions occur if, for example, an agency has not yet completed the classification of the geologic unit(s) in question. In such cases, the mitigation paleontologist, using the results of the analysis of existing data, may assign preliminary values pending agency concurrence. Ideally, the predetermined paleontological sensitivity values of geologic units are provided by agencies prior to the mitigation paleontologist beginning work on a given project, and have been used by the lead agency in determining paleontological resource requirements for the project **(2.1).**

Literature Search

The literature search is the second component of the analysis of existing paleontological data. There is no standard literature search area size – in many cases, the most appropriate search area might be the geologic unit's entire distribution, the depositional basin in which the unit is located, or the entire distribution of the geologic unit within the state in which the project is located for more widely distributed geologic units. In other cases, it might be most appropriate to limit the search to a member or facies of a geologic unit that is known to be distinct from the other portions of the unit in terms of its fossil content.

The purpose of the literature search is to obtain published paleontological locality information and relevant geological and stratigraphic information, as well as qualitative information regarding the scientific importance of paleontological resources in a project area and in the same geologic units elsewhere in the region. The surveyed literature can include published scientific papers and unpublished gray literature such as technical reports written by government agencies and mitigation paleontologists. Detailed fossil locality data are typically not provided in recently published scientific papers. However, other information relevant to the analysis can consist of general information regarding fossil localities including the types and abundance of fossils collected, physical characteristics of the fossil-producing strata, the depositional environments in which fossils were preserved, and the scientific importance of the fossils. In many cases, project specific geotechnical reports are also very useful and provide critical information about the thickness of surficial deposits and the depths at which potentially fossil-bearing rock units are likely to occur. Popular websites including Wikipedia entries are not a reliable source of scientific knowledge and should not be a substitute for literature searches - even for the preparation of typically more abbreviated paleontological resource sections of National Environmental Policy (NEPA) documents (see Section 8) **(2.2).**

Paleontological Records Search

The third component of the analysis of existing data is a paleontological records search, the purpose of which is to obtain fossil locality data from within a project area in order to determine the extent of previous paleontological work and fossil discoveries, in particular geologic units and the types, modes of preservation, and relative abundance of known fossil assemblages from these units. Record searches for areas outside the project area can also be useful for establishing paleontological sensitivity for the same formation based on findings from another, adjacent geographic area. These data in turn provide a means for establishing the potential of a given rock unit to produce fossils within the project area. Record searches also provide information that can ensure that recorded localities in the project area are re-evaluated and avoided by the project if needed. Quantitative and qualitative information about fossil localities is used to determine the need for a field survey or construction monitoring of a project area.

The size of the area for paleontological records searches is more confined and precise than that for literature searches. Depending on the lead agency, the search area may either be specified or left to the discretion of the mitigation paleontologist. The format that the data are in at the source institutional/agency may also play into the determination of the search area. For small, block area projects, it is common to search for fossil localities within the same formation within one-mile of the project area. For larger block area projects or linear projects such as interstate pipelines, transmission lines, and highways, a good minimum search area is a one-mile buffer of the project area (one mile from the external boundaries of a project, or one mile on either side of the centerline of a linear project), although it may be more expedient to search the same township or county, depending upon the format of the data.

Paleontological locality data on public lands are confidential and are maintained by both government agencies and institutions including museums and universities. In many jurisdictions, fossil locality data are only provided to paleontologists in the possession of a valid paleontological resource use permit. Institutions are not under any obligation to provide locality data, and many charge for this service. Regardless of whether a locality search request is answered, it is critical to document that the request was made in whatever type of paleontological report is required for the project. Paleontological localities known to the authors have been destroyed simply because they were not identified due to either inadequate analyses of existing data or institutions holding such data were unwilling to provide locality data. Importantly, the PRPA prohibits public disclosure of paleontological locality data from Department of Interior and USFS managed lands without permission. Once received, paleontological locality data must be kept confidential by the recipient of those data.

Paleontological locality data, including both institutional/agency records and locality records obtained from literature searches (and/or local experts), are vital to the development of paleontological resource impact mitigation plans, and they play a critical role in the decision making process for field survey and construction monitoring requirements. It is extremely useful to digitize fossil locality data originally contained on hard copy maps and documents upon receipt. These data are utilized for the data analysis, continued use in future projects, and to supplement the dataset with the results of subsequent searches conducted as they are completed. The results of record searches are also an important component of paleontological reports (see Section 8), although detailed locality data should only be included in copies of the report provided to the applicable agencies. The inclusion of record search requests and results document that the analysis of existing data was conducted as required by the regulatory agency, and it provides the justification for the mitigation recommendations included in the report (or mitigation plan) both for the agency and the project proponent. It is important to bear in mind that an absence of fossil locality records is more likely to reflect the lack of prior paleontological field work in a particular area than the actual absence of fossils in that area. However, this may not be the case for areas that have been the subject of intensive and long term paleontological field work (2.3).

Land Ownership Analysis

The fourth component of the analysis of existing data is a determination of land ownership, an important issue in the increasingly complex web of regulatory requirements that in certain situations result in impact mitigation procedures that vary by land ownership type. Knowledge of land ownership in a project area as well as the regulatory environment that applies to land ownership is essential before undertaking any subsequent analyses or mitigation actions. All five other components of the analysis of existing data should be applied equally regardless of land ownership type unless otherwise specified by the lead agency. The major land ownership distinctions are federal, state, tribal, county, city, and private. Differences between certain types of federal, state, and tribal land may also affect the scope of mitigation paleontological work. For example, mitigation requirements may vary between different classifications of state land in some states, and also commonly vary between federally managed lands, even at the level of field and district offices. Land ownership data are available in a number of formats including hard copy maps and GIS data coverages. Because land ownership changes frequently, it is important to obtain the most recent and most accurate data available. This is often available from and provided by the project proponent and should be requested at the initiation of any project (2.4).

Aerial Photograph Review

The fifth component of the existing data analysis, aerial photograph review, is extremely easy to accomplish using widely available technology such as Google Earth. The purpose of this step is to virtually examine the terrain within the project area from above (or using ‘street view’) in order to estimate the amount and locations of exposed potentially paleontologically sensitive bedrock or surficial deposits. The result of the aerial photograph review provides information that is useful for the evaluation of paleontological resource potential as well as the logistical planning for field work (2.5).

Consultation with Local Technical Experts

The sixth and final component of an analysis of existing data is consultation with local technical experts. Such experts are researchers who are currently active in the area of interest, have worked there previously, or otherwise possess specialized knowledge of its paleontology and geology. These experts include agency personnel and avocational paleontologists who are knowledgeable of the area. The types of contributions a technical expert can make to the analysis are important, and include information on undocumented or unpublished fossil localities, particularly productive (or unproductive) stratigraphic or geographic locations, detailed stratigraphic information, and information about any paleontological concerns including specialized data recordation procedures in support of ongoing research. If recent fossil collection activities are not taken into consideration, it could cause the paleontological potential of an area to appear lower than it actually is and skew recommendations based on the results of analyses of existing data or field surveys. In addition to supplementing the data obtained from literature and record searches, the information provided by technical experts can provide invaluable information for field surveys or other future mitigation actions. Contacting a technical expert is the responsibility of the mitigation paleontologist, although there is no obligation on the part of the expert to provide support for the project (2.6).

All six components of the analysis of existing data can be efficiently examined and analyzed together using GIS technology (Figure 1). The output of the analysis of existing data can be presented in a variety of formats, but should always include a discussion of the methods used, as well as the results obtained. If the analysis is a preliminary step to additional work, it may only involve synthesis of the data into a format that is useable in a later project report (i.e. field survey report), or it may form the subject of a report unto itself. A report based on an analysis of existing data is appropriate for many types of projects, and we recommend that it be called a paleontological resource impact evaluation report in order to avoid confusion with other types of reports (see Section 8). The purpose of these types of reports is typically to synthesize information necessary to evaluate the paleontological sensitivity of a project area. This information, in turn, can be used by a project proponent and the lead agency to make a determination of the need for paleontological impact mitigation measures such as field surveys, construction monitoring,

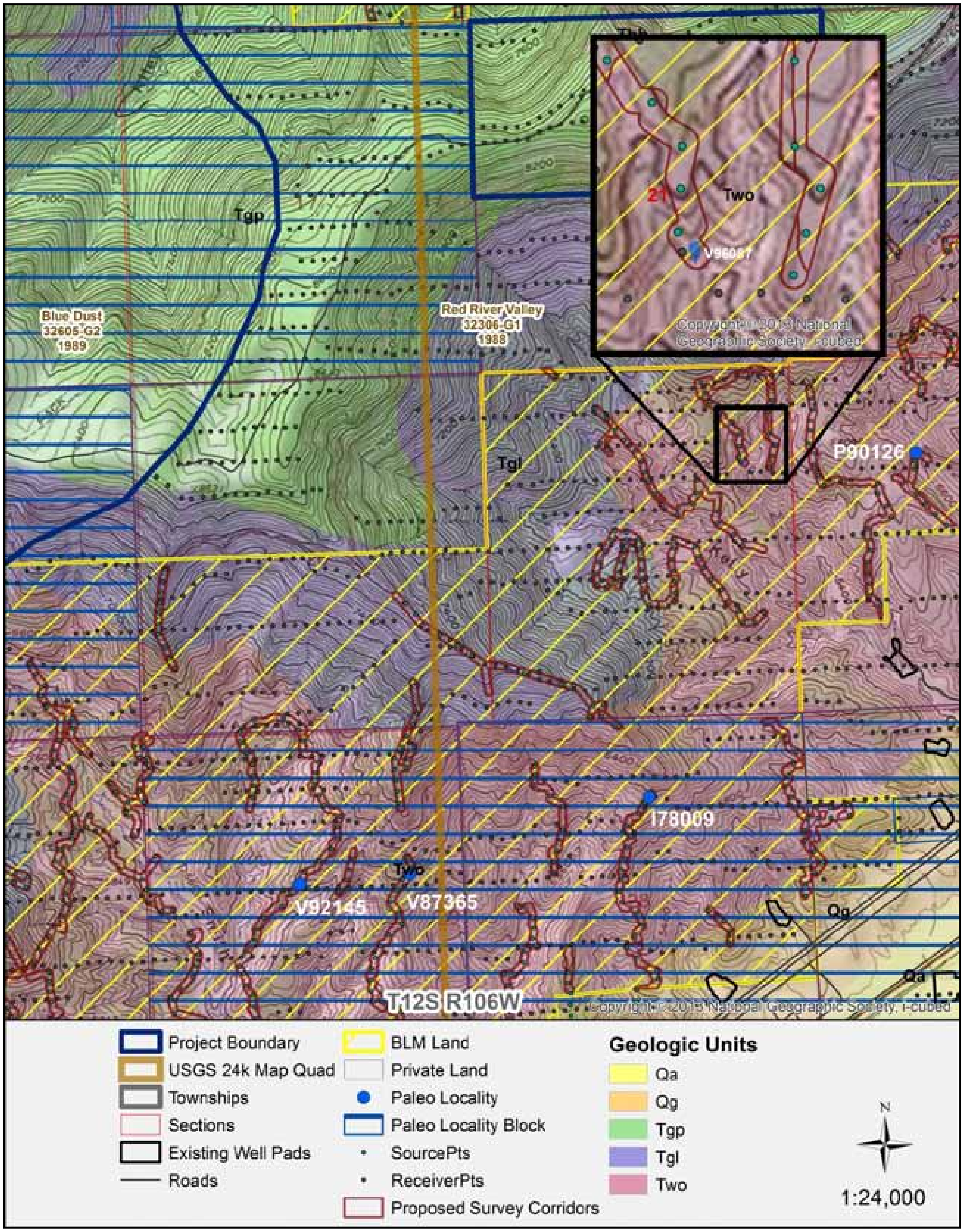

Figure 1. Fictional portrayal of information obtained from an analysis of existing data. Previously recorded fossil localities, topography, geology, project infrastructure locations, and land ownership are displayed.

or more project specific mitigation recommendations. It is also common for the product of an analysis of existing data to provide the basis for paleontological resource analyses for NEPA studies such as Environmental Assessments (EAs) and Environmental Impact Statements (EISs). If a report based on the analysis of existing data is not required, then consultation with the lead agency (if applicable) should take place in order to determine the need for impact mitigation measures, and the consultation may include the development of project specific mitigation recommendations (2.7).

3. RESEARCH MODELS AND SCIENTIFIC CONTEXT

When properly implemented for a project with significant paleontological resources, the impact mitigation process can result in the discovery, recovery, and curation of well documented fossil collections permanently housed in curation facilities, where the fossils are then accessible for research and educational purposes. While the mitigation process does not include conducting hypothesis driven research per se, every impact mitigation program should be designed around a research model that places it in a scientific context, and which will allow the results of the program (i.e., fossil collections and associated data) to be employed in later research activities.

Essentially, a research model should serve as road map that guides the implementation of the mitigation work including the development of the threshold criteria for scientific importance, which fossils are collected, how they are collected, and the types of data that are collected (3.1). For smaller projects, a research model may be focused on a single fossil locality. For larger projects, multiple research models may be needed. Research model development should be built into project scopes of work and budgets, and the actual research models should be presented in paleontological resource impact evaluation mitigation evaluation reports and paleontological resource monitoring and mitigation plans (see Section 8). This approach will help ensure that these types of reports make detailed recommendations for field surveys, construction monitoring, and impact mitigation (3.2).

The research model concept is analogous to a research design in cultural resource management (CRM), which is a more or less standard requirement for excavation permits beyond simple testing, and may also be required for construction monitoring treatment plans. Like a CRM research design, a paleontological resource research model should include a statement of research objectives and specific research problems, hypotheses to be tested, methods to be employed to address the research problems, and a discussion of the expected results. Final survey and monitoring reports should, in their results sections, reference the research model and include a discussion of how the mitigation results preliminarily support or otherwise modify the research model (3.3).

The development of a research model is not currently implemented for the majority of paleontological resource impact mitigation projects, but is considered to be a best practice because it adds scientific value and integrity to the mitigation process and resulting fossil collections (3.2).

4. FIELD DATA COLLECTION

The collection of accurate field data is vitally important, and is one of the most complex aspects of mitigation paleontology. The main issue is to design and implement a data recordation protocol that promotes accuracy and is efficient, adaptable, and intuitive. The protocol also should be easy for field crew members to learn, readily comparable between field crew members, and designed for use on all sizes and types of projects. Ideally, the protocol should be designed so that it can be quality checked by the principal investigator, field supervisor, and/or project manager so that data corrections and methodological changes can be introduced if necessary. Field data often need to be collected quickly, especially on certain types of mitigation projects. Typically, there is only one opportunity and a brief window of time in which to record data. For example, when monitoring a mass grading project, the topography is modified rapidly and often drastically, and entire fossil localities (and enclosing strata) are graded away almost immediately after fossils have been salvaged.

In many cases, agency guidelines (if they exist) are vague about what data are required to be collected for mitigation paleontology projects. This decision is typically left up to the discretion of the principal investigator or field supervisor based on his or her training and field experience. Even agencies with robust procedural guidelines such as the BLM require little more than standard fossil locality data for project and permit reporting purposes. In fact, in order to properly implement a mitigation project with any degree of complexity, a lot of data must be recorded. A well designed research model can go a long way towards establishing, up front, the data recordation protocol to be followed in the field. It is often not just important to know what data to collect and how to collect it, but perhaps equally as important to know what data not to collect. It is well beyond the scope of this paper to recommend and describe detailed data capture procedures or provide a comprehensive list of data that should be collected. Most paleontologists prefer to do things in their own way, and projects may require variations in data collection and management. Rather, in this section we provide recommended minimal data capture guidelines that constitute best practices for typical paleontological mitigation paleontology projects. Additional data should be collected on specific projects depending upon scientific or reporting aspects of projects as determined by the principal investigator, field supervisor, project manager, or agency personnel.

Field data are traditionally recorded in field notebooks and on hard copy topographic maps, aerial photographs, and/or hard copies of grading plans or plan and profile sheets. Customized hard copy field forms (e.g. locality forms, photographic logs, etc.) are far more effective than field notebooks in most cases, especially when a crew of more than one person is involved (4.1). However, other readily available and relatively inexpensive data recordation devices include global positioning system (GPS) receivers, tablet computers, and digital cameras. For GPS receivers, sub-meter level precision may be needed in certain field applications. However, a position error of 20 to 30 feet is probably sufficient for most applications (4.2). Increasingly, digital data and integrated data recording systems are being utilized in the environmental consulting industry, and undoubtedly will replace hard copy field notes and field forms in the near future. Data entered directly into relational database management systems on tablets or advanced GPS units save significant amounts of data entry time. On the other hand, these data continue to require careful quality checking in the office because of the inherent difficulty of capturing information accurately in the field, which requires extra attention to detail and can be a drain on precious field time (a constant challenge in itself).

Prior to the commencement of any mitigation project, it is important to provide information about the project to crew members typically in the form of an orientation and training session (see Section 5). An important component of such a pre-field orientation session is a review of the types, preservation, and data needs of anticipated paleontological resources, as well as a review of field data collection procedures and associated data management responsibilities. This includes a review of field data forms and/or digital custom form applications, recording procedures and protocols, and nightly data management procedures. In particular, it is critical to discuss thresholds for paleontological significance for the purpose of providing guidance about what constitutes a paleontological locality, because this may vary by project as discussed below (4.3).

All data recording protocols should include capture of 'negative data' because such data can be important for resource management. There are two aspects to negative data in mitigation paleontology projects. The first is documentation of all areas that were surveyed or monitored regardless of whether fossils were found or not. This serves the dual purpose of providing data on where fossils were not present during surveys or monitoring, and also, as a best practice, providing a record that the field work was completed according to the scope of work and agency requirements. If possible, a GPS track log file and/or polygons depicting locations of field crew activities along with GIS locality data should accompany the agency copy of the mitigation report. The second aspect of negative data involves non-scientifically important fossil localities. Although these localities are often omitted from final reports, all fossil locality data are useful for resource management and should be reported. The primary distinction between scientifically important and non-important localities is that important fossil localities (those with fossils of scientific value, and as defined using agency provided significance criteria when applicable) are subject to mitigation whereas non-important fossil localities are not. Most land managers want negative data including non-important fossil localities because it provides information on the overall abundance and quality of preservation of fossils and the distribution of fossil-bearing strata in a project area (4.4). In addition, this data is critical during the analysis phase of subsequent projects. Finally, paleontological localities deemed non-significant may be reevaluated for significance at a later time.

The significance threshold for fossil localities varies by geologic unit, geographic area, agency criteria, and ongoing research related to the fossils within a project area. For example, in the middle Eocene Uinta Formation in northeastern Utah, fossil turtles consisting of both complete carapaces and fragments thereof are prolific. A survey of 17,000 acres yielded 3,910 localities that include turtles, for a density of one locality per 4.35 acres. Of these, approximately 110 localities were recorded as scientifically important localities because they yielded relatively complete carapaces, some of which were associated with crania and post-crania. Another 3,800 localities were recorded as non-important because they produced exploded scatters of turtle carapace fragments with no associated cranial or post-cranial remains that either represented common taxa or were poorly preserved and unidentifiable (Imhof et al., 2008). Indeed, fossil turtles are so abundant in certain Uinta Formation strata that it is impractical to report isolated carapace fragments even as non-important fossil localities. Consequently, in this case a minimum non-significance threshold needs to be established and adhered to during field work. In stark contrast, in the stratigraphically overlying upper middle Eocene Duchesne River Formation, fossil reptiles, including turtles, are exceedingly rare. Even an isolated turtle carapace fragment found in this unit should be recorded as a significant fossil locality because of the rarity of turtles and the associated potential scientific contribution from the discovery of additional specimens (4.4).

Before discussing field data specifically, a final consideration involves data confidentiality, which is another aspect of data collection and management that varies between projects. It is a best practice to err on the side of discretion whenever working on a mitigation project, and this should be strongly emphasized to field crews. For example, it is important that field crew members refrain from posting any information about a project, including fossils that were found, on their websites or social media sites. This includes not posting images that may identify geological context or are geographically referenced. It is also important that field crew members refrain from discussing any aspect of projects, especially paleontological data, with non-project personnel. Such discretion is expected by clients who are paying for this work. Under PRPA is unlawful for federal fossil locality data to be disclosed to the public (see Section 8) (4.5). However, disclosure to appropriate agency and curation personal is necessary.

There are two general categories of field data: paleontological data and project data. Paleontological data document the locations and types of fossils and their geologic context. These data provide the contextual information necessary to make the associated salvaged fossils scientifically valuable. Without adequate information concerning stratigraphic provenance and taphonomic fabric, most fossils become just pretty objects that immediately lose their scientific value. Project data, on the other hand, include details of the work performed on a daily basis and other project-related information and are discussed in greater detail below. Some clients also require project-specific daily logs that typically serve the purpose of reporting what work was done, where it was done, how many hours were spent at the field site, and localities found (if any). It is a best practice to fully and properly complete all client or company required project paper work. This may include vehicle inspection forms, job hazard analyses or other safety related forms, and project daily logs. These requirements are supplemental to scientific and project data recorded by field crews, and will not be discussed further (4.6).

Five general types of field forms suffice for most mitigation paleontology projects, and all contain both paleontological and project data fields (Table 1). Much of the information listed on fossil locality forms, such as geographic coordinates, stratigraphic and lithologic data, and fossil identifications, is standard for paleontological field work. The primary difference for mitigation projects is that the locality is associated with a project name and tied to a survey or monitoring area. A survey or monitoring area, in turn, is a subdivision of a project area depending on the project type, whether it be an alignment segment between highway mileposts, pipeline station numbers, or geophysical source points; or a transmission tower, wind turbine, well pad, or quarter-quarter section. Another important component is whether the locality is scientifically important or not, whether fossils were collected (non-important fossil localities typically are not), and preliminary mitigation recommendations depending upon the nature of the fossil locality and the type of anticipated impact. As discussed in Section 8, there is no single formula that can be used for designing mitigation recommendations. Best practices related to impact mitigation are those that accomplish the objectives of the project while preserving the value of paleontological resources. Finally, it should be noted that the information on field locality forms is not identical to fossil locality forms that are produced for mitigation reports – the former have some different data fields and they report preliminary information (4.7).

Monitoring and survey area logs accomplish the same thing for monitoring and survey projects, respectively, and can be utilized in place of or in addition to standard field notes. Such logs document what work was done in which part of a project area, whether the project has a linear (e.g., pipeline, transmission line, or roadway alignments) or a non-linear (e.g., solar energy generation facilities, residential developments, or landfills) footprint. The purpose of these log forms is to capture information about sub-areas within a project area to provide details about what was done and when, and observations about each area, regardless of whether fossils were found. It is not possible to accurately characterize any but the smallest of project areas unless the project area is subdivided into more meaningful sub-areas. Finally, both monitoring and survey area logs should also include a listing of other associated data such as scientifically important and non-important paleontological localities, stratigraphic logs and photographic points recorded within them, and bulk matrix or other samples collected (4.7).

Lithologic information is applicable to fossil locality logs, monitoring logs, and survey logs (see gray shaded fields under stratigraphic log in Table 1). The fossil-bearing stratum is typically recorded on the fossil locality log, while the complete exposed stratigraphic profile within a survey or monitoring area along with positioned fossil localities is recorded on monitoring and survey area logs. The purpose of a stratigraphic log is to record thicker sequences, and can either be used to record a traditional stratigraphic section or a trench log (log of strata exposed in a linear exposure such as a pipeline trench). Photographic logs simply provide a way to track digital photographs taken of localities, fossils, and other visual project aspects so that they can be used in mitigation reports and locality forms (4.7).

5. FIELD SURVEYS

The purpose of a field survey is to locate and document exposed fossils and potentially fossil-bearing surface strata within a project area, to re-locate previously recorded fossil localities, and to document areas that have high potential to produce subsurface fossils. It is assumed that basic required skills, such as finding and identifying fossils and documenting their geologic and stratigraphic context, have been mastered by professional mitigation paleontologists during the course of their academic training and/or pre-mitigation professional experience. In other words, the scientific skills required to prepare for and successfully complete a field survey are prerequisites to undertaking a mitigation project. As such, these subjects are not covered in this paper.

It is important to prepare for all field work in advance, and such preparations are generally similar whether the proposed work involves a field survey, construction monitoring, or other types of mitigation field activity. Pre-field preparation should also be included in scopes of work and budgets, and is focused on assembling information and providing training to those who will be doing the work. Field crew members should be provided with the results of the existing data analysis completed for the project (or similar information if a formal analysis was not completed), key publications and technical reports relating to the geology and paleontology of the general geographic area and geologic units involved, and maps and/or construction design or grading plans of the project area. A discussion of the necessary field equipment, data recordation and management procedures (see Section 4), and safety concerns

Fossil Locality Log	Monitoring Area Log	Survey Area Log	Stratigraphic Log	Photographic log
Locality #	Monitor Name	Surveyor Name	Recorder Name	Photographer
Date	Date	Date	Project #	Date
Project #	Project #	Project #	Project Name	Project Name
Project Name	Project Name	Project Name	Infrastructure Name	Photograph Number
PLSS Location	Arrival and Departure Times	Survey Area Name	Unit	Location Reference
UTM or Lat/Long (NAD 83 datum)	Infrastructure Name	Survey Area Type	Thickness	Direction/Bearing
Found By	Infrastructure Type	Infrastructure Name	Rock Type	Photograph Description
Survey Area Name	Land Owner	Infrastructure Type	Color Fresh	
Survey Area Type	PLSS Location	Land Owner	Color Weathered	
Land Owner	County	PLSS Location	Texture	
Location Description	State	County	Grain Size	
Topography	Weather Conditions	State	Sorting	
Formation	Safety Concerns	Survey Type (pedestrian, visual, aerial)	Rounding	
Member	Equipment	Survey Start and Stop	Carbonate	
Age	Excavation Activities	Topography	Cementation	
Stratigraphic Position	Project Start and Stop	Amount and Approximate Locations of Bedrock Exposures	Bottom Contact	
Lithology	Continuous or Spot-Check	Formation	Sedimentary Structures	
Fossil Type(s)	Formation	Member	Fossils	
Field Taxonomic ID	Member	Age	Points Recorded	
Field Element ID	Age	Stratigraphic Observations	Start and Stop Points	
In Situ or Float	Stratigraphic Observations	Lithologies	Dip/Strike	
Preservation Quality	Lithologies	Site Sketch		
Taphonomic Observations	Site Sketch	Associated Fossil Localities		
Depositional Environment	Associated Fossil Localities	Associated Photographic Points		
Locality Dimensions	Associated Photographic Points	Associated Stratigraphic Points		
Collected?	Associated Stratigraphic Points	Matrix Collected		
Significant?	Matrix Collected	Field Recommendations		
Field Recommendations				
Photograph Numbers				

Table 1. Recommended types of field forms and minimal data fields. Gray shaded fields represent repeated subparts of a form for recording successive stratigraphic units and photographs.

should also be provided. Importantly, pre-field training should include a discussion of scientifically important versus non-important fossil localities, and fossil evaluation criteria and collection procedures. Ideally, for larger field surveys an orientation to the project area should be provided by a technical expert (e.g., a researcher who does field work in the area) should take place, and such an expert, if available, should be kept informed of the results of the project as it proceeds (5.1).

If required, paleontological resource use permits must be obtained prior to field work. Furthermore, when working on projects on federal land or with federally mandated requirements, it is necessary to coordinate with agency personnel, typically in field or district offices, before initiating field work. For example, for BLM paleontological resource use permits it is mandatory to check in with the local paleontology coordinator. Additionally, it may be necessary to coordinate with the paleontology coordinator

Figure 2. Field paleontologists Lauren Seckel and Hugh Wagner surface prospecting for fossils in the Ohio Creek Formation, Piceance Creek Basin, Colorado.

or regional paleontologist with regard to extensive fossil discoveries as defined below. Field work on tribal lands typically requires an access permit and daily check-ins. It is highly recommended that an email or other written authorization that contains details about the survey methodology be obtained from the applicable agency prior to beginning any field work on a project (5.2). Copies of this written authorization should be carried by each member of the field crew when in the field.

Land ownership is an important consideration when planning for field work. It is a complex topic, and the primary issues for both field surveys and construction monitoring concern whether a permit(s) is required to conduct field work and collect fossils, and whether or not fossils can be collected if discovered. It is essential to obtain written right-of-entry from the land owner prior to entering any private property, even if crossing over private land to work on federal or state land. Be sure to understand the trespass laws of the state you are working in. Fossils should never be collected from private land without written permission from the land owner (see Section 7).

Archeological field surveys are typically not conducted without 75% or greater ground visibility. This percentage is variable and is usually at the discretion of the principal investigator or local agency office. Some local agency offices extend a similar requirement to paleontological field surveys with regard to snow cover. However, the differences between these resources make this restriction inappropriate for paleontology. The small size of many scientifically important fossil specimens, and the presence of small bone fragments on the ground surface that could indicate more extensive subsurface fossil remains, makes it impossible to determine whether fossils are present in areas where the ground surface is not fully visible. For these reasons, the ground should be completely free of snow before a paleontological field survey commences (5.3).

Scopes of work and budgets for paleontological field surveys should be based on a pedestrian examination of outcrops of potentially fossil-bearing rocks or surficial deposits including the time necessary to perform reconnaissance for outcrops. All survey activities should be confined to the project area. In rocks and surficial deposits with high and very high sensitivity, all exposures should be surveyed. However, in rocks with moderate or unknown sensitivity, spot-checking of exposures of rocks and surficial deposits is typically an acceptable level of effort. Because exposures of sedimentary rocks are not continuous over the landscape in most areas, often being restricted to ridges, canyon walls, stream cuts, badland knobs, and so forth, surveys should be focused in such areas (Figure 2). Where walking evenly spaced transects is a standard procedure for archeological surveys, it is not a best practice in paleontology; rather, a survey field crew should spread out to cover as much ground in as little time as possible, as opposed to hiking closely together. Field surveyors should be cautioned to avoid the traditional research-oriented approach of making a beeline to the best-looking outcrops. For mitigation projects, all outcrops need to be thoroughly prospected – many important fossil discoveries have occurred in unlikely settings, including small exposures that are often ignored by researchers. For example, certain highly fossiliferous rock units are known to yield scientifically significant fossils even in areas with weathered and entirely vegetated exposures including flat prairie, so this should be taken into account during the scoping and planning process. For archeological surveys, a slope exclusion is sometimes imposed in order to eliminate steeper areas with a low likelihood of containing archeological sites. Slope exclusions should not be imposed on paleontological field surveys because of the high likelihood of finding fossils in steeper and more rugged terrain where bedrock is more likely to be exposed. However, field crews should be advised to exclude areas that are too steep to survey safely (5.4). Because fossils are never identifiable from a vehicle, windshield surveys are never appropriate for fossil prospecting and are only useful for determining the physical locations of rock outcrops from a road. For these reasons, field survey reports should differentiate between areas that were subject to pedestrian versus windshield survey (or any form of non-pedestrian visual inspection) (5.5).

There are two general types of field surveys with various permutations and exceptions. Block surveys are often employed at the programmatic level and provide a resource clearance for a larger project with unknown infrastructure locations by surveying the entire project area. Infrastructure-specific surveys are targeted to planned locations of specific project elements with anticipated ground disturbance within a larger project area (e.g. well pads, or seismic source points), and may include a survey buffer. The word 'survey' may or may not include fossil collection, whereas a paleontological resource inventory connotes resource documentation with no collection (see Section 7). The activities of the field survey generate the data used in reporting and result in mitigation recommendations. Impact mitigation in the form of fossil collection may occur at the time of initial fossil discovery during a field survey, or be deferred until input from the principal investigator, agency, client, and/or land owner has been obtained. Although resource avoidance has traditionally been the agency-preferred approach to impact mitigation, the fact is that most surface fossils have a very limited lifespan due to environmental factors such as weathering and erosion, not to mention poaching (theft) by humans. Therefore, fossil collection and museum curation is the best practice for paleontological resource preservation. This is another practice that deviates significantly from CRM, where most resources are recorded, but not collected. Clients are frequently concerned that collecting surface fossils identified during a field survey and repositing them in a curation facility will be more costly than avoiding the resources and believe that it is less costly to re-engineer the project in order to relocate it away from fossil localities. In the case of block surveys, if a project has not yet been designed, it may be possible to avoid scientifically important fossil localities. However, for projects that have been designed, it is often less costly to collect, prepare, identify, report, and curate isolated surface fossils than to reroute or move project infrastructure, and as a best practice, this should be explained to clients. Exceptions certainly exist, such as bone beds or large fossils (see extensive fossil discoveries below), and fossiliferous ant hills that may be time consuming to prospect and collect, since they may contain hundreds of small fossils. Of course the client always retains the option to pay for mitigation if it is not feasible to move the project to avoid a fossil locality. A client is under no obligation to mitigate impacts to paleontological resources that will not be affected by the project, because there will not be any project-related impacts. Fossil collection is not permitted on some tribal lands, and in these cases, for scientifically important fossils documented during field surveys, resource avoidance is the only mitigation alternative, necessitating project relocation. However, in the case of fossil discoveries of very high scientific importance, it is worth contacting the appropriate tribal authorities to make a case for fossil collection and curation (5.6).

It is advisable to exclude the mitigation of 'extensive' fossil discoveries from initial scopes of work unless of course that is the sole purpose of the project. During routine field surveys and monitoring in paleontologically sensitive rock units and surficial deposits, one expects to find fossils, and typical fossil discoveries can be anticipated and budgeted for. However, extensive fossil discoveries are those that are not anticipated, and are outside of the scope of work of normal mitigation. Typically, these include bone beds or other exceptionally rich accumulations of vertebrate fossils, or large fossils such as complete or nearly complete skeletons of large mammals or reptiles. In the case of such discoveries, the client and agency (when applicable) should be notified immediately, and the locality should be avoided until a decision on a mitigation approach has been reached. Generally, the locality will be avoided by the project, and the mitigation paleontologist or agency should contact an institution or researcher(s) who may have an interest in it. However, the client may choose to have the site excavated, and in such cases, the preparation of a locality specific mitigation plan may be required. There are cases in which it has been necessary for a client to provide security for fossil discoveries, even non-extensive localities (5.7). 'Unanticipated discovery' is another CRM term that is sometimes misapplied to mitigation paleontology. In CRM, an unanticipated discovery is a discovery that is very important and requires additional intensive mitigation work. Examples include a human burial or a buffalo kill site. Therefore, the terms unanticipated discovery and extensive paleontological discovery are functionally equivalent. However, it is a best practice to avoid the use of CRM terminology in mitigation paleontology, thereby minimizing continued confusion between the two disciplines (5.8).

Some additional important and often confusing terminological issues are worth discussing. In particular, these include the terms: disturbance area, project area, buffer, survey area, right-of-way, and area-of-potential-effect. Every project for which a mitigation paleontologist is contracted has a disturbance area that is never larger than the project area boundary. The disturbance area may include a buffer, and the disturbance area plus the buffer constitute the survey area. Linear survey areas are often referred to as survey corridors. The size and magnitude of planned disturbance varies greatly from minor for such activities as laying seismic cables across the landscape, to major for such activities as mass grading and open pit mining. The size of the buffer is also variable, and is determined by the agency or the client, depending on regulations and project objectives. The buffer provides flexibility for the project so that if resource surveys identify environmental concerns within the buffer such as fossil localities, archeological sites, or threatened species, the disturbance area can be shifted within the area surveyed to avoid them without having to perform additional resource surveys. However, the buffer also serves the practical purpose of reducing the possibility that project personnel or equipment that stray from the disturbance area will adversely impact the sensitive resources. There is no one appropriate buffer size since project needs and requirements are so variable. In our experience, survey areas, whether linear or not, can have buffers that vary from 10 feet from the disturbance area boundary, to 200 feet from the disturbance area boundary (= 400 feet total in addition to disturbance area width for linear projects). For mitigation paleontology, a buffer of 50 to 100 feet wide is adequate in most circumstances. Right-of-way, abbreviated ROW, is a term that refers to a linear easement for which a legal right has been granted to pass through property owned by another. For most projects the ROW represents an area within which all project activities must occur. The size of an area-of-potential-effect, abbreviated APE, is resource dependent and may be larger than the project area. The term APE is usually used in connection with NEPA related studies, and because the meaning and size are variable between local agency offices and resources, we recommend avoiding the use of APE in mitigation paleontology.

Various forms of exploratory 'shovel testing' are employed by archeologists in order to determine the presence of cultural resources in areas where the ground surface is obscured by vegetation, or where there is a known feature of unknown extent and eligibility. A key assumption in shovel testing is that human habitation is tied to certain features of the landscape, such as areas with low topographic relief and close proximity to water; and it is also assumed that despite climatically induced environmental change, the overall geomorphology of the area has not changed significantly between the time of earlier human occupation and the present day. With the arguable exception of the late Pleistocene, fossil occurrences are tied to depositional environments on the basis of lithofacies and taphofacies rather than the topographic features of the modern landscape. Therefore, the use of archeological testing techniques such as exploratory shovel testing to infer the presence or absence of paleontological resources is meaningless. This practice is typically imposed by uninformed agency personnel who lack paleontological training, and should be advised against by mitigation paleontologists. It is possible that future techniques or technologies will be developed that will be useful tests for the presence of subsurface paleontological resources. However, at the current time no such tests exist (5.10).

Field paleontologists know that fossils, especially small specimens, can be quickly eroded and exposed at the surface, and just as quickly be transported away from the locations of their initial exposure as the result of natural forces such as wind and rain. Therefore, the idea of an expiration date for an agency-required paleontological survey is nonsensical because erosion and exposure rates vary regionally, by rock unit (lithology), and are also related to the areal extent of rock exposures in an area. A time limit for CRM surveys exists but is highly variable depending on a number of factors. A five-year expiration date for paleontological field surveys is a common agency recommendation – meaning that the survey has to be repeated if the project has not been built within five years. Using local paleontological knowledge and experience, mitigation paleontologists should provide recommendations regarding the frequency of repeated field surveys and provide justification to land managers in field survey reports and end of year permit reports (5.11).

6. CONSTRUCTION MONITORING

Unlike field surveys, there is no academic training available for the basic skills of paleontological resource construction monitoring. On-the-job training is the only option. The purpose of monitoring is to reduce damage or destruction (i.e., minimize adverse impacts) to scientifically important fossils that are unearthed during construction. The job of a paleontological monitor is largely visual, but it is also mentally and physically demanding, nevertheless. Monitoring entails conducting inspections of

Figure 3. Field paleontologist Pat Sena monitoring mass grading activities in upper Pliocene strata of the San Diego Formation as exposed during construction of residential housing in coastal San Diego County.

excavation sidewalls, graded surfaces, trenches, and spoils piles for evidence of fossils exposed by excavations, often on surfaces that are obscured by debris and clouds of dust (or snow). The inspections must be conducted at a safe distance from the excavation equipment in the controlled chaos of a construction site (Figure 3). Time is of the essence because if equipment is running, the freshly exposed fossil can be destroyed with the next scoop of a track-hoe bucket or the next pass of a scraper or bulldozer. For this reason, the equipment operator must be alerted before the fossil is irreparably damaged.

Monitoring stands apart from other aspects of mitigation paleontology in that it requires not only a specialized skill set, but also a particular temperament. For example, most mitigation paleontologists would agree that being skilled at finding surface fossils in traditional paleontological field surveys does not necessarily translate into the ability to find fossils in an active construction site. Also, it is necessary to stay alert at all times both for safety reasons, and because depending upon the density of subsurface fossil occurrences, weeks can go by without a fossil discovery and then a fossil is exposed with no warning.

“Monitoring a construction site is like looking for fossils during flight deck operations onboard the USS Nimitz.”

—Patrick J. Sena, a long-time monitor (and ex-marine) for the Department of PaleoServices at the San Diego Natural History Museum

In this sense, paleontological monitoring is like fishing — long periods of inactivity punctuated by intervals of increased activity. However, if you do not have a line in the water or are not actively monitoring, you will not have any hope of catching a fish or finding a fossil. For this reason, a monitor does not have the luxury of letting his

Phase	Field Survey	Construction Monitoring
1. Preliminary Mitigation Evaluation - Is the locality worth exploring?	Initial examination indicates that fossil(s) are either possibly identifiable and meet pre-determined threshold criteria for scientific importance, or unidentifiable in which case locality should be recorded as non-significant and no further action is required (skip to Phase 4). Time is not usually a critical factor for all phases.	Initial examination indicates that fossil(s) are either possibly identifiable and meet pre-determined threshold criteria for scientific importance, or unidentifiable in which case locality should be recorded as non-significant and no further action is required (skip to Phase 4). Locality avoidance is not typically an option, even in the case of extensive fossil discoveries as defined in Section 5. Time is usually a critical factor for all phases.
2. Locality Exploration - Is/Are the fossil(s) worth collecting?	Determine areal extent of locality by surface prospecting and probing surface sediments with hand tools. Western harvester ant (Pogonomyrmex occidentalis) hills should also be explored. Unless necessary avoid the use of adhesives or consolidants, and focus on exploration rather than stabilization or excavation. In cases in which partially exposed fossil(s) are determined to be non-significant following exploration, or can be avoided or collected later, skip to Phase 4. Locality avoidance is typically an option for scientifically important fossil localities, and is likely preferable for extensive fossil localities as defined in Section 5, depending upon client priorities.	Determine lateral and vertical extent of locality using hand tools, and if possible in the case of larger localities, with heavy equipment. Unless necessary, avoid the use of adhesives or consolidants and focus on exploration rather than excavation. If the fully explored fossil(s) are then determined to be non-significant, skip to Phase 4, and no further action is needed.
3. Locality Excavation and Collection		
(Phases 3 and 4 are partially concurrent.)	Collect fossil(s) from ground surface by hand quarrying or if necessary by larger, but permit-conformable, sized quarry. Use adhesives and consolidants as necessary. Collect fossiliferous anthills if scoped for. Collect bulk matrix samples if small fossils are present. If the budget and schedule permit, collect and wash test samples to determine whether the density of small fossils warrants bulk sampling.	Collect unearthed fossil(s) by hand quarrying and/or with the assistance of heavy equipment if needed and appropriate, and if applicable, from the ground surface or spoils piles. Use adhesives and consolidants as necessary. Collect bulk matrix if scientifically important small fossils are present. Heavy equipment can be used to stockpile matrix away from construction activity. If the budget and schedule permit, collect and wash test samples to determine whether the density of small fossils warrants bulk sampling.
4. Locality Documentation		
(See Section 4 for greater detail.)	Record locality as non-significant if fossils discovered were found to lack scientific importance. For scientifically important fossil(s), complete locality data recordation during surface collection and/or excavation phases, but prior to jacketing or packing and removal of fossil(s) from locality. Additional mitigation recommendations could include collection if avoidance is not feasible, or deferred collection pending client and/or agency approval. If client-preferred mitigation is avoidance, survey and record an alternative corridor or project infrastructure location which avoids scientifically important fossil localities.	Record locality as non-significant if fossils discovered were found to lack scientific importance. For scientifically important fossil(s), complete locality data recordation during surface collection and/or excavation phases, but prior to jacketing or packing and removal of fossil(s) from locality. Additional mitigation recommendations are usually not relevant to localities discovered during monitoring because such localities are typically graded away.
5. Laboratory Work	Transport fossil(s) to paleontological laboratory for preparation identification, and pre-curation work.	Same as Field Surveys.

Table 2. Phases of the fossil salvage process (collection to pre-curation) during field surveys versus construction monitoring.

Figure 4. Georgia Knauss operates a Trimble GPS receiver while Dale Hanson examines rocks of the Sentinel Butte Formation (Fort Union Group) exposed in a natural gas pipeline trench in North Dakota.

or her guard down for a moment. Many paleontologists find monitoring to be excruciatingly tedious, so it is not for everyone.

Before discussing specific monitoring procedures, and for the purpose of avoiding confusion, it is worth pointing out that some agencies do not consider paleontological monitoring to be mitigation. The distinction made by some agencies is that monitoring refers to the process of discovering fossils during ground disturbance, whereas mitigation is the process of reducing impacts by removing fossils from the path of construction. This is a distinction that these agencies have made for monitoring other types of natural resources. However, as a practical matter, monitoring and mitigation go hand in hand during excavation activities and for the field paleontologist, fossil salvage is a logical extension of the monitoring process.

Pre-field preparation procedures for monitoring are similar to those recommended for field surveys (see Section 8). Monitoring should be a mitigation requirement when avoidance is not an option and construction will disturb bedrock units or surficial deposits with a high potential to contain fossils of scientific importance (6.1). Continuous monitoring, refers to a full-time level of effort, and is typically required for project areas (or portions thereof) with high and very high sensitivity. Spot-checking refers to a part-time level of effort, and is typically required for project areas with moderate or unknown sensitivity (also applied to low sensitivity when using SVP guidelines in California). Operationally, spot-checking can be a challenge in cases in which the project area is a great distance away from the nearest other project, and there are no other mitigation activities available for the monitor. As the name indicates, spot-checking means performing limited inspections at monitor-selected locations within a project area, and there is the possibility that fossils may be missed by the monitor in such situations since he or she is not always present. Regardless of the stipulated monitoring level of effort, the principal investigator should have the authority to increase (or decrease) the monitoring effort should the monitoring results indicate that a change is warranted.

In some instances, monitors have the opportunity to do a brief, final surface inspection prior to ground disturbance to ensure that no scientifically important fossils were missed during or exposed after the preceding field survey (6.2). However, in most cases monitors typically only watch active construction excavations, which can vary from relatively small disturbance areas such as access roads, oil and gas well pads, drilling for footings, and trenching for pipelines; to relatively large disturbance areas such as mass grading for residential or commercial development, new roadway construction projects, solar energy generation facilities, and open pit mining operations. In most sedimentary rock units and surficial deposits, drilling with an auger with a tool diameter of two feet or less, typically pulverizes the sedimentary matrix, including any contained fossils. Therefore, monitoring of drilling activities when a small auger is used is typically not recommended. However, if a monitor is already on site inspecting project-related excavation activities, the drilling spoils should be periodically checked for the presence of fossils and the breakage characteristics of the matrix should be checked to see if the drilling is yielding rock fragments large enough to contain identifiable fossils (6.3). Some types of ditching equipment are known to turn rock to a fine powder, obliterating any evidence of fossils in the spoils piles. If such equipment is in use, the only option for monitoring is to inspect the trench sidewalls for exposed fossils (Figure 4). This procedure has been shown to be highly effective in identifying fossils in cross section depending on the lithology of the rock unit and types and sizes of fossils the rock unit is known to contain. Track hoe excavations have been found to be more conducive to the discovery and recovery of unearthed fossil remains than ditching machines, because they produce larger blocks of rock which can contain more complete fossils. Finally, when equipment is not running due to lunch breaks, end of shift periods, and/or equipment breakdown, there is an extra opportunity to safely examine the cut, document the stratigraphy, and dig through spoils piles. For all these reasons, and especially for large footprint projects, monitors do a lot of walking (6.4).

Monitoring inspections should be performed as close to the active cut or other type of excavation as is safe in order to see fossils as they are unearthed, whether in spoils piles or exposed in excavation sidewalls or horizontal graded surfaces. Monitoring cannot succeed if monitors are not within visual range of the excavation, ideally 5 to 20 feet but no greater than 30 feet, and even at that distance fossils may not be visible (6.4). There are specific Occupational Safety and Health Administration (OSHA) safety requirements for the types and depths of excavations that can be entered by project personnel, and it is critical that these safety requirements be strictly adhered to. For example, monitors should not enter trenches that are greater than five feet deep; and should not approach the edge of a trench that is more than six feet deep without a guard rail. Also, monitors should never walk underneath any construction equipment, and should stand at a distance greater than the length of the extended arm of equipment that can rotate, such as track hoes. Be sure to consult with project safety personnel prior to entering the construction area for site-specific safety requirements. However, as a rule of thumb, monitors should never do anything that feels unsafe. It is important for their safety that monitors understand the movement patterns of construction equipment around the project area (e.g. haul road), and use standard hand signals to communicate with equipment operators. If the monitor cannot see the operator, chances are that the reverse is also true and the operator cannot see the monitor. Verbal communication with all project personnel, including the foreman, environmental inspector(s), grade checker, other environmental monitors, and project geologist, is also very important. Although there is a safety benefit to communication, it is also very helpful for the success of monitoring to develop a good working relationship with all project personnel. Developing an attitude that the field paleontologist is just another member of the project team has been proven to help minimize the perception that paleontologists are 'elitist academics out to shut down construction.' Overall, this team approach will greatly increase the likelihood that in the event fossils are unearthed and unseen by the monitor, the operator will alert the monitor to their presence (6.5).

Monitors should be paying constant attention to, and documenting on a field form or in a field notebook, the stratigraphy of the project area as it is sequentially revealed in exposed strata. A minimum of one stratigraphic section should be measured as the project progresses, even if no fossils are found, and the monitor should consult with the project geologist if practical for helpful geologic information about the project site and surrounding area. In the case of larger projects, it may be necessary to measure multiple stratigraphic sections in order to document facies changes and refine the stratigraphic position of local channel features and surfaces of erosion. Measuring stratigraphic sections on an active construction site is challenging because of discontinuous exposures, here-today-gone-tomorrow parts of the section, compaction which tends to obscure the stratigraphic profile, and ubiquitous dust and/or snow. However, the stratigraphic work need not take away from the monitoring effort. This is because the stratigraphy can be documented in the current monitoring area and added to and revised as the excavation moves and progresses up or down section. Having a working stratigraphic framework of the emerging section makes it possible to more unequivocally plot the stratigraphic position of discovered fossils. On projects with more than one monitor, all monitors should work cooperatively to ensure that the stratigraphic framework for the entire project area is documented consistently. For linear projects that follow the approximate contours of the landscape, such as a pipeline trench, and unless the bedding planes are dipping noticeably (in which case standard stratigraphic sections are preferable), a trench log may be the best option for documenting the lithologic changes along the project alignment and their relationships to discovered fossil localities. All stratigraphic and structural geologic observations should be for the purpose of interpreting the context of the fossil assemblages within the project area, and should never be construed as providing data for project geotechnical or engineering design purposes. For projects involving drilling operations, vertical stratigraphic position (i.e., depth below ground surface) can roughly be estimated by measuring the distance from the ground surface to the level of the bit on the auger. All fossil localities must be tied to the stratigraphic sections measured for the project, and all

geologic documentation should be included in the final monitoring report. A stratigraphically well documented project should make it possible to interpret facies relations and depositional environments, as well as the relative age relationships of the recovered fossil assemblages (see Section 8, figures 2 and 3) (6.6).

An unfortunate monitoring practice, but one which some project managers and equipment operators actually prefer, is for monitors to make themselves scarce on the job, and spend the majority of their time sitting (or sleeping) in their vehicles. The rationale is that by not actively monitoring, fossils will not be found and this will decrease project costs. Requiring monitors to stand too far from the equipment to visually observe the excavation under the guise of safety concerns is another way of preventing monitors from making fossil discoveries and thereby reducing perceived financial risks. Monitors and the firms and organizations they represent should educate clients and construction personnel about monitoring best practices, particularly with regard to safety, but also with regard to the need to be within view of the active excavation in order to keep the project in compliance with agency-approved environmental requirements. It may also be worth pointing out to clients that unless the land is owned by the project proponent, without adequate monitoring there is the potential for financial risk to projects, particularly if fossils with scientific importance (may translate to economic value on privately owned lands) are destroyed by construction equipment. Additionally, impeding the monitoring effort could be in violation of project conditions of approval or construction permits (6.7).

The discovery of a fossil(s) during monitoring initiates the recovery process with fossil evaluation and salvage (see Section 7). After a brief evaluation to determine whether the fossil discovery has the potential to be scientifically important, the monitor should immediately alert the equipment operator and make any other necessary project-specific notifications depending upon the nature of the fossil(s) and the requirements of any approved project monitoring and mitigation plan. The fossil discovery (plus a 20-foot buffer depending upon locality dimensions) should be cordoned off with high visibility flagging, and additional personnel immediately mobilized, as-needed, to provide monitoring or fossil salvage support while the discovery is explored and evaluated. Construction activity should not be discontinued, but should be directed away from the discovery locality in consultation with the construction foreman. Equipment should operate no less than 20 feet from the fossil discovery locality, although this buffer should be increased if the monitor believes that the extent of the fossil locality may be larger than what is currently exposed. All monitors should have expertise in fossil evaluation and salvage techniques (6.8).

7. FOSSIL SALVAGE: FROM COLLECTION TO PRE-CURATION

Broadly speaking, fossil salvage activities for mitigation paleontology projects can be separated into two categories: fossils that are collected during field surveys and fossils that are collected during construction monitoring projects. For the purpose of this paper, fossil salvage also includes laboratory fossil preparation, fossil identification and pre-curation. Although both salvage categories have many similarities in field procedures, they also have some important differences primarily having to do with impact mitigation. One of the most critical differences between the two is the amount of time available to complete salvage operations. For example, decisions regarding fossils discovered during monitoring have to be made quickly because the paleontological resource has already been impacted, whereas typically there are more options for fossils discovered during field surveys, and time is less of a factor. The fossil salvage process generally has five phases, as discussed below and summarized in Table 2.

Phase 1 of the salvage process involves a preliminary evaluation of the fossil(s) exposed by construction equipment or found on the surface. The decision should follow pre-determined threshold criteria for scientific importance (or agency specific criteria), and should determine whether or not the fossil(s) discovered warrant salvaging. If the decision is not to salvage, the locality should be recorded (see Section 4) as non-important and no further action taken. Note that locality avoidance is typically not an option for localities discovered while monitoring because the locality has likely already been impacted (7.1).

If the discovered locality contains one or more fossils that clearly have scientific importance, or that have the potential to have scientific importance based on what is exposed (i.e., visible), then Phase 2 of the salvage process, locality exploration, should begin. Mitigation evaluation continues during this phase because sometimes the full scientific importance of fossils cannot be determined until they have been more completely exposed. Locality exploration involves surface prospecting to determine the boundaries (lateral extent and depth) of the locality and the distribution and concentration of fossils. Digging is typically done using hand tools (e.g., small shovels, trowels, hammers, chisels, etc.). Because time is of the essence

Figure 5 (previous page top). Field paleontologists from the San Diego Natural History Museum's Department of PaleoServices plaster jacketing the skeleton of mysticete whale discovered in upper Pliocene strata of the San Diego Formation during construction of a water facility at the San Diego Zoo.

Figure 6 (previous page bottom). Field paleontologists from SWCA Environmental Consultants salvaging a fossil leatherback turtle from steeply dipping strata of the Miocene Monterey Formation in San Clemente, California.

Figure 7. Paleontologists Mark Roeder and Patrick Sena screenwash sedimentary matrix samples from the middle Eocene Duchesne River Formation at the Utah Field House Museum of Natural History in Vernal, Utah.

on active construction projects, heavy equipment can be useful to expedite the locality exploration process and can also facilitate access to the locality (e.g., by digging an access ramp), as long as the equipment does not come into direct contact with the fossil(s). If during the exploration phase, the locality is determined to lack scientific importance, it should be recorded as non-important, and no further action is needed. However, if during exploration the locality is determined to have scientific importance, the fossils can be collected; fossil collection can be deferred until the principal investigator, agency and/or client have evaluated the scientific importance and/or mitigation options; or the entire locality can be avoided (Phase 3). Avoidance is an option if the proposed activity is easily moved (e.g. a seismic project source point), or if the locality is extensive and would be prohibitively costly to mitigate. In such cases it is important to survey an alternative project infrastructure location or corridor that avoids other scientifically important fossil localities. Unlike field surveys, mitigation by fossil collection is typically the only option for scientifically important fossils discovered during construction monitoring. However, it is never necessary to shut down the project due to the discovery of a fossil. Furthermore, the stipulation sometimes applied to CRM projects that construction work be suspended project wide pending agency review and approval of a site specific mitigation plan should not be applied to paleontological discoveries (7.2).

Fossil collection (Phase 4) and documentation (Phase 5) are considered to constitute impact mitigation because they remove fossil(s) (and/or collected fossiliferous ant hills and matrix samples), along with associated information, from the construction disturbance area. Locality excavation and fossil collection for mitigation paleontology projects is a complex topic due to the many considerations involved. Standard types of fossil salvage techniques for construction monitoring projects include pre-construction surface collection, ‘pluck n’ run’ (for isolated and quickly collected fossils), small quarries, large excavations, and bulk matrix collection. Standard types of fossil salvage recommended for deferred collection (i.e., collected later pending client or agency consultation techniques for field surveys) include surface collection (including high-grading of western red harvester ant hills), small quarries, large excavations, and bulk matrix collection (including ant hills). Excavations to collect fossil(s) discovered during field surveys or prior to construction may require a special permit. On BLM managed land, an excavation permit is required for any ground disturbance that exceeds 1 square meter in size and an environmental assessment of the excavation site must be performed as part of the permitting process (although is some cases the NEPA evaluation done for the larger project may streamline this process or make a subsequent analysis unnecessary). Fossiliferous concretions can be surface collected or excavated during monitoring, and should be documented and then removed from the project area whole for later preparation in a laboratory setting.

Salvage techniques appropriate to the size and preservation of the discovered fossils should always be used. All monitors should be knowledgeable of fossil salvage and sampling techniques and be properly equipped with field tools and supplies, including archival quality reversible adhesives and consolidants. Speed and efficiency are crucial for salvaging fossil localities found during construction monitoring. Medium- to large-sized fossils or groups of fossils should be excavated as blocks, still encased in matrix to provide additional stability and to expedite excavations and minimize construction delays (Figures 5 and 6). Removing enclosing matrix to fully expose a fossil adds substantial time and increases the possibility of breakage during transport. As during the exploration phase, construction equipment can be used during Phase 3 to expedite fossil excavation so long as the equipment does not come into direct contact with the fossil(s). Construction equipment is also useful during Phase 4 and can lift heavy plaster jackets into vehicles for transport offsite. Equipment operators are usually willing to provide assistance to expedite the salvage process and reduce construction delays. Prior to moving or jacketing any fossil specimens, ensure that all data are recorded including the original orientation and concentration of the fossils. If applicable, a scaled quarry map should be produced to accurately record critical taphonomic data. Properly label all bags, containers, and plaster jackets with field locality numbers. If needed and within scope, rock or sediment samples for future analysis (e.g., radiometric or biochronological dating) should be collected at the time fossils are salvaged (7.3).

Screenwashing for small fossils (vertebrate, invertebrate and plant) is a critical procedure that has been demonstrated to yield results unobtainable via any other means, and has greatly increased the taxonomic diversity and number of specimens available for study in formations wherein it has been employed (Table 3, Figure 7). For fossil accumulations including bone beds (whether considered to be 'extensive' fossil localities as defined in Section 5 or not), it may be necessary to collect bulk matrix samples, or excavate and jacket blocks of more indurated fossil-bearing sedimentary rock, depending on fossil size, durability, quality of preservation, and other factors evaluated by the field supervisor or principal investigator. SVP (2010, p. 7) provides guidance for bulk matrix sampling, recommending the collection of 600 pound test samples and if warranted, screenwashing of 6,000 pounds or more of matrix from each "site, horizon, or paleosol," depending on the "uniqueness" of the fossil content. However, because of variation in fossil density within and between geologic units, smaller samples may be sufficient based on the results of rarefaction analysis, or in cases in which the locality contains abundant fossils or has less matrix available for sampling. During Phase 3 and 4 work, construction equipment can be used to collect bulk matrix and/or stockpile matrix away from the disturbance area for later processing by paleontologists.

If a locality contains at least one scientifically important fossil, then it should be considered scientifically important and recorded as such (see Section 4). However, other than generalized significance criteria, there is little agency guidance provided about what to actually collect at a locality. Using the significance criteria alone, the implication is that only 'scientifically significant' fossils should be collected. However, partial collection of fossil localities is generally not considered good scientific practice in vertebrate paleontology. For example, leaving some unidentifiable bone fragments at an outcrop after collecting the bulk of a given specimen could prevent a broken skeletal element from being reunited. The best approach is to incorporate guidance from technical experts and/or regional museums during the development of threshold criteria for paleontological importance so that field paleontologists are as well informed as possible about the criteria for scientific importance and fossil collection. Based on knowledge of the research context and paleontology of the area (see Section 3), collect all identifiable specimens that have scientific value using BLM or other federal 'significance' criteria, if applicable. If non-important but identifiable specimens representing other taxa are present, it is a best practice to make a census collection that reflects the taxonomic diversity of the locality for paleoecological analysis. Assuming locality avoidance is not the chosen mitigation option, it is the responsibility of the mitigation paleontologist to fully collect all scientifically important fossils from within a project area. In such cases the project scope of work and budget should be designed to accommodate this level of collection and subsequent curation needs (7.4).

Field paleontologists (technicians/surveyors/monitors) should refrain from collecting any non-paleontological natural resource objects from a project area, regardless of land ownership, and regardless of the legal status. These include modern bones and antlers, cultural artifacts (projectile and spear points, etc.), plants, rocks, and non-important (poorly preserved and unidentifiable) fossils. Nothing should be collected for personal use. Collecting for personal use on a mitigation project is unprofessional and may invite unanticipated problems for a project (7.5).

Land ownership is an important consideration pertaining to fossil collection. As emphasized in Section 2, it is critical that land ownership be known prior to undertaking any field work, and that pertinent regulations be fully understood. Regardless of their scientific value, fossils should never be collected without written permission from the land owner or without an approved paleontological resource use permit. In some southern California counties, all scientifically important fossils recovered from privately

Table 3. Examples of screenwashing results from representative impact mitigation projects completed by the Department of PaleoServices, San Diego Natural History Museum (Both projects in middle Eocene Santiago Formation, Oceanside, California).

	Localities	Specimens	Type Specimens	lbs	lbs/specimen	Specimen/lb
Ocean Ranch	30	2,409 (217 invert., 2,183 vert)	53 (22 vert., 30 invert)	26,250	1,681	*0.7 - 263
Jeff's Discovery	6	4,828 (88 invert., 4,736 vert)	28 (23 vert., 5 invert)	16,650	3,148	5.9

*Range per sample provided because highly variable for this project

owned lands during construction monitoring projects are required to be curated at a designated regional paleontological curation facility. However, in other states, land owners own all fossils on their lands, are not required to reposit them in a curation facility, and only occasionally donate them to a curation facility. Assuming right-of-entry is granted, the standard practice for field surveys on large (interstate) projects with hundreds of land owners involved is to evaluate and document all fossils, and notify land owners in writing of any that have scientific importance. Land owners are then provided with the option to have the fossil(s) collected for land owner use, left in place in the path of construction (waiving the project proponent of any liability in the event of damage), or to have them collected, prepared, and donated to a curation facility. The donation may be tax-deductible. A similar procedure is followed for construction monitoring projects, the primary difference being that the fossil likely has already been impacted at the time it was discovered, so the decision to salvage has to be made by the monitor usually without the possibility of immediate land owner input. This removes the option of having the fossil left in the path of construction, and all fossils with scientific importance should be collected by default.

Fossil collection policies for mitigation projects on Native American tribal lands are variable and can be challenging. Of foremost importance is to respect all tribal policies and work within them to reduce impacts. Some Tribes do not permit fossil collection even by professional paleontologists, and yet they still have the resource management objective of reducing impacts to paleontological resources associated with energy development. The mitigation strategy in this scenario is avoidance, which works well for fossils discovered during field surveys but can be problematic for fossils discovered during construction monitoring because it is too late to avoid them once their presence is known. Unless it is for the purpose of permanent preservation in a curation facility, a fossil should never be physically moved from its original locality, thereby removing it from its stratigraphic context. While it may be worthwhile to recommend fossil collection to the on-site tribal monitor or other tribal representative if a scientifically important fossil is discovered during monitoring, there may be no option provided by the Tribe other than to document the fossil and leave it in place. In-situ molding of scientifically important fossils found on tribal lands during field surveys has been shown to be an effective means of collecting scientifically useful information in cases where fossil collection is not permitted (Imhof et al., 2008), and this approach could also be employed for scientifically important fossils found while monitoring (7.7).

In all cases, fossil localities should be differentiated stratigraphically, even if they are geographically proximate. Using GPS receivers, fossil localities should be geographically documented appropriately for their size. Single, isolated fossils should be recorded as locality points. Taking into account GPS position error (typically 20-30 feet for most recreational quality GPS receivers), larger localities should be documented as lines for localities exposed along beds, and polygons for non-linear localities. If the GPS receiver lacks the capability to record lines and polygons, a series of points should be recorded (again taking into account GPS position error) (7.8). Additional information on locality documentation can be found in Section 4.

The final phase of fossil salvage includes laboratory work (Phase 5). This phase includes fossil preparation, identification, completion of any necessary associated analyses, and pre-curation. Preparation includes removal of surplus and concealing sedimentary matrix, repair and conservation using archival adhesives and consolidants, and limited infilling (with archival products) of voids that compromise the structural integrity of the fossils. In consultation with the curation facility, fossils should be prepared to the point of curation - operationally the point at which the bulk of enclosing matrix has been removed and the curation facility does not need to do additional preparation work prior to curation (see Section 9). Bulk matrix samples should be screeenwashed (see SVP, 2010, p. 7), floated with heavy liquids if appropriate, and picked/sorted for small fossils. All fossils should be identified to the level of genus or lowest taxonomic level possible by a paleontologist with technical expertise with that taxonomic group. As a practical matter, salvaged fossil specimens are not typically identified to the level of species because the level of detailed study needed to determine species crosses into the realm of research. It is assumed that the curation facility will verify the fossil identifications if there is a

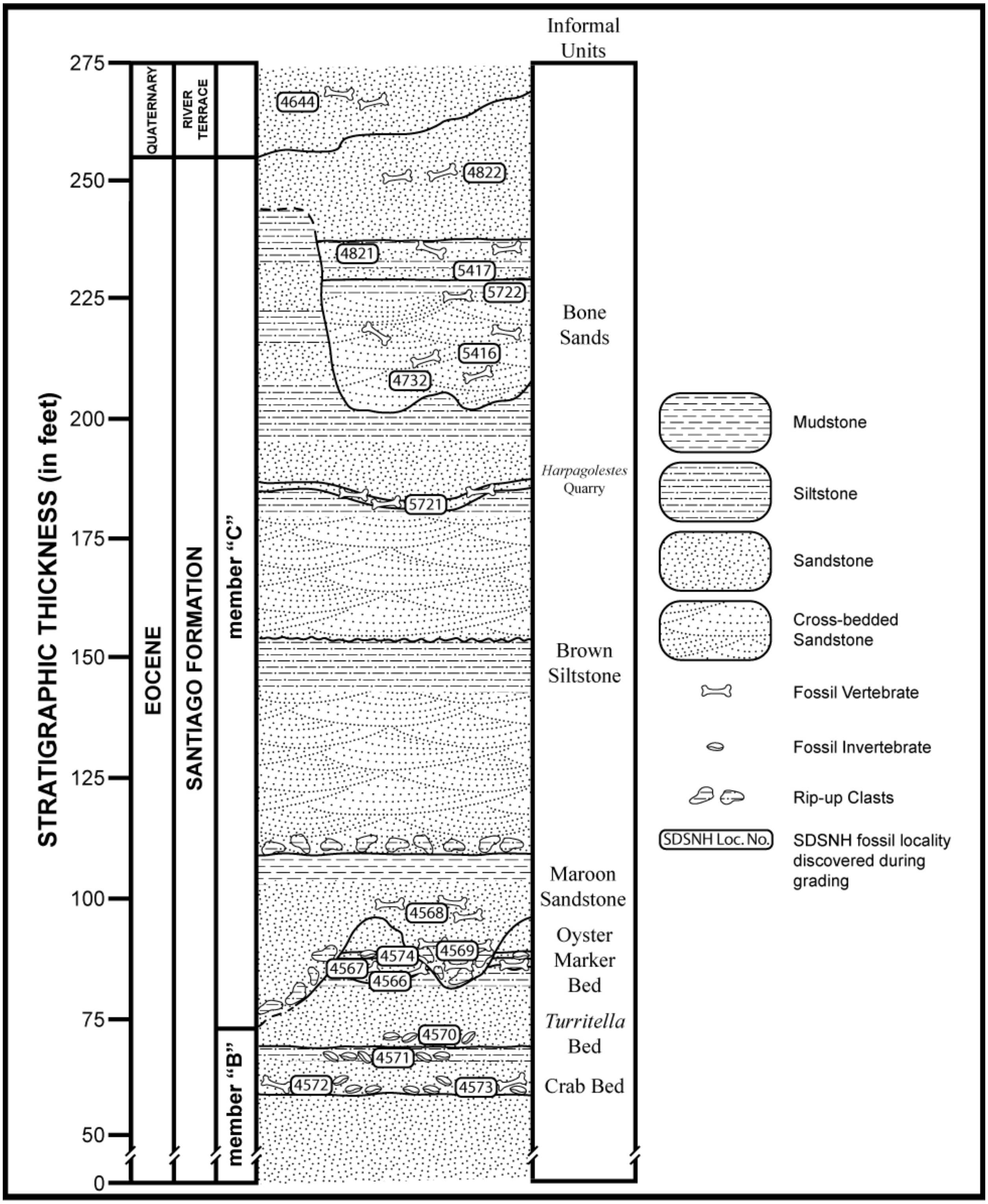

Figure 8. Composite stratigraphic column for the Ocean Ranch Project, City of Oceanside, California. Diagram depicts the lithologies, stratigraphic contacts, and stratigraphic positions of some of the fossil localities discovered within exposures of the Santiago Formation and Quaternary stream terrace deposits. Diagram courtesy of the Department of PaleoServices, San Diego Natural History Museum.

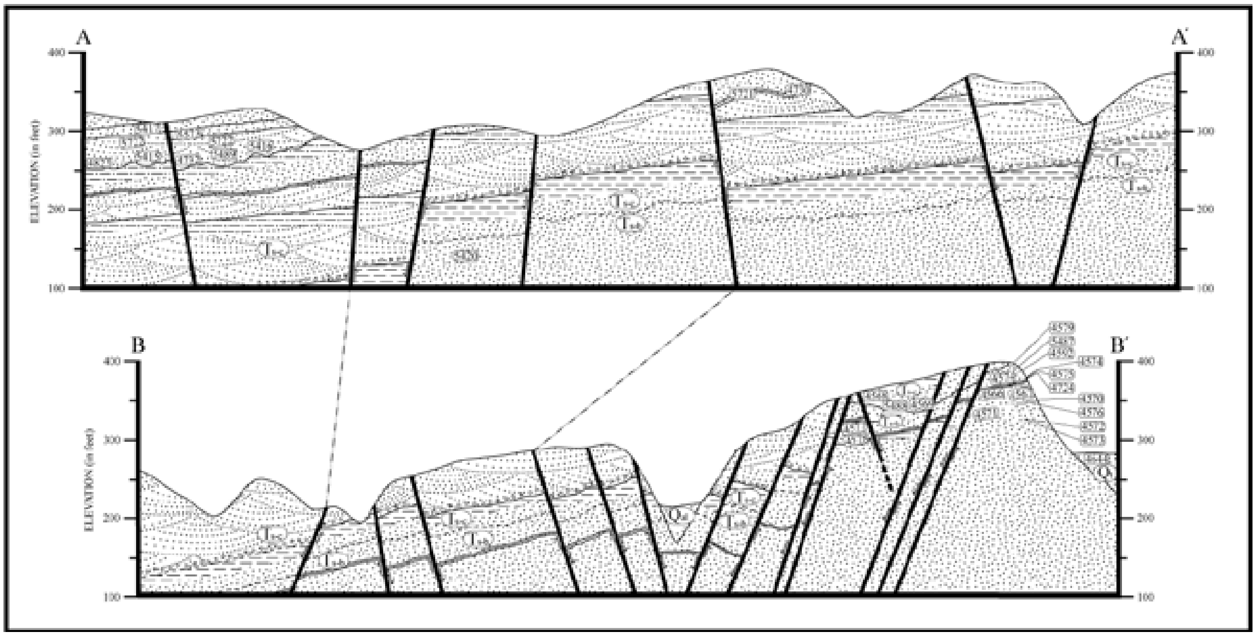

Figure 9. Diagrammatic cross sections through the Ocean Ranch project site, City of Oceanside, California. Diagram depicts lithologies, stratigraphic contacts, faults, and positions of fossil localities discovered within exposures of members 'B' and 'C' of the Santiago Formation (Ts-b, Ts-c) and a Pleistocene stream channel deposit (Qt). The base of the maroon sandstone is the boundary between Santiago Formation members 'B' and 'C'. See Figure 2 for rock symbol legend. Diagram courtesy of the Department of PaleoServices, San Diego Natural History Museum.

staff member with the necessary technical expertise. If included in the scope of work, additional analyses relating to the paleontological resources mitigated should be completed for inclusion in the monitoring or field survey report (e.g. palynological, radioisotopic, magnetostratigraphic, petrographic, etc.). Pre-curation entails entry of field (e.g., geographic, topographic, and stratigraphic position) and laboratory (e.g., taxonomic, taphonomic, and preparation details) data into a computerized database, as well as proper labeling (e.g., temporary inventory or permanent catalogue numbers) and packaging fossils (e.g., placement in vials and/or specimen trays and construction of fiberglass-reinforced 'hydrocal' support cradles) for transport to the curation facility according to the terms of the curation agreement. Laboratory fossil preparation procedures for individual specimens should be recorded on a fossil preparation log form which should be provided to the curation facility along with the fossil collection (7.9). Data management is discussed in greater detail in Section 8.

8. DATA MANAGEMENT AND REPORTING

In this section we propose best practices in data management and reporting. Purely business data-related functions such as accounts payable/receivable, contracts, and human resources are not discussed because these have minimal overlap with best practices in mitigation paleontology. As with field data collection, data management and reporting requires the establishment of a system that works for the individual mitigation paleontologist or larger mitigation program – currently there is no universally correct system.

Data management strategies should emphasize efficient data entry, accuracy, regular backup, and efficient retrieval of information. Networked databases permit data entry, storage, and manipulation by multiple users working remotely. In mitigation paleontology, various types of data are generated prior to and during field work (see Section 4) and subsequent analyses such as fossil preparation, specimen inventory, and specimen identification. There are numerous interrelated datasets that must be computerized, analyzed, and synthesized for inclusion in project reports, annual permit reports, and associated data that accompanies fossil collections reposited at curation facilities (Table 4). Effective management of these data represents a logistical challenge, especially for large projects such as those that include multiple agencies, multiple states, multiple land ownership types, multiple curation facilities, complex geology, or large numbers of fossils. Often, the data consist of a combination of purely electronic information such as coordinate based geographic coordinates and digital images, and non-electronic information in the form of hard copy field forms, scientific papers, and paleontological resource use permits. Increasingly, information in hard copy format is being scanned or entered into databases for more efficient organization and rapid retrieval. As discussed below, the product ('deliverable') in mitigation paleontology is the final project report that documents

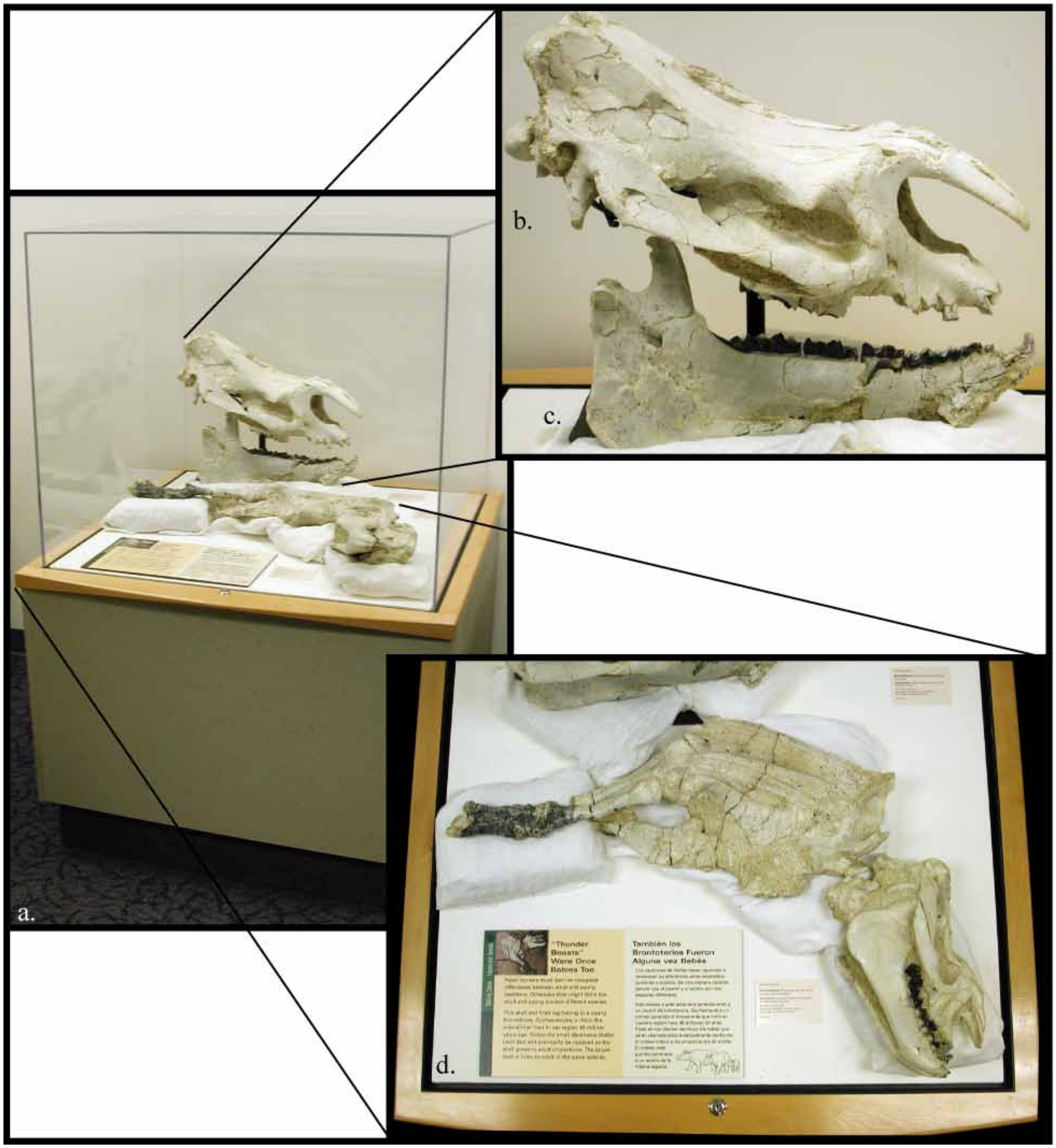

Figure 10. Adult and juvenile specimens of the brontothere Duchesneodus on display at the San Diego Natural History Museum. The specimens were salvaged from the middle Eocene Santiago Formation in Oceanside, California.

the work performed. Therefore, all data types are related to the completion of the project and the content and format of final project reports (8.1).

Final project report requirements vary by agency, and should be prepared to meet or exceed agency standards even if no agency is involved (8.2). Although there are permutations of each, and differences may exist within them depending upon regulatory requirements, fossils discovered, mitigation recommendations, land ownership, and other factors, there are five general types of reports in mitigation paleontology (Table 5). However, not all of them necessarily report on actual impact mitigation. For example, a paleontological impact evaluation report is a preliminary assessment of the potential for impacts on paleontological resources within a project area based on an analysis of existing data with no field survey. The term 'assessment' is also often applied to such reports and is confusing because it may or may not include a field survey. For example, SVP (2010) proposes the term pale-ontological resource impact assessment report for a level

Data Type	Typical Data Source Format	Uses and Considerations
Fossil Locality (newly recorded)	GIS data, hard and electronic copies of field data forms	Agency confidential appendix in project report; non-georeferenced summarized data for client final project report; end of year permit report
Fossil Locality (previously recorded)	GIS data, hard and electronic copies of field data forms	Analyses of existing data; non-georeferenced summarized data for client final project reports
Survey areas	GIS data, hard and electronic copies of field data forms	Final project reports, end of year permit reports. Surveyed areas need to be compared to changes in infrastructure locations throughout pre-construction phase of project
Monitoring areas	GIS data, hard and electronic copies of field data forms	Final project report, end of year permit reports
Field Photographs	Images and photographic logs	Locality forms in agency confidential appendix in final project report; project reports
Aerial Photographs	Digital Orthophotograph Quads (USDA - National Aerial Imagery Project, Google Earth, etc.)	Cost proposals; analyses of existing data (pre-field work review)
Geologic Maps	Digital or hard copy USGS and state geological survey maps, published scientific literature	Analysis of existing data; final project reports
Topographic Maps	Digital or hard copy USGS Topographic Quadrangle Maps	Analysis of existing data; final project reports
Digital Elevation Models	GIS data	Analysis of existing data; final project reports
Literature	Digital or hard copy scientific publications and gray literature	Analyses of existing data; final project reports
Site Geology and Stratigraphy	Digital or hard copy scientific publications and gray literature; hard and electronic copies of field data forms	Final project reports, information for curation facility
Land Ownership	Client or agency provided data usually as GIS or AutoCAD files	Agency confidential appendix in project report; non-georeferenced summarized data for client final project report; end of year permit report
Fossil Identifications	Principal investigator and technical expert(s): hard or electronic copy	Agency confidential appendix in project reports; project reports for client; identifications to lowest possible taxonomic level above species, and detailed descriptions of elements
Literature	Digital or hard copies of scientific publications and gray literature	Analyses of existing data; project reports (a copy of each cited reference is required for NEPA document administrative records)
Project Reports	GIS data, hard and/or electronic copy	End of year permit reports
Fossil Preparation	Hard and/or electronic copies of lab preparation forms	Project files, curation facilities
Paleontological Resource Use Permits and Authorizations	Hard and/or electronic copy	Project reports, paleontological resource use permit files
Annual Permit Reports	GIS data, hard and/or electronic copy	Paleontological resource use permit files
Curation agreements	Hard and/or electronic copy	Paleontological resource use permit files
Project and Staff Schedules	Hard and/or electronic copy	Project implementation
Client, Agency and Curation Facility Communications	Hard and/or electronic copy	Permit files, project files (including administrative record if applicable)

Table 4. Typical data types, formats and uses in mitigation paleontology ('Final Project Report' refers to any report type listed in Table 5).

of effort equivalent to an analysis of existing data with a field survey. We prefer the terms paleontological impact evaluation report and paleontological field survey report to clearly differentiate between reports that do not and do contain field survey results, respectively.

This distinction would also avoid confusion with environmental assessments (EAs) under NEPA, which may or may not include field surveys. A report based only on an analysis of existing data with no field work is sometimes referred to by clients and agencies as a 'desktop' review or analysis. However, this term is problematic because it is vague. A field survey report may or may not have been preceded by a stand-alone impact evaluation report. If not, a survey report should contain the results of the analysis of existing data as well as the results of the field survey. Likewise, a monitoring report may or may not have been preceded by a stand-alone impact evaluation report and a field survey report. If not, a monitoring report should contain the results of the analysis of existing data and field survey if one was completed. A field survey is not always a prerequisite to monitoring based on agency requirements and/or surface sensitivity (8.3).

Monitoring and mitigation plans are most commonly an agency requirement for large projects, and agencies use the results of an analysis of existing data and/or field survey to make detailed recommendations on monitoring locations and procedures, and impact mitigation (fossil salvage) procedures. For smaller projects, this information, in a less detailed format, may be included in either the paleontological evaluation report or the field survey report (8.4).

In reference to mitigation paleontology, NEPA documents are based on paleontological resource analyses completed under the National Environmental Policy Act (1969), and include sections of Environmental Impact Statements (EISs), Environmental Assessments (EAs), and Categorical Exclusions (CXs). CEQA documents are parallel in their overall scope and approach to NEPA documents, but are triggered by the California Environmental Quality Act (1970), and consist of Environmental Impact Reports (EIRs). It is common for CEQA EIRs and NEPA CXs to include field surveys, whereas they may or may not be required during NEPA EISs and EAs (however, they may be a mitigation measure that is required in subsequent field surveys). It is beyond the scope of this paper to discuss the NEPA/CEQA process in detail, but paleontological resource sections completed for NEPA/CEQA studies generally consist of three sections (analysis of existing data, impacts analysis, and mitigation measures; Table 5). An analysis of existing data generally provides the information needed to prepare the existing conditions (also known as affected environment) section. The impacts analysis (also known as environmental consequences) analyzes the anticipated impacts of the project or project alternatives on paleontological resources. Mitigation measures (as needed) are developed based on the results of the impacts analysis. The administrative record is an important part of the NEPA process because it contains all references and other sources used in the analysis. All paleontological reports, including NEPA/CEQA sections, should be written by or at a minimum, reviewed by, a professional mitigation paleontologist (8.5).

The BLM has requirements for the content of project and annual permit reports for work conducted under paleontological resource use permits (BLM, 1998, 2008). These requirements are also generally useful for preparing reports for other federal agencies that lack their own resource management and reporting procedures. BLM end-of-year project reporting requirements fall entirely within the recommended content of field survey and monitoring reports listed in Table 5. BLM end of year permit reporting requirements are different than those for project reports (see BLM 1998). Annual permit reports are due on December 31st of each year. Some states (e.g. Colorado and Utah) also have annual permit reporting requirements, but these vary by state.

There are various other issues related to paleontological reports, and paleontological locality confidentiality is one of the most important. It is unlawful to disclose to the public the locations of fossil localities on federal land and state lands in some states, either previously recorded or newly recorded during field surveys or monitoring. Some paleontologists find the policy of fossil locality confidentiality objectionable for reasons that are outside of the scope of this paper, and the issue continues to be the subject of debate despite the passage of the PRPA (2009). However, mitigation paleontologists should always treat paleontological locality data as confidential. This can be a difficult task when working with clients and sharing GIS data. All final project reports should omit legal locations, coordinates, and photographs of fossil localities in client copies and include this information as a confidential appendix of locality data for agency copies (8.7). However, all fossil localities, both scientifically important and non-important, should be recorded and reported (8.8). Because avoidance is a legitimate mitigation approach (although not the preferred approach for paleontological resource preservation), it is necessary to disclose the avoidance areas to clients so they can avoid known paleontological localities. This is typically dealt with by providing a map and/or GPS data with the avoidance area as a polygon that encompasses the fossil locality without displaying the actual locality. Similar polygons can be used to identify areas that are recommended for monitoring based on field survey results without disclosing locality coordinates. All field survey and monitoring reports should include documentation of areas that were surveyed or monitored, regardless of whether fossils were found (see Section 4). All reports should include stratigraphic documentation of the project area with stratigraphically positioned fossil localities as appropriate to the project. Examples of graphically portrayed stratigraphic data are provided in Figures 8 and 9 (8.9). As discussed and described in Section 3, paleontological resource impact evaluation reports and monitoring and mitigation plans should contain research models, and final survey and monitoring reports should reference the research models and include a discussion of how the mitigation results preliminarily support or otherwise modify them.

It is appropriate for all types of paleontological resource reports to include recommendations (including mitigation measures as needed) relevant to the proposed project. Standard post-field survey mitigation recommendations for individual fossil localities include (in no par-

Paleontological Resource Impact Evaluation Report	Paleontological Field Survey Report	Paleontological Monitoring Report	Paleontological Resource Monitoring and Impact Mitigation Plan	NEPA/CEQA documents
Summary and/ or Introduction	Summary and/ or Introduction	Summary and/ or Introduction	Introduction	Existing Conditions/ Affected Environment
Methods	Methods	Methods	Laws, Ordinances, Regulations, and Standards	Environmental Consequences/ Impact Analysis
Laws, Ordinances, Regulations, and Standards	Laws, Ordinances, Regulations, and Standards	Laws, Ordinances, Regulations, and Standards	Project requirements (including agency-provided sensitivity classification if applicable)	Mitigation Measures
Project requirements (including agency-provided sensitivity classification if applicable)	Project requirements (including agency-provided sensitivity classification if applicable)	Project requirements (including agency-provided sensitivity classification if applicable)	*Institution/agency Search Results (without locality coordinates)	References
Institution/agency Search Results (without locality coordinates)	*Institution/agency Records Search Results (without locality coordinates)	*Institution/agency Records Search Results (without locality coordinates)	Monitoring Methods and Procedures	Administrative Record
Geologic Map Review and Literature Search Results	*Geologic Map Review and Literature Search Results	*Geologic Map Review and Literature Search Results	Mitigation Methods and Procedures	
Research Model	Field Survey Results	*Field Survey Results	Research Model	
Recommendations	Recommendations	Monitoring and Mitigation Results (stratigraphy and fossils recovered, if any)	Recommended Monitoring Locations and level of effort	
References	References	Recommendations	Additional Pre-construction tasks	
	Appendix: Documentation of Areas Surveyed	References	References	
	Confidential Appendix: Fossil Locality Data	Appendix: Documentation of Areas Monitored	Appendix: Fossil Localities Discovered During Pre-construction field surveys	
	Appendix: Receipt of Fossil(s) from Curation Facility	Confidential Appendix: Fossil Locality Data		
	Appendix: Permit(s)	Appendix: Receipt of Fossil(s) from Curation Facility		
		Appendix: Permit(s)		

Table 5. General types and typical minimum content of mitigation paleontology reports (*if not already completed for an earlier report for the same project or project area. Cite earlier reports).

ticular order):

- Clearance: No further action recommended
- Salvage: Collect fossil locality(s) if collection was deferred during survey
- Avoidance: Avoid fossil locality by moving project elements
- Sample: Collect bulk sedimentary matrix sample and screenwash for small fossils
- Monitor: Monitor locality or larger sensitive area during construction

In this paper we provide only general guidance with respect to the development of mitigation measures because this is a highly complex aspect of mitigation paleontology. There is no one-size-fits-all solution for designing mitigation measures. The broad post-field survey mitigation approaches listed above appear simply at face value, but become far more complex when extended to large project areas and taking into account such factors as amount of ground disturbance, specific agency and regulatory requirements, client objectives, potential for impacting scientifically important fossils, land ownership, and ongoing research projects in the area. Project complexity may necessitate the development of novel mitigation strategies. The best approach is to work closely with the agency (if any) and client while taking into account the paleontological resource potential of the project area (see Section 3) and the standards of the designated curation facility. Effective mitigation measures in mitigation paleontology accomplish client objectives while meeting regulatory requirements and preserving (reducing adverse impacts on) paleontological resources (8.10).

9. CURATION FACILITIES

In the mitigation and resource management world, museums are often referred to as repositories, or curation facilities, and mitigation paleontology would not be possible without them. However, not all curation facilities have the educational and outreach missions of museums – some are primarily designed for collections storage with access for research purposes. Curation facilities are the essential endpoint in the impact mitigation process as they are the final destination for mitigation generated fossil collections (Figure 10). At these facilities, institutional fossil locality numbers are assigned, individual specimens or specimen 'lots' are catalogued with unique specimen numbers, field data are entered into computerized databases, and fossil specimens are housed in museum cabinets. Like fossil collections made during research projects, mitigation fossil collections should, as a best practice and in many cases an agency requirement, be curated in a facility where they are available for research and educational purposes. The Department of the Interior requires that a repository meet curation standards outlined in departmental manual 411 and also be approved by the permitting agency for a given project (9.1). Additional information about the role of curation facilities in mitigation paleontology can be found in SVP (1996).

In addition to their essential role in the long term preservation of paleontological collections, curation facilities serve a critical function on the front end of the mitigation process. All federal and some state issued paleontological resource use permits require that the project proponent or applicant possess a curation agreement (also referred to as a repository agreement) (9.2). Some institutions charge a fee for issuing curation agreements. To the best of our knowledge, all federally approved curation facilities require that every recipient of a curation agreement be a professional mitigation paleontologist (see Section 1). The role played by curation facilities therefore represents an important additional check to the permitting process in ensuring that, in circumstances wherein curation agreements are required to obtain paleontological permits, only qualified paleontologists receive them. However, it is important to understand that regardless of one's qualifications, there is no obligation on the part of curation facilities to provide curation agreements or to accession fossils collected as the result of paleontological mitigation. The incentive to regional repositories to grant curation agreements is primarily to fulfill their mission, grow their regional scientific collections, and enhance the use for research and educational purposes. It is also necessary for curation facilities to charge one time fees for collections curation and storage because of the additional costs related to processing the incoming collections, purchasing cabinets and curation supplies, and providing and maintaining the physical space for long-term preservation. While many institutions charge a one-time fee for curation and storage, the rates vary greatly between institutions (9.3).

Collections space is an ongoing concern for curation facilities, and many institutions have little or no collections expansion space. Naturally, this limitation affects decisions about which fossil collections can be accessioned. Overall though, it has become increasingly apparent to curatorial personnel that it is in the best long term interest of paleontological resource management and preservation to ensure that mitigation fossil collections have a high degree of scientific value that justifies the space they occupy. In other words, the fossil collections need to be well documented (see Section 4) and consist of specimens with educational value and scientific importance (research potential), and not just 'bone scrap' or 'plant hash' The issue of scientific value has, at least in part, driven agencies to develop criteria for establishing the 'scientific significance' of fossils so that the decision to collect or not collect can be made in the field. This issue also underscores the importance of close communication between mitigation paleontologists, agency paleontologists, and the curation facilities with which they work, especially with regard to an understanding of the museum's research focus and the types of fossils that the curators consider worthy of accessioning and that are pertinent to the research focus of the institution. If a curation facility is not willing or able to accession fossils that meet agency defined scientific significance criteria, it is the job of the mitigation paleontologist to find an institution that will (9.4). Currently, agency guidance is lacking for the disposal of fossils collected on federal lands by museums. This adds to the importance of ensuring that fossils collected during impact mitigation have scientific value and are worthy of curation.

Consider that most archeological repositories were completely filled with artifacts years ago, and many no longer accept collections - those that do are highly selective. This fundamentally and permanently changed cultural resource management so that now, archeological artifacts are only rarely collected. There is a lesson to be learned here with respect to mitigation paleontology that has not been lost on curators and resource managers. The preservation of mitigation fossil collections depends on the ability of curation facilities to store these collections. Consequently, storage space must remain a central focus of resource managers and curation facilities alike. However, curatorial personnel have to make the long term storage commitment, and should assess one-time curation fees based on the institution's costs for providing long term storage and preservation. It is in the best interest of institutions to set high scientific standards for mitigation paleontologists to adhere to for obtaining curation agreements and curating fossil collections.

Obviously, problems can and do arise when there is not a pre-construction permitting process and no requirement for obtaining a curation agreement prior to working on a mitigation paleontology project. In the absence of agency guidelines for determining scientific significance and guidance from curation facilities, there have been numerous cases of poorly documented and/or unidentifiable mitigation fossil collections being delivered to curation facilities across the western United States. While this continues to be a problem in some parts of California, the situation has greatly improved during the last decade with respect to fossils from federal lands (e.g. from BLM and USFS managed lands). Furthermore, in the absence of agency oversight, it is easy for mitigation paleontologists to end up with 'orphan collections' – these are fossil collections that are never delivered to a curation facility.

Curation facilities also function as storehouses of associated paleontological data. Locality data, in particular, are vital to the work of mitigation paleontologists (see Section 2) because without access to recorded locality data, it is difficult to know the extent of previous paleontological work and discoveries in a given geographic area or geologic unit. In addition, access to these data provides a means for protecting previously recorded fossil localities from destruction by proposed construction project. Locality data, in the form of precise geographic coordinates (or as precise as possible), should be shared with professional mitigation paleontologists upon request. The types of locality data that are useful to mitigation paleontologists requesting a records search include stratigraphic data (e.g., formation, member, and/or horizon), sedimentological data (e.g., lithology, sedimentary structures, and facies), taphonomic data (e.g., bioclast orientation, packing, and sorting), and information about the conditions of discovery (e.g., natural outcrop or construction site) and depth below original ground surface (if applicable). A reasonable fee for providing this paleontological record service is frequently assessed because it is necessary to support the data management infrastructure of the curation facility (9.3). It is important to emphasize that curation facilities that accept mitigation fossil collections and the fees that come with those collections, have a responsibility to make paleontological data available to professional mitigation paleontologists and to do so in a reasonable and timely fashion. Thus, requests for paleontological collections data should be treated as a high priority by these facilities.

Ideally, the following information for a given recorded fossil locality should be provided by the curation facility: a map plot of the locality and geographic coordinates (this information will be kept confidential); the stratigraphic context of recorded localities (i.e., a description of strata exposed at a locality, the nature of contacts, lithologic descriptions, stratigraphic thicknesses, geometry of deposit, etc.); the nature of the exposure (i.e., natural outcrop, temporary artificial exposure, road cut, etc.) ; the conditions of discovery (i.e., general prospecting, construction monitoring, etc.); the types of recovered fossils (including a listing of catalogued fossils); a description of the taphonomy of the locality (i.e., how the fossils were preserved in the original stratum including mode of preservation, taxonomic composition, specimen orientation, specimen packing, degree of fragmentation, etc.); and method of recovery (i.e., recovered as float, excavated as single element, bulk matrix sampling followed by screenwashing, quarry excavation, etc.) (9.5).

In addition to providing an important service by reviewing the qualifications of individuals who are seeking curation agreements and requesting paleontological data (9.6), curation facilities have other quality assurance roles. As discussed above, these include requiring that mitigation collections consist of fossils of scientific value that are properly documented and pertinent to the research focus of the institution. Curation facilities also have the leverage and scientific credibility needed to ensure that fossils are properly identified, and should require that fossils are prepared and conserved using proper adhesives and consolidants prior to their arrival at the institution. The degree to which fossils are prepared and identified should be included within the language of the curation agreement or otherwise communicated to the mitigation paleontologist prior to fossil delivery. Some curation facilities require that specimen numbers be affixed to specimens prior to delivery, and that they arrive in archival trays of specific sizes or, in the cases of some small fossils (e.g. isolated teeth), mounted on pins. All curation facilities require associated data recorded during a mitigation project (e.g., field notes, measured stratigraphic sections, field maps with plotted collecting localities and locations of measured stratigraphic sections, and field photographs documenting collecting sites and taphonomic conditions). In addition, most curation facilities also require a copy of the final mitigation (survey or monitoring) report (9.7). Unless absolutely necessary, fossil collections from the same project, and especially the same locality, should not be divided between different curation facilities (9.8). Mitigation paleontologists must have a clear understanding of the expectations and standards of each of the curation facilities they work with as these standards vary greatly.

10. BUSINESS ETHICS AND SCIENTIFIC RIGOR

Ethical standards in mitigation paleontology involve individual professional mitigation paleontologists placing the purpose of impact mitigation - to preserve and minimize adverse impacts (per NEPA/CEQA) to scientifically important paleontological resources - at the forefront of their business decisions (10.1). Adhering to rigorous scientific standards and following best practices is the best way to ensure that such decisions are ethical. The best practices described in this section are intended to provide general guidance only since the issues involved are evolving. Issues surrounding business ethics and scientific rigor in mitigation paleontology can generally be broken into three overlapping categories: 1) project scoping and implementation, 2) project personnel, and 3) external pressure.

Project Scoping and Implementation

Project scoping typically happens during the preparation of cost proposals or in preliminary discussions with clients about the amount and type of work that needs to be done. Because cost proposals are usually competitive bids, there is an obvious incentive on the part of consultants to scope the project in a way that lowers project costs as much as possible in order to capture as much business as possible. This is free enterprise and there is nothing wrong with trying to maximize efficiency, reduce costs, and make one's clients as happy as possible in a competitive marketplace. However, ethical concerns exist when proposals to undertake projects are scoped in a manner that is insufficient to properly accomplish the work in a manner that is consistent with agency policies, mitigation best practices (outlined in this paper), and accepted professional standards (SVP, 1991, 1995, 1996, 2010) in paleontology. We refer to this as 'underscoping,' and it is likely more prevalent and less detectable in mitigation paleontology than in other, larger resource disciplines because there is usually very little, if any, specific and direct agency guidance provided during the scoping process. In some areas the amount of agency guidance provided during project implementation is increasing. Underscoping is involved if a consultant knowingly underestimates the tasks and associated costs needed to properly complete a project. Greater agency participation during the scoping process would be helpful. Additionally, there are many cases in which clients do not permit agency interactions during the scoping process. Nevertheless, if allowed, it is advisable to consult with agency paleontologists, paleontology coordinators, or project managers during the scoping process, especially for large projects. A professional mitigation paleontologist should be provided with the opportunity to provide input on scopes of work that are developed by project managers or other personnel that lack paleontological expertise (10.2).

A scope of work contains the details of the work that is to be done typically including some combination of an existing data analysis, field survey, construction monitoring, fossil salvage, preparation, identification, analysis, curation, and reporting. The proposal budget is an estimate of the amount of money needed to complete the scope of work. Often, underscoping in a cost estimate manifests itself as an insufficient level of effort to complete the tasks listed in the scope of work. An example of underscoping would be to lower proposal costs by planning to do pedestrian surveys in less time than it should take to properly survey an area, such as scoping for a 'windshield' survey rather than a pedestrian survey (as discussed in Section 5, there is very little that can actually be accomplished via a windshield survey other than locating rock outcrops along a road). However, low bids are not always problematic or unethical, since a consultant with greater local knowledge of a project area may submit a better-informed bid that is lower. Regardless of whether any aspect of a project is intentionally or accidentally underscoped, it may be necessary to negotiate a contract modification with the client in order to, as a best practice, complete the project according to agency requirements and accepted professional standards (10.3).

An important and challenging aspect of mitigation cost proposals is estimating the number, types, and costs associated with fossils discovered during a project, including the added costs of reporting and if fossils are salvaged, the costs of lab work and curation. There are various ways to produce an informed estimate of fossil discoveries including the number and types of fossils that have been previously found in a given project area. The results of previous mitigation projects completed in the same geologic units in the same general area provide a means of estimating the density of fossil localities which can in turn, for example, be used to predict the number of scientifically important fossil localities per area of disturbance, per mile of survey corridor, or per well pad location.

The decision about whether to include the costs of fossil discoveries in a proposal or include an assumption that no fossils will be found significantly affects the project budget, and an assumption of negative findings will obviously result in a lower estimated cost. However, a client might not be pleased if fossils are then indeed found and additional unanticipated costs are incurred. While it does not necessarily imply an ethical concern and there is no single correct answer, a best practice is, to accurately and in good faith, reflect the likelihood of fossil finds and the resulting costs in proposals. If there is a low likelihood of fossils, then it is appropriate to include an assumption of negative findings. However, if there is a high likelihood of fossils being discovered, then an assumption of negative findings represents underscoping, is not a best practice, and risks alienating one's client (10.4). Keep in mind that some clients understand the risk and do not want fossil-related costs included in cost proposals, whereas others actually prefer an overestimate. These differences in client expectation and preferences underscore the importance of understanding a client's needs.

Overscoping is far less common then underscoping since it typically makes a project cost more and the firm less likely to be selected by a client. However, doing more work than is needed to accomplish the goals of the project is also an ethical conflict and is not consistent with best practices. The reality is that clients rarely want to fund a research project, and often shy away from proposals that seem to include what they view as extraneous tasks that sound like scientific research. However, this is not to say that fossil collections made during mitigation projects should not be collected in a way that supports future research. A properly scoped mitigation project should be designed to accomplish the objective of reducing adverse impacts on scientifically important fossils in a manner that anticipates future paleontological research (see Sections 4, 8, and 9). Another aspect of overscoping involves proposing to do work that has no paleontological resource potential (i.e. there is little to no chance that paleontological resources will be impacted by a proposed action). An example would be a proposal for monitoring an area in which the substrate is composed of granite (or other geologic unit/rock type with extremely low paleontological potential). In cases of very low paleontological sensitivity, recommend to the agency and/or client that impact mitigation is unnecessary (10.5). While the response in such cases may well be that the requirement is still in effect, it is ethical for a mitigation paleontologist to make a good faith effort to inform the parties about very low paleontological resource potential when applicable. In summary, there are numerous potential ethical pitfalls that can befall a project during scoping and implementation, but they can all be addressed by closely adhering to a scientifically sound scope of work. In this way, scientific rigor and ethical standards are upheld.

Project Personnel

Making scientifically appropriate personnel decisions when staffing mitigation projects is the second category of ethical practices. As discussed in Section 1, the most critical aspect involved is to use professional mitigation paleontologists to staff all project tasks for which paleontological knowledge is necessary. While this may not necessarily include project management, it most certainly includes project scoping, existing data analyses, field surveys, monitoring, fossil preparation, fossil identification, faunal/floral analysis, report preparation, and curation. All field monitors should be vetted in order to ensure that they are properly qualified. Hiring underqualified employees or overstating a worker's qualifications in order to put less-than-qualified people in the field, usually to avoid paying a professional's salary, is a persistent issue for federal permitting officers. Additionally, professional mitigation paleontologists should be utilized to write paleontological resource reports including NEPA/CEQA documents, or at the very minimum, should supervise their preparation, review, and sign off on them (see Section 8) (10.6).

Professional mitigation paleontologists should be the only project personnel (other than GIS staff) with access to paleontological locality data. Clients do need to know where avoidance areas are in order to be able to avoid them, but this information can be less precise than locality coordinates (see sections 5 and 8). No paleontologist is an expert in all paleontological subdisciplines and taxonomic groups. Recognizing the specialized nature of paleontology, subject matter experts, whether on staff or subcontracted, should be used to identify fossils collected during mitigation projects to the lowest taxonomic level and for any other specialized analyses, but also for obtaining information about a project area and its paleontological content (10.7). With regard to permitting, the majority of agencies grant paleontological resource use permits to individual principal investigators, rather than to firms. It is important that project personnel be aware of this, since the responsibility to complete the work in compliance with regulations and according to accepted professional standards is the responsibility of the principal investigator. Finally, professional mitigation paleontologists who prepare mitigation reports should, according to universally accepted scientific practice, properly cite all sources including gray literature, agency policy, other technical reports, NEPA/CEQA documents, and museum record searches. Obviously, plagiarism and falsification are clear violations of ethical standards (10.8).

External Pressure

External pressure that is brought to bear on a consultant by an agency or client is the third category of ethical concern. However, with regard to best practices, the concern is how the mitigation paleontologist responds to such pressure rather than the pressure itself. In recent years, the ongoing confusion between paleontology and archeology, has, in certain jurisdictions in California for example, resulted in agency required (and even consultant recommended) mitigation measures that stipulate archeological shovel testing procedures for ascertaining the presence of paleontological resources (see Section 5). Because there is no scientific basis for the use of such methods to inform the presence, content, or abundance of paleontological resources, the use of archeological testing techniques for paleontological resources is not recommended (10.9). Another frequently observed example of unethical pressure concerns agency personnel or clients asking mitigation paleontologists to change their mitigation recommendations. A professional mitigation paleontologist should develop mitigation recommendations that are consistent with the objectives of resource preservation, and stand by them. If an overseeing agency or client wishes to modify the recommendations, it is appropriate for the consultant to listen, negotiate in good faith, and modify the mitigation measures based on new information, if appropriate. Any modifications along with associated justifications should be documented in the final project report. However, downgrading (or upgrading) mitigation measures as the result of pressure from either clients or agencies is not a best practice because it will increase the likelihood of adverse impacts to the resource. Mitigation recommendations from a consultant are just that – if an agency or client wishes to ignore them, that is their prerogative. However, if possible, the overseeing agency should be informed if client modifications to mitigation recommendations are contrary to best practices (10.10).

CONCLUSIONS

It is the experience of the authors that actually adopting and consistently following the details of the best practices we propose is a constant challenge, from the point of project scoping and budgeting, through project initiation and implementation, to project completion. In other words, as with everything, it is always harder to do things well. However, the long term payoff will be a sustainable and professional field of applied paleontology that stands on its own apart from other fields of paleontology, and that is clearly distinct from archeology and CRM. This will result in a much more consistent, more professional, and higher quality job of mitigating impacts and preserving non-renewable paleontological resources. Another benefit to adopting best practices will be the development of a more cohesive community that works together with agency and museum partners to succeed in common goals to preserve paleontological resources and manage fossils using scientific principles and expertise, while also successfully achieving the project objectives of proponents. Ultimately, the industry-wide adoption of and adherence to scientifically rigorous and ethical best practices will require the combined efforts of mitigation paleontologists, policy makers, resource managers, and museums. The development of best practices is the necessary first step, and is a process that other more established resource disciplines have undergone during the course of their evolution.

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The motivating force behind this project was the need, as expressed among many mitigation paleontologists in the course of countless conversations over years, for a comprehensive set of best practices to help create and ensure a universal high scientific standard for the purpose of preserving paleontological resources via impact mitigation. Thus, foremost, we are thankful to all professional mitigation paleontologists and the amazing work they have done throughout North America over the last several decades. Their legacy laid the ground work and provided the inspiration for this paper. We are also indebted to the efforts of the many museum paleontologists across the continent who have made critically important contributions by directing numerous salvage projects, and whose institutions are the repositories of the specimens, data, and ultimately, the scientific knowledge generated by mitigation fossil collections in the form of research publications. Finally, we thank the tireless efforts of the paleontologists who serve in government agencies, and acknowledge their essential role in the stewardship of non-renewable paleontological resources.

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APPENDIX A

QUALIFICATIONS AND PERMITTING

1.1 The following are suggested as minimal requirements for paleontological principal investigators, paleontological field supervisors, and field paleontologists. Paleontological principal investigators and paleontological field supervisors are considered to be qualified professional mitigation paleontologists. The field paleontologist is an introductory level position for training to be a professional mitigation paleontologist.

Paleontological Principal Investigator

- Graduate level academic training (M.S. or Ph.D.) in paleontology and sedimentary geology or equivalent professional experience.
- Demonstrated professional experience and competency with paleontological resource mitigation procedures and techniques.
- A working knowledge of how paleontological resources and their associated data are used in conducting and publishing professional paleontological research.
- Knowledge of federal, state, and local laws and procedures that apply to all aspects of mitigation paleontology.

Paleontological Field Supervisor

- Academic training (B.S. or M.S.) in paleontology and sedimentary geology or equivalent professional experience.
- Field experience in impact mitigation procedures (including fossil salvage/collection).
- Stratigraphic competency.
- Knowledge of fossil curation procedures.
- Authorship experience with mitigation reports.
- Knowledge of resource management strategies and concerns.
- An understanding of the regulatory environment, including knowledge of federal, state, and local laws and procedures that apply to mitigation paleontology.
- Project management experience.
- An understanding of the consulting business.

Field Paleontologist (technician/surveyor/monitor)

- Academic training (B.S., B.A., or M.S.) in paleontology and sedimentary geology or equivalent professional experience.
- Ability to find fossils in both undisturbed and disturbed (construction) settings.
- Knowledge of fossil collection and salvage techniques: hand quarrying, pluck n' run, systematic excavation, bulk matrix collection, etc.
- Ability to identify fossils to a basic level (taxon and element) and evaluate their scientific importance.
- Ability to identify and describe sedimentary rocks and surficial deposits.
- Ability to measure and describe stratigraphic sections and tie fossil localities to them.
- Ability to record a field interpretation of the taphonomy of fossil assemblages, and recognize and describe unusual depositional or preservational conditions and associations.
- Ability to interpret depositional environments based on site geology and paleontology.
- Sufficient knowledge of geology to communicate with a registered professional geologist when necessary.
- Ability to properly complete field forms, operate a GPS, photograph fossils and localities, and plot localities on grading plans when applicable.
- Understanding of safety requirements.
- For professional mitigation paleontologists and field paleontologists, experience in similar rock units with similar fossils is far more important to the successful outcome of a mitigation project than experience in the same state.

1.2 Be sure that no work is undertaken without the proper permit or other written authorization.

ANALYSES OF EXISTING PALEONTOLOGICAL DATA

2.1. By reviewing geologic maps at the most precise scale available, determine the geologic units within a project area and their areal distribution.
2.2. Complete a thorough literature review using an appropriately sized search area.
2.3. Complete a paleontological record search using an appropriately sized search area.
2.4. Determine the land ownership and the pertinent regulatory requirements.
2.5. Conduct an aerial photograph review to determine locations of potentially paleontologically sensitive bedrock exposures.
2.6. Consult with local technical experts for information on the paleontology and geology of the area.
2.7. Synthesize the results of the analysis for use in determining the need for impact mitigation measures.

RESEARCH MODELS AND SCIENTIFIC CONTEXT

3.1. Every impact mitigation program should be designed around a research model that places it in a scientific context, and which facilitates later research activities. It should serve as road map that guides the implementation of the mitigation work including the development of the threshold criteria for scientific importance, which fossils are collected, how they are collected, and the types of data that are collected.
3.2. Research model development should be built into project scopes of work and budgets, and the actual research models should be presented in paleontological resource impact mitigation evaluation reports and paleontological resource monitoring and mitigation plans.
3.3. A research model should include a statement of research objectives and specific research problems, hypotheses to be tested, methods to be employed to address the research problems, and a discussion of the expected re-

sults. Final survey and monitoring reports should, in their results sections, reference the research model and include a discussion of how the mitigation results preliminarily support or otherwise modify the research model.

FIELD DATA COLLECTION

4.1. If working with a crew, design and use forms (hard copy or digital) for data capture during field work rather than using traditional field notebooks.

4.2. Always use a GPS receiver to record geographic coordinates. While sub-meter level precision may be needed in certain field applications, a position error of 20 to 30 feet is recommended for most situations.

4.3. Provide pre-field training and project orientation on data recordation and project-specific fossil locality significance and non-significance thresholds to field crew members.

4.4. Using field data, photographs, and/or GPS track logs or polygons, document all areas that were physically surveyed regardless of whether fossils were found, as well as those areas cleared visually or through desktop review. In addition to scientifically important fossil localities, document non-scientifically important localities as defined based on the paleontological resource abundance and preservation of the geographic area and/or geologic unit.

4.5. Avoid unnecessarily or improperly disclosing any project information including survey and monitoring data. Sensitive fossil locality data should only be shared with appropriate agencies and curation facilities (and not clients, although it is acceptable to disclose less precise areas recommended for resource avoidance).

4.6. Fully complete all client and company required paper work including vehicle inspection forms, job hazard analyses or other safety related forms, and project daily logs.

4.7. Ensure that field data capture the minimum recommended information in order to meet the needs of clients, the requirements of agencies, and the scientific standards of curation facilities. This includes paleontological locality documentation consistent with accepted professional and scientific standards, and documentation that the scope of work was fully and properly completed.

FIELD SURVEYS

5.1. Thoroughly prepare all field personnel for field work: existing data and key publications, maps and design plans, field equipment needs, safety concerns, data procedures, parameters for significant versus non-significant localities, fossil collection, and criteria for field mitigation recommendations.

5.2. Obtain all required paleontological resource use permits, access permits, and right on entry in writing prior to field work initiation. Coordinate with agency personnel as needed. Obtain written authorization from the applicable agency prior to beginning any field work on a project. Understand all land ownership issues and trespass laws prior to field work.

5.3. Ensure that the ground surface is free of snow prior to initiating any field surveys.

5.4. Field surveys should be scoped for a pedestrian examination of fossiliferous outcrops of bedrock and surficial deposits. All survey activities should be confined to the project area. In rocks and surficial deposits with high and very high sensitivity, all exposures should be surveyed. However, in rocks with moderate or unknown sensitivity, spot-checking of exposures of rocks and surficial deposits is typically an acceptable level of effort. Field surveyors should not walk transects, but should spread out to cover as much ground as possible and focus their inspections on exposures of fresh and weathered bedrock and surficial deposits. All exposures should be thoroughly examined and documentation provided in the survey report.

5.5. Avoid windshield surveys since they are not useful for finding fossils. If they are used to provide visual clearance for a portion of a project area, be sure to differentiate between areas that were subject to pedestrian versus visual survey in the field survey report.

5.6. When possible and cost effective, recommend fossil collection rather than resource avoidance for the greater goal of resource preservation. Block surveys provide the client with the greatest flexibility for avoiding scientifically important fossils if that is their preference. However, a client is under no obligation to mitigate impacts to paleontological resources that will not be affected by the project, because there won't be any project-related impacts. Be cognizant of the resource management policies and objectives of all land owners with regard to fossil collection. Never collect fossils on private land without written permission from the land owner.

5.7. Exclude extensive fossil discoveries from scopes of work, but be sure to communicate the rationale and possibility of their occurrence to clients. If discovered, clients typically choose to avoid them with their project. If they elect to mitigate impacts to the locality (usually in the form of an excavation to salvage the fossil[s]), preparation of a locality specific mitigation plan may be required. If avoided, the mitigation paleontologist or agency should report the locality to an institution or researcher with an interest in it.

5.8. Avoid the use of cultural resource management terminology in mitigation paleontology so as to minimize confusion between the two disciplines.

5.9. Understand the dimensions of the disturbance area, project area, buffer (if any), and area-of-potential-effect, prior to commencing field work.

5.10. If requested to perform exploratory shovel testing for paleontological resources or similar inappropriate technique, educate the requestor about the futility of such an exercise.

5.11. Using local paleontological knowledge and experience, mitigation paleontologists should provide recommendations regarding the frequency of repeated field surveys and provide justification to land managers in field survey reports and end of year permit reports.

CONSTRUCTION MONITORING

6.1. Monitoring should be a mitigation requirement when construction will disturb bedrock units or surficial deposits with a high potential to contain fossils of scientific importance. Continuous monitoring is generally stipulated for geologic units with high and very high sensitivity, whereas spot-checking is generally stipulated for geologic units with moderate and unknown sensitivity. The principal investigator should have the authority to increase or decrease the monitoring level of effort if warranted.

6.2. In some cases, monitors have a brief opportunity to do a final surface check immediately prior to ground disturbance to ensure that no scientifically important fossils were missed during the preceding field survey.

6.3. Active construction excavations should be monitored by inspecting freshly exposed surfaces and spoils piles from a safe distance. Be aware of the effects of certain types of construction equipment on bedrock and contained fossils. When equipment is not running, use the opportunity to examine the excavation, document the stratigraphy, and check through spoils piles. In most sedimentary rock units and surficial deposits, drilling with an auger with a tool diameter of two feet or less, typically pulverizes the sedimentary matrix, including any contained fossils. Therefore, monitoring of drilling activities when a small auger is used is typically not conducted or recommended.

6.4. Monitoring cannot succeed if monitors are not within visual range of the excavation, ideally 5 to 20 feet, but no greater than 30 feet, and even at that distance fossils may not be visible.

6.5. Monitors should strictly adhere to all project and OSHA safety requirements, particularly with regard to working around heavy equipment and entering project excavations. As a rule, monitors should never do anything that feels unsafe. Monitors should understand the movement patterns of construction equipment, and use hand signals to communicate with operators. Establishing a good relationship and open communication with all project personnel is beneficial to the success of the monitoring effort.

6.6. Regardless of whether fossils are found, monitors should document the stratigraphy of the project area for the purpose of interpreting its paleontological record, as well as facies relationships and depositional environments. All fossil localities should be tied to the stratigraphic section for use in the monitoring report.

6.7. Monitors should be on site at all times during project excavations in paleontologically sensitive bedrock and/or surficial deposits. Monitors and the firms they represent should educate clients and construction personnel about monitoring practices, particularly with regard to safety, but also with regard to the need to be within view of the active cut.

6.8. When a potentially scientifically important fossil is discovered, fossil salvage activities begin (see Section 7). The monitor should immediately alert the equipment operator and after an initial evaluation, make any other project-specific notifications. The fossil locality should be cordoned off, if applicable, and additional personnel mobilized as needed to support monitoring and locality exploration and evaluation. Construction should be directed away from the locality with a minimum buffer of 20 feet, although the buffer size should be increased if the monitor determines that the locality is larger. Monitors should have expertise in fossil evaluation and salvage techniques.

FOSSIL SALVAGE: FROM COLLECTION TO PRE-CURATION

7.1. Following fossil discovery, a preliminary mitigation evaluation should be performed based on pre-determined threshold criteria for scientific importance (or scientific significance criteria for BLM lands), the purpose of which is to determine whether or not the fossil(s) observed warrant salvaging.

7.2. If the preliminary mitigation evaluation determines that the fossil(s) at the locality have scientific importance or appear to have scientific importance based on what is visible, locality exploration should be initiated. Locality exploration could result in a determination that the fossil(s) lack scientific importance, in which case the fossil(s) should be recorded as non-important and no further action is required. If one or more of the fossils at the locality are scientifically important, then the locality should be recorded as significant. For localities discovered during field surveys, there are typically three standard mitigation options: collection, deferred collection, and avoidance. If avoidance is the preferred option, then an alternate route or project location that avoids other scientifically important fossil localities should be surveyed. Unlike field surveys, mitigation by fossil collection is typically the only option for scientifically important fossils discovered during construction monitoring.

7.3. For all important fossil localities, salvage techniques appropriate to the size and preservation of the fossil remains should always be used. All monitors should be knowledgeable of fossil salvage and sampling techniques and properly equipped. Medium- to large sized specimens or groups of specimens should be excavated encased in matrix to provide stability, expedite the excavation and minimize construction delays. Construction equipment can be used to expedite fossil excavation so long as the equipment does not come into direct contact with the fossil(s), and can also lift heavy jackets onto vehicles for transport off-site. All containers and jackets should be properly labeled prior to removal from the locality.

7.4. It is the responsibility of a professional mitigation paleontologist to collect all scientifically important fossils from within a project area, and the project scope of work and budget should be designed to accommodate this.

7.5. Field paleontologists should refrain from collecting any non-paleontological objects from a project area, regardless of land ownership, and regardless of the legal status.

7.6. Fossils should not be collected from privately owned land without written permission, and professional mitigation paleontologists should understand pertinent regulations. For fossils discovered during field surveys, land owners should be provided with the choice to keep the fossils, donate them, or leave them in place waiving the project proponent of any liability in the event of damage. For fossils discovered during construction monitoring, unless the land owner can be reached immediately, all fossils with scientific importance should be salvaged by default.

7.7. When working on Native American tribal lands, respect all tribal policies and work within them to reduce impacts. Document all fossil localities, and if locality avoidance is the only mitigation option, consider implementing a field specimen molding protocol for specimens with high scientific value.

7.8. Fossil localities should be differentiated stratigraphically, and should be recorded as points, lines, or polygons taking into account the position error of the specific GPS receiver being used.

7.9. Once transferred from the field to the laboratory, fossils should be properly prepared to the point of curation. Matrix samples should be washed, floated if appropriate, and picked, and all fossils should be identified to the level of genus or lowest taxonomic level possible by a paleontologist with technical expertise with that taxonomic group. Any additional analyses within the scope of work should be completed, and pre-curation work including preparation of a fossil catalogue, entry of field and laboratory data into a computerized database, and properly labeling and packaging fossils in preparation for transport to the curation facility, should be completed.

DATA MANAGEMENT AND REPORTING

8.1. Data management strategies should emphasize efficient data entry, accuracy, regular backup, and efficient retrieval of information.

8.2. Project reporting requirements vary by agency, and final project reports should be prepared to meet or exceed agency standards even if no agency is involved.

8.3. Paleontological survey and monitoring reports should include the results of the existing data analysis if it was not included in a prior standalone project report.

8.4. Monitoring and mitigation plans should be based on an existing data analysis and/or field survey, and should make detailed recommendations on monitoring locations and procedures, and impact mitigation (fossil salvage) procedures.

8.5. All paleontological reports, including NEPA/CEQA sections, should be written by or at a minimum, reviewed by, a professional mitigation paleontologist.

8.6. BLM or other agency reporting requirements must be followed when working on agency-managed lands and/or projects.

8.7. Mitigation paleontologists should always treat all fossil locality data as confidential. Locations (i.e. legals, coordinates, photographs) of fossil localities in client copies should be prepared in a confidential appendix of locality data for agency and repository copies.

8.8. All fossil localities, both scientifically important and non-important, should be recorded and reported.

8.9. All field survey and monitoring reports should include documentation of areas that were surveyed or monitored, regardless of whether fossils were found.

8.10. It is appropriate for all types of reports to contain recommendations (including mitigation measures if appropriate) relevant to the proposed project. Recommendations, including mitigation measures, should be developed by working closely with the agency (if any) and client while taking into account the paleontological research potential of the Project area (see Section 3) and the standards of the curation facility. Effective mitigation measures accomplish client objectives while meeting regulatory requirements and preserving (reducing adverse impacts on) paleontological resources.

CURATION FACILITIES

9.1. Mitigation paleontologists should ensure that all scientifically significant fossils collected during mitigation projects are curated at an approved curation facility.

9.2. Mitigation paleontologists should obtain curation agreements in advance of project scoping and obtaining paleontological resource use permits.

9.3. When necessary to support data management costs and sustain the ability to accession and house mitigation fossil collections, curation facilities should charge mitigation paleontologists for data searches and for the curation and storage of fossil collections.

9.4. Mitigation paleontologists should only collect and reposit paleontological resources that have scientific value (fossils that meet significance criteria).

9.5. Unless the locality has been graded away, curation facilities should provide locality data in the form of legal locations (PLSS) and precise geographic coordinates.

9.6. Curation facilities should ensure that recipients of curation agreements and sensitive paleontological data are professional mitigation paleontologists.

9.7. Mitigation paleontologists should ensure that all fossils are properly identified, prepared and documented according to the terms of the curation agreement and the standards of the institution.

9.8. Unless absolutely necessary, fossil collections from the same project, and especially the same locality, should not be divided between curation facilities.

BUSINESS ETHICS AND SCIENTIFIC RIGOR

10.1. Recognizing that mitigation paleontology is a business, all decisions, including scoping of projects and formulation of budgets, should be made in a manner that promotes the intrinsic scientific value, research potential, and long term preservation of non-renewable paleontological resources.

10.2. It is advisable to consult with agency paleontologists, paleontology coordinators, or project managers during the scoping process, especially for large projects. Also, a professional mitigation paleontologist should provide input on all scopes of work and budgets developed by personnel who lack paleontological expertise.

10.3. Obtain contract modifications/change orders as needed in order to ensure that all mitigation work is properly completed, and that all scientifically important paleontological resources are properly collected, prepared, identified, and curated.

10.4. If there is a high likelihood that fossils will be found during a project, incorporate this into the scope of work and budget rather than building a no findings assumption into the proposal. If there is little to no paleontological potential, a negative findings assumption is appropriate.

10.5. In cases of very low or no paleontological sensitivity, recommend to the agency and/or client that impact mitigation is unnecessary.

10.6. Employ only properly trained and experienced paleontologists to do mitigation work, and avoid the use of so-called cross trained personnel unless they are legitimately qualified and have the demonstrated expertise to perform the work. Only professional mitigation paleontologists as defined herein should be used to conduct record searches, prepare paleontological technical reports including mitigation plans, and write paleontological resource sections for NEPQ/CEQA documents.

10.7. Recognizing the paleobiodiversity of the fossil record, utilize professional mitigation paleontologists and/or subject matter experts to ensure that fossils recovered during mitigation are accurately and properly identified to the lowest possible taxonomic level, for conducting faunal and floral analyses, and for obtaining local paleontologic or geologic expertise for a project area.

10.8. Cite (but never plagiarize) paleontological resource and other types of reports and never falsify reports.

10.9. Insist on employing paleontological field techniques to do paleontological work. Succumbing to pressure from an uninformed overseeing agency to employ archeological or other scientifically unproven techniques is not consistent with best practices.

10.10. Avoid letting clients or agencies alter impact mitigation measures in a manner that conflicts with the objective of paleontological resource preservation. Report occurrences of client mandated alterations to agencies. If possible, the overseeing agency should be informed if client modifications to mitigation recommendations are contrary to best practices.

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ARTICLE

RECOMMENDED STANDARDS FOR FIELD ASSESSMENTS IN MITIGATION PALEONTOLOGY

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ABSTRACT—Protection and management of paleontological resources on most federally administrated public lands is mandated by the Paleontological Resources Protection Act of the Omnibus Lands Act of 2009. In addition, many state and local jurisdictions have protections for paleontological resources. These agencies set requirements and conditions of approval (COA) on proposed actions occurring on lands within their jurisdiction. Mitigation paleontology is a growing practice focused on assisting agencies with managing paleontological resources and fulfilling the paleontological COA required of a proponent for a proposed action. Although background research and file searches are important and necessary aspects of assessing the paleontological resources of an area, field assessment, or survey, of these resources is arguably the most important, and complicated, step in the process. This paper proposes basic standards for conducting field assessments for paleontological resources. Topics, such as survey techniques, monitoring, field tools, field safety, locality documentation, geological descriptions, stratigraphy, and photography will be explored.

INTRODUCTION

Protection and management of paleontological resources on most federally administrated public lands is mandated by the Paleontological Resources Protection Act (PRPA) of the Omnibus Lands Management Act of 2009. In addition, many state and local jurisdictions have protections for paleontological resources or antiquities. These agencies set permit requirements and the conditions of approval (COA) on proposed actions occurring on lands within their jurisdiction. Mitigation paleontology is a growing practice focused on assisting agencies with managing paleontological resources and fulfilling the paleontological COA required of a proponent for a proposed action. Although some mitigation paleontology projects may involve research or a research plan, the primary function of a mitigation paleontologist is to identify paleontological resources in a particular area, or the potential to discover paleontological resources in that area, and to help manage or mitigate potential adverse effects to those resources (BLM, 2009).

Mitigation paleontology is comprised of several facets that include desktop reviews, paleontological resource analysis, field assessments, monitoring, resource recovery, and reporting of paleontological resources. Desktop reviews typically include a background investigation of all available documentation regarding known paleontological resources, as well as the paleontological sensitive geologic units in an area of concern. Literature reviews, scrutiny of published geological maps and reports, files searches in agency or institutional records, and review of previous paleontological reports are all important aspects of a comprehensive background investigation. Reporting on the findings of desktop reviews and field assessments is another important step in protecting paleontological resources. A quality report is typically a succinct technical paper outlining the paleontological resources and geology of an area, the potential to discover scientifically significant paleontological specimens, methods, results, and mitigation recommendations. Perhaps one of the most important aspects of the report are the recommendations made for mitigation or management of the paleontological resources. The Principal Investigator, as the trained, qualified, and permitted paleontological professional, has the obligation and responsibility to make appropriate mitigation or management recommendations for the paleontological resources based on professional interpretation of the data presented in the report. These recommendations typically include plans, which an agency may (or may not) choose to implement. Although background research, file searches, and reporting are extremely important and necessary aspects of assessing the paleontological resources of an area, field assessment and mitigation of paleontological resources, including construction monitoring or salvage, are arguably the most important and complicated steps in the process. These steps are the focus of this paper.

A growing number of professionals, including paleontologists and cross-trained cultural resource specialists, biologists, and others, are finding employment in mitigation paleontology. These professionals are utilized to complete various tasks, including field surveys, construction monitoring, and other mitigation measures. Unfortunately, many non-paleontologically trained technicians have little or no formal training in geology or geological field methods. Furthermore, many paleontologists are trained in biological, environmental, or ecological based programs and generally have limited training in geology or geological field methods. Although these groups may be adept at recognizing fossils, most are not appropriately trained to collect or document all of the necessary contextual data. Standards for field assessment and documentation during mitigation are dependent upon the ultimate utilization and reposition of the fossil resource. Normally, a specimen(s) is destined for preservation in a systematic collection where it may be integral in research and education. Therefore, proper documentation of contextual data during field assessment and mitigation is essential. For paleontological resources, the contextual data includes the geologic setting in which they are found. The most fundamental of the data required to interpret the geological history, depositional environment, ecology and habitat, and evolutionary context of a fossil are the stratigraphy, lithology, and taphonomy of the fossil locality.

Because careful documentation of this contextual data is crucial, and because many personnel conducting field investigations for paleontological resources may not be properly trained in geological field methods, a need exists for a basic framework within which field investigations should be conducted. This paper proposes basic standards for conducting field assessments for paleontological resources during mitigation project. Topics such as survey techniques, monitoring, field tools, field safety, locality documentation, geological descriptions, stratigraphy, and photography are explored.

Note: The basic standards proposed herein are presented as a reference point for future discussion and have not been endorsed by CFR, SDSM&T, or any other professional organization.

GENERAL FIELD SAFETY

Safety should be the principal concern during any field activity. No work is so important, or deadline so pressing, that individual safety must be sacrificed. In fact, every person at a worksite should have 'Stop Work Authority' and the right/responsibility to use such authority if conditions become too dangerous to safely perform the work at hand. At minimum, OSHA 10 Construction or similar safety training should be completed by all field personnel. Additional and specific safety training should be completed as needed or required for any particular project. Prior to conducting any field work, a project-specific health and safety plan (HASP) should be prepared documenting hazards with the associated risks and appropriate control/mitigation measures to protect field personnel from these hazards. The HASP should be reviewed by field personnel prior to field activities.

MITIGATION PALEONTOLOGY

Some lead agencies utilize classification systems which rank geologic units based on the potential of the unit to produce significant paleontological resources to facilitate these evaluations. For example, the United States Forest Service (USFS) utilizes the Fossil Yield Potential Classification (FYPC) System (USFS, 2005) and the Bureau of Land Management (BLM) utilizes the Potential Fossil Yield Classification (PFYC) System (BLM, 2008a, 2008b). These classifications systems are periodically revised and help resource managers to determine what level of evaluations and mitigation an area may require. Lead agency evaluation of a proposed undertaking relative to an area's potential to yield paleontological resources should trigger a consultation with a qualified professional paleontologist (SVP, 2010).

Many lead agencies do not have paleontological sensitivity ranking systems with which to classify the potential of formations to yield scientifically significant paleontological resources on lands within the agency's jurisdiction. Furthermore, many regions in the United States have not been thoroughly analyzed with regards to determining the sensitivity ranking of the formations within. These situations require significantly more research and sound judgment from qualified, professional paleontologists in order to determine the most acceptable mitigation measures to include in the mitigation plan.

According to the Society of Vertebrate Paleontology (SVP, 2010), for areas determined to have moderately high, high, or unknown potential to yield scientifically significant paleontological resources, an adequate paleontological evaluation of the area must include:

- A pedestrian ground survey for paleontological resources. Documentation and surface salvage should be conducted prior to ground disturbing activities, if applicable;
- Monitoring for paleontological resources by a qualified paleontologist of all ground-disturbing activities that impact a previously undisturbed rock unit;
- Documentation and salvage of paleontological resources discovered during ground-disturbing activities;
- Screen or screen washing of sediments to recover small (yet no less important) specimens, if applicable;
- Transferral of recovered specimens (and data) to an approved repository for preparation, stabilization, repair, identification, cataloguing, and curation;
- A final report of findings, including significance and management recommendations.

Qualified Paleontologists

Utilizing properly educated, experienced, or otherwise qualified personnel to conduct paleontological resource investigations is imperative. However, in the growing field of mitigation paleontology, experienced and qualified paleontologists are in short supply. Therefore, companies may find that relatively uneducated low-cost field personnel are attractive alternatives to experienced paleontologists. The use of unqualified personnel is unacceptable and can potentially result in damage to paleontological resources or loss of critical paleontological data. What constitutes a qualified paleontologist must be addressed so that there is a uniform set of qualifications that all companies, project proponents, and lead agencies can use to determine if mitigation personnel are qualified. SVP (2010) set out to identify the basic qualifications for mitigation paleontologists. However, there remains a need for a more thorough guidance for identifying (and/or permitting) properly qualified paleontologists.

The following four-tiered hierarchy is an example of recommended qualifications for properly qualified mitigation paleontologists:

Principal Investigator (PI, Qualified Professional, Project Paleontologist)—A PI is a practicing paleontologist who is recognized by the paleontological community and lead agency as a Qualified Professional Paleontologist. A PI must be able to demonstrate familiarity and proficiency with paleontology in a stratigraphic (geological) context. The PI is the primary permittee and is responsible for all aspects of permitting, planning, evaluation, oversight, management, documentation, performance of paleontological personnel, and reporting for paleontological resources (BLM, 1998; BLM, 2009). A PI should meet the following requirements that are loosely based on the requirements outlined by the SVP (2010):

1. A graduate degree in paleontology or geology, or a BS degree in paleontology or geology with significant experience (10+ years) conducting field paleontology. The PI must have demonstrated competence in field paleontology/geology techniques, documentation, technical writing, project planning and execution, surveys, and monitoring. An advanced degree has less importance than demonstrated competence and experience.
2. Documented two or more years of professional experience working under the supervision of a PI or project paleontologist with administrative and project management experience.
3. Proficiency in recognizing fossils in the field and determining their significance.
4. Experience collecting vertebrate fossils in the field.
5. Education or training in field geology, field paleontology, stratigraphy, and biostratigraphy.

Field Agent—A qualified professional paleontologist, a field agent should generally meet all of the criteria required of the PI. The field agent can work in the field without the direct supervision of the PI and can lead and organize field crews and projects but is not ultimately responsible for the permitting, reporting, planning, etc.

Paleontological Resource Monitor (Field Monitor, Construction Monitor)—May be utilized for supplemental on-site monitoring of surface-disturbing activities when the PI or a Field Agent is unavailable. Has some paleontological field experience, but must work near PI or Field Agent. In general, a PI or Field Agent must be in communication with the Field Monitor using a portable communication device, such as a cell phone or two-way radio, and must be able to reach the location of the field monitor in no more than two hours so that prompt examination of any newly discovered paleontological resource can be made. A resource monitor should meet the following requirements that are loosely based on the requirements outlined by the SVP (2010):

1. BS or BA degree in paleontology or geology, and at least one year of experiencing conducting paleontology field investigations, or
2. Enrollment in upper division classes pursuing a degree in the fields of geology, and demonstrated two or more years of experience conducting paleontological field investigations, or
3. AS or AA in geology, paleontology, biology, and five or more years of demonstrated experience conducting paleontology field investigations, or
4. MA in cultural resources (or related field), and five or more years of documented paleontological experience, and demonstrated ability to identify paleontological resources, document localities, and collect and salvage fossils, or
5. BA in cultural resources (or related field) and significant (10+ year) documented field experience in paleontology. Field experience should include demonstrated ability to identify paleontological resources, document localities, and collect and salvage fossils.

Field Assistant/Technician—A field assistant should meet all of the same general criteria of monitors, except that they may have limited paleontological field experience. Field assistants must conduct all work under the immediate, onsite supervision of PI or Field Agent. Field assistants should have at least eight hours of training or experience received from a qualified paleontologist in identifying paleontological resources prior to performing field work. To ensure proper supervision, an appropriate ratio of Field Assistants per PI or Field Agent must be maintained. The complexity of the project, the area to be covered, and the field experience of the assistants are factors that should be considered in determining the appropriate onsite personnel. However, no more than six field assistants per PI or Field Agent are recommended.

Guidelines for Conducting Paleontological Resource Surveys

Before any field work begins, all appropriate notifications to the lead agency and proponent should be made and all necessary authorizations obtained.

Field Surveys are pedestrian reconnaissance, or prospecting, performed in areas where there is potential for significant fossils to occur or where the probability of encountering significant fossils is unknown. Surveys occur within the boundaries of a proposed action and in areas where ground-disturbing activities are anticipated. Surveys are performed prior to any ground-disturbing activities. Therefore, it is most efficient if the location of the disturbance is finalized prior to surveys. Alternatively, if the location of the disturbance is not specifically known, then a large block survey (see below) can be completed over a larger area, being sure to encompass all potential areas of disturbance. Field surveys are often facilitated by staking, which delineates the project area and features within. Field surveys, as well as mitigation plans and measures, are not intended to be (nor should they be) scientific research studies (BLM, 2009). Rather, they are meant to identify, recover, or avoid paleontological resources, thereby protecting the resource from damage or destruction. However, proper scientific techniques and accepted paleontological procedures must be utilized during all mitigation efforts. Surveys must be conducted by appropriately trained, qualified paleontological personnel (BLM, 2009). The field crew can be led by a Field Agent (see qualifications listed above) but must be supervised by a Qualified Professional Paleontologist. The authors recommend that it is inappropriate for anyone not meeting the qualifications listed above (or similar qualifications) to conduct or supervise paleontological resource surveys or monitoring.

In general, surveys can be divided into two categories; linear surveys and block surveys. Linear surveys are conducted on proposed areas which are naturally linear, such as proposed pipelines, transmission lines, roadways, railways, and seismic exploration projects (source and receiver lines). Linear surveys typically follow the proposed right-of-way (ROW) of the proposed action, with a predetermined buffer zone or offset. The survey creates a ROW corridor within which the authorized activity (e.g. construction) can safely take place. The proposed route is typically staked, marking the centerline of the proposed ROW. Paleontological surveys on linear projects typically utilize a 30 to 92 m (~100 to 300 ft) buffer, centered on the ROW. The survey corridor width is generally set by the agency, but can also be influenced by the project proponent. For example, the lead agency may require a 60 meter (~200 ft) corridor centered on the ROW. However, the proponent may ask for a wider corridor (e.g. 90 m or ~300 feet) so that extra 'wiggle room' is available during the construction activities.

- Surveys must be conducted when the conditions allow for clear observation of the ground. Surveys should not be conducted when ground conditions such as snow cover prevent clear observations.
- Linear surveys should be conducted in a down-and-back method; that is, one side of the ROW is surveyed going one direction, and the other is surveyed on the way back. Alternatively, two or more surveyors (depending on the width of the ROW) may conduct the survey in one direction, surveying the entire ROW in one pass.
- The base of outcrops in areas of moderate–high fossil potential should be slowly, carefully, and systematically searched for float fossil material. Float material may indicate additional fossils in the outcrop above. If float material is found, it should first be gathered and documented before trying to trace its source. Loose sediments may be dislodged during ascent of an outcrop and can potentially obscure anything below.
- In general, it is not necessary to survey areas which have been disturbed by previous activities. Or to be more clear, fossils found in previously disturbed bedrock are no longer in situ. Therefore, these fossils are lacking nearly all of their contextual data and are no longer scientifically significant.
- If access along the ROW is sufficient, strategic planning for pickup and dropoff points, or vehicle staging points, can reduce the distance that surveyors must walk. A staged or waiting vehicle also provides shelter, a place to warm up or cool down, and an opportunity to refill water bottles.
- If access along the ROW is poor or absent, then the use of ATVs or UTVs to access survey areas may be warranted to reduce the overall duration (and cost) of the survey and the distances that crew member must physically traverse. Off-road vehicles can also provide a means for transporting water, tools, and other supplies into remote or hard to access areas.
    - All appropriate authorizations (and permits) to operate these vehicles should be obtained from the lead agency and/or landowners. In addition, all persons operating off-road vehicles should have proper training on the safe use of these machines in rough or uneven terrain.
    - Note: Conducting surveys while riding horses, ATVs, UTVs, or other off-road vehicles is generally not allowed by agencies, and is certainly not recommended. Surveyors simply cannot adequately recognize paleontological resources while safely operating these modes of transportation.

Block surveys are most common for projects involving broad areas of ground-disturbing activities, such as well pads, commercial/residential developments, and mines. Block surveys require pedestrian survey of all areas with moderate to high potential to yield paleontological resources. However, this does not mean that all lands within a proposed project boundary must be inspected. Areas that are densely vegetated, lacking geologic units with unknown, moderate, or high potentials, and areas obscured by soil, alluvium, or colluvium can generally be excluded from the survey. Because the distribution of paleontological resources is directly related to the distribution of sedimentary geologic units exposed on the surface, focus should be directed to areas where units with moderate to high or unknown potential to yield paleontological resources are well exposed. Although bedrock may be obscured by vegetation, soil, or alluvium, efforts should be made to determine the thickness of the cover. Areas in which ground-disturbing activities are likely to penetrate to depths which could impact the underlying bedrock should be noted. If bedrock with moderate to high, or unknown fossil potential is likely to be encountered during disturbance activities, then recommendations should be made regarding the need for later monitoring during those activities.

If paleontological resources are at risk of theft or damage by the proposed action, data collection alone does not constitute mitigation. All significant fossils that may be damaged or destroyed during project activities must be collected, along with all relevant contextual and location data (BLM, 2009). Small specimens may be collected during the survey (see Collecting below). However, larger specimens or a concentrations of significant fossils located during the field survey may require additional time and personnel in order to properly document and collect the fossils. In this situation, the specimen(s) should be stabilized as needed and the site documented. At this point, a determination needs to be made as to whether avoidance is necessary or whether full recovery of the specimen will be required prior to ground-disturbing activities. This decision is made based on input from the PI, lead agency, and proponent. Funding for recovery is the responsibility of the proponent. However, in many cases full recovery of the specimen offers public relations, economic, and/or timing advantages for the proponent, and should always be the first consideration. Avoidance should be secondary, considering the primary goal of mitigation paleontology is to protect paleontological resources. Avoiding the specimens only allows the effects of weather and erosion or theft to destroy the fossils.

Good ground visibility must be available during survey operations. Therefore, surveys during periods when the ground is covered in snow are not acceptable. Wildlife timing restrictions, such as critical nesting or birthing times, may further restrict or delay field surveys. Proper planning and communication between the PI, proponent, and lead agency can substantially reduce schedule delays and/or misunderstandings.

Guidelines for Conducting Paleontological Resource Monitoring

Monitoring is the practice of observing activities that result in ground disturbance. The paleontological resource monitor is on site to recognize, identify, document and salvage any scientifically significant paleontological resources encountered during the ground-disturbing activities. Only qualified paleontological monitors (see qualifications above) should conduct monitoring, and monitors should be accomplished at recognizing paleontological resources. Furthermore, the monitor must be able to document the stratigraphic and geological context of the paleontological resource (SVP, 2010). Monitors should be properly equipped with tools and supplies so that the rapid documentation and salvage of the resource can be accomplished. Monitors should have all of the appropriate safety training, such as OSHA 10 Construction.

There are two types of monitoring: 1) on-site, performed during ongoing ground-disturbing operations; and 2) spot-checks, performed during or after ground disturbing activities, or at key times during the progress of the project. On-site monitoring can be further divided into grading and sloping monitoring, and trenching/excavation monitoring.

On-Site Monitoring—On-site monitoring should be required during all ground-disturbing activities in areas with high potential to yield scientifically significant paleontological resources. The need for a full-time monitor is usually established in the findings of the initial preconstruction survey, but may also be determined on the basis of the local geology or the nature of the proposed action. According to SVP (2010), for ground disturbing activities in rock units with known high potential, a monitor will need to be present during all earth-moving activities. After 50% of the excavations are completed within an area or rock unit and no paleontological resources have been discovered, then the level of monitoring can be reduced or suspended at the discretion of the project paleontologist and with agreement from the lead agency (SVP, 2010).

Every effort should be made to complete documentation and fossil recovery with minimal work stoppage. However, an extended period of work stoppage may be required in some cases, so coordination with the project proponent is important. Prior to beginning the monitoring work, the monitor, site supervisor, and equipment operators should agree on procedures for brief work stoppages to allow for the examination and assessment of fossil finds.

The construction paleontology monitor must assess any finds, salvage exposed or disturbed fossil material and related data, and take appropriate steps to mitigate any current or potential damage (BLM, 2009). Monitors should also consider that microfossils may be present in the disturbed material but may not be visible in the matrix or with the naked eye. It may be appropriate to collect samples of matrix for micropaleontological recovery (see Collecting). Monitoring is also dependent on the ability of the monitor to visually identify fossil material on the ground or in spoils. Therefore, construction activities in paleontologically sensitive areas must occur only during times with sufficient light or ground visibility.

Grading and Sloping—Monitoring during grading and sloping operations usually involves an appreciable degree of walking. As equipment, such as bulldozers, belly scrapers, and road graders strip off layer after layer of earth, the construction paleontology monitor follows them (Fig. 1). A monitor's task is to investigate newly exposed bedrock for paleontological resources. The monitor should follow at a safe distance such that they are not obscured by dust and are in clear visual contact with the equipment operators. The monitor should be aware that the equipment could stop or turn around at any time. Should a scientifically significant paleontological resource be found, the monitor should:

- First, flag or otherwise mark the find with lathe, pin flagging, or other barricades.
- Then, notify the construction foreman or equipment operator of the find.
    - Often, the foreman will redirect equipment operators temporarily so that the paleontology team can quickly assess, document, and salvage the paleontological resource.
- Contact the PI and inform them that a discovery has been made. The PI will contact the appropriate agency personnel, if required.

FIGURE 1. Left: belly-scraper removing bedrock on well pad in the Wind River Basin. Right: mud reserve pit on well pad in the Wind River Basin. Photography by R.J. Moses.

- The paleontological team should rapidly assess the significance and extent of the new discovery. The paleontological team, agency, and proponent should evaluate the discovery and discuss the options available to mitigate the impacts to the resource. Several options are available for mitigation and require careful consideration. Ultimately, economics usually dictate which course of action is taken. In some situations, documentation and salvage of the resource is cheaper than rerouting the project. In this situation, the paleontological team must determine the appropriate collection protocol and conduct the salvage in the quickest acceptable manner. In other situations, a reroute may be cheaper, or quicker, and is chosen instead. In this case, collection of the resource is perhaps unnecessary from technical aspect, and the proponent cannot be made to pay for recovery of the specimen. However, protection of paleontological resources is the primary mandate of mitigation paleontology and every effort should be made to convince a project proponent to fund salvage of the specimen or find funding elsewhere. In some cases, an interested institution may wish to salvage the specimen for inclusion into their display or research collections.
- All appropriate documentation should be made before and during salvage or excavation of the paleontological resources.

Trenching—Monitoring for paleontological resources during trenching typically involves significantly less walking than grading and sloping operations. Trenching is usually conducted for pipelines, buried utilities, and drainage culverts. However, other activities may involve digging foundations for buildings or transmission towers, or even canal building and expansions. Trenching is usually accomplished using a backhoe, excavator (trackhoe), or trenching machine (wheel or chain) (Fig. 2).

Soil and bedrock removed during trenching is called spoils. Monitoring during trenching activities typically involves examining the spoils piles for paleontological resources. Trenching, particularly trenching accomplished with a chain or wheel trencher, results is significant damage to fossils, if encountered. All trenching equipment quickly removes large quantities of spoils and/or can travel over 10 feet per minute. Field data show that a large excavator with a skilled operator can produce one scoop (or bucket) of spoils every 8–15 seconds. As a result, a monitor has only this very short time to examine the spoils of the previous scoop for paleontological resources. Safety becomes a significant concern in these situations because the monitor must be close to the equipment in order to observe the most recent spoils. Be vigilant and stay within unobstructed view of the equipment operator.

Trenches should also be inspected for signs of paleontological resources. This task too is potentially hazardous. A trench or excavation should never be entered until all appropriate safety measures are in place. Therefore, most trenches and excavations must be observed from the edge of the cut. Be aware that the edges of the cut may be unstable and can collapse into the trench with little notice. Be observant of fractures developing parallel to the trench cut; these are good indicators that the trench walls are not stable.

Spot Checks—Circumstances may dictate that spot-checking of disturbed areas and spoils piles at key stages in construction operations is more appropriate than continuous monitoring of operations. The determination to utilize spot-checking methods rather than continuous monitoring should be made by the PI and agreed to by the lead agency, before implementation. Spot-checking of exposed fossil-bearing bedrock or spoils material prior to placing spoil material back into the excavation can be an effective method for discovering paleontological resources. Furthermore, this method can also reduce overall monitoring costs and decrease the time a monitor must be exposed to hazardous construction activities. Spot-checking methods are most appropriate in areas where the expected potential for fossil discovery is low–moderate, or unknown. The decision to utilize spot-checking methods should be carefully considered. If spot-checking is to be

FIGURE 2. Left: Ditchwitch 7610 chain-style trencher with six inch cutting teeth. Electric trace wire (yellow) was installed into trench before piping was installed. Right: pipeline trenching using a tracked excavator. Spoils pile in right of image. Photography by R.J. Moses.

utilized, the construction crew and/or project proponent should be instructed that if any fossils are encountered, the Project Paleontologist or lead agency must be notified immediately. Spot-checking methods also require that the paleontologist be available on short notice. The following are examples of when spot-checking methods for monitoring may be appropriate:

- After pipeline trenching operations are complete but before pipe is placed and the trench backfilled.
- After construction of drilling reserve pits or relatively small exploration trenches/pits.
- After excavation of foundations or footers.

FIELD TOOLS

Tools are important aspects of completing any project efficiently, correctly and with sufficient quality. With the exception of modern digital electronic devices, such as Global Positioning System (GPS) receivers, data-loggers, and digital photography, the tools of the trade for field paleontology have changed very little in over 150 years. Having the appropriate tools in the field during surveys or monitoring is crucial for properly documenting new paleontological resources and for properly stabilizing and recovering delicate fossils. The following list of tools identifies the typical field equipment needed for surface collecting and shallow excavations. Larger specimens or more significant excavations may require additional tools. Bone preservation and characteristics of the encasing rock can vary significantly, and may further dictate what tools are required. Some tools need not be carried at all times but should be readily available, if needed.

Most field paleontologists prefer a lightweight field kit that can be easily carried in a field pack and on a tool belt, while leaving sufficient room for food/water and other necessities. Table 1 outlines suggested field equipment. This equipment should be carried or near at hand during field investigations.

STANDARDS FOR PALEONTOLOGICAL RESOURCE DOCUMENTATION

Documentation is the single most important task for any field paleontologist. Fossils with no contextual or locality data have little scientific value. Therefore, the field paleontologist should make all appropriate efforts to collect as much data regarding the specimen and locality before collecting or removing the specimen. Locality field forms are useful tools in assisting a crew member in collecting the extensive data set. Photography is another crucial form of documenting localities and specimens. Digital cameras have greatly improved this task. GPS data-loggers with data dictionaries can also facilitate data collection but should never replace hand written field notes. Additional advantages of these digital data collection methods include allowing for quick and accurate incorporation of data in final reports, maps, and locality forms. Otherwise, data must be transcribed from the hard-copies into digital formats.

Data may be divided into three major categories: geographical data, geological data, and paleontological data. Geographical data include the coordinates, relative location, and Public Land Survey System (PLSS; Sec., Township, Range) location. Geological data include lithology, sedimentology, and stratigraphy (Table 2). Paleontological data include anatomy, taxonomy, and taphonomy.

Locality Documentation

Naming schema—Naming a new paleontological locality is an important step in the documenting process. Once the site is named, it can be properly tracked in photos, field notes, reports, digital records, and repository records. Therefore, naming must be done in a manner that is meaningful, logical, and trackable. No one naming schema is absolutely the most acceptable method. However, the following (or similarly devised) schema has particular advantages. Figure 3 demonstrates a locality naming conven-

TABLE 1. Personal field equipment, modified after Compton (1985) and Leiggi et al. (1994). Items marked * are required at all times.

Durable field pack for carrying supplies*	Rain gear
Field notebook*	Small and medium size paintbrush
Writing utensils*	Whisk broom
Hand lens (10X magnification)*	Tweezers
A compass with inclinometer*	Awl and dental probe
Durable canteen or water bottle*	Quality steel chisels
Rock hammer*	Measuring tape
Camera*	Consolidant (acetone or alcohol soluble)
Scale bar*	Glue (cyanoacrylate)
GPS*	Specimen vials or repurposed medication vials
Two way radio*	Zip seal plastic bags (quart and gallon)
Cell phone	Toilet paper (for wrapping specimens)
Work gloves	Plaster casting bandages
Clipboard with document storage (if using field forms)	

tion that has several practical advantages. The following example incorporates several important bits of information that allow the location to be easily referenced to an individual field member (RJM), a year (2014), month (February), and date (14th), and the specific sequential discovery (001). As described above, documentation is the single most important aspect of field paleontology. Because all documentation should be made in field notebooks and locality forms, this naming convention allows for the rapid determination of who collected the data and where it can be found. Furthermore, the year, month, day, and number of the locality allow the locality to be tied to a specific field book or file, and section within.

Another advantage of this naming convention is that it allows for multiple collections (specimens or jackets) from the same locality. In other words, multiple specimens or plaster jackets removed from the same locality can be easily documented and tracked by adding sequential letters or numbers following the 12-digit locality number (e.g. RJM14-0214-001a, b, c, or RJM14-0214-001-01, 02, 03).

Geography—The geographical location of a locality is crucial contextual information that helps future researchers relocate a locality, and more importantly, re-examine the stratigraphy, lithology and sedimentology associated with the specimen. Geographic location is best document utilizing multiple methods.

1. The location should be determined using a 1:24,000 scale, topographic map, or GPS (see Digital methods), and plotted on the map.
2. The PLSS or similar land survey location should be documented.
   a. Quarter/Quarter (or preferably Qtr/Qtr/Qtr), Section, Township (or Tier), Range, Quadrangle, County, and State should be documented in field notes and/or on a locality form.
   b. Be sure to note scale, year, and source of the quadrangle map.
   c. Map aids, including templates which divide sections into qtr/qtr/qtr at various maps scales (though usually 1:24,000), are extremely useful for completing this task in the field.
3. GPS Coordinates must be recorded for the locality. Coordinates must be recorded in Universal Transverse Mercator (UTM) or latitude-longitude format.
   a. The datum that the coordinates were recorded in must be documented (e.g. NAD83, NAD27, WGS84).
   b. If UTM coordinates are used, the zone must also be documented (e.g. NAD83 UTM Zone 13N).
   c. If latitude-longitude is used, decimal degrees format (ddd.ddddd) is recommended.
   d. Accuracy of the coordinates should be within ± 10 m (~30 ft).
4. It is also recommended that relative geographic location of the specimen or locality be documented. For example, distance and direction from streams, roads, towns, or other landmarks should be recorded.

Paleontology

Anatomy—The taxonomic identity of a specimen(s) is based upon the structural features or characters (morphology) of the remains encountered. The morphology of osteological and dental anatomy provides the basis for separation of various taxonomic entities. Qualified personnel should have sufficient background to make an assessment of which osteological and/or dental element are present in order to make identifications, and perhaps more importantly at this operational stage, to make a significance analysis. Some portions of the anatomy are more important for taxonomic identifications and evolutionary significance, so some portions of the anatomy are more important than others.

Geographical Data	Geological Data	Paleontological Data
PLSS Location	Lithology	Anatomy
QTR/QTR/QTR	Texture	Taxonomy
Section	Fabric	Taphonomy
Township	Sedimentology	Orientation
Range	Sedimentary structures	Degree of articulation
Map Quadrangle	Nature of contacts	Number of individuals
Scale	Stratigraphy	Quality of preservation
Year	Stratigraphic unit	Fragmentation/breakage
Source	Stratigraphic position within unit	Size of accumulation (m2, m3)
County		Bone modification
State		Weathering
Coordinates		Polish/abrasion
UTM		Scratches/ tooth marks
Lat-Lon (ddd.ddddd)		Borings/root traces
Coordinate system datum		Mode of preservation
Zone/Meridian		
Relative geographic location		

TABLE 2. Types of geographical, geological and paleontological data that should be collected for the characterization of a paleontological resource locality. Modified from Rogers (1994).

Taxonomy—Seemingly, taxonomic identification of the fossil resource would be one of the most important aspects of assessment, and in large part, this is true. Understanding which fossil type(s) occur in a particular situation is a basic component of any assessment program. However, the precise identification of a specimen is normally difficult under field conditions, and more often results only after laboratory preparation and extensive comparisons during research. In the interim, qualified personnel are required to undertake initial identifications and determine relative significance. For example, an identifiable single vertebra from an unusual stratigraphic position or an unusual paleoenvironmental setting may have as much scientific significance as a much more completely preserved specimen where many have been encountered previously. Hence, research repositories often contain specimens that would not be considered by some as 'museum quality.'

Normally, field identifications should remain conservative in order not to be misleading. Sometimes, identification down to vertebrate class may be sufficient, but qualified personnel should be able to identify a specimen to familial and perhaps even generic level, depending on the specimen.

Taphonomy—The taphonomy (transition from the biosphere to the lithosphere) of a paleontological resource occurrence is also important during assessment. Taphonomy is particularly important in the reconstruction of paleoenvironments, as well as in other disciplines in paleontology. Field documentation is instrumental in taphonomic assessment because nearly every field occurrence is unique. Therefore, extensive documentation is required to capture data concerning the presence of osteological and dental elements, preserved condition, and orientations of elements.

Sketch maps of the fossil(s) are particularly important, especially for associated or articulated specimens. Sketch maps preserve the orientation and association of element as they occurred in situ and graphically display relationships that may not be conveyable through notes and descriptions alone. Additionally, sketch maps help refresh memories of what is contained in a jacket, or help preparators to know where in a jacket the fossils are and in what orientation they may be found (Fig. 4). Always utilize a datum (or origin) and a square meter grid to accurately capture the details of the site and specimen(s). The following items should always be included on a sketch map:

- North arrow
- Locality and specimen/jacket number(s)
- Collector
- Date
- Sketch should be drawn to scale, utilizing a grid and gridded paper (many field books have gridded pages.)
- Bones and other fossils should be labeled (when known)
- Trend/plunge should be noted, if applicable
- Anatomical position (anterior/posterior, dorsal/ventral) should be labeled when able to determine

Subtle features of the sedimentary matrix encasing the specimen can easily be destroyed during excavation (Rogers, 1994). The following features should be noted prior to disturbing a fossil:

- Orientation: General orientation can be captured with

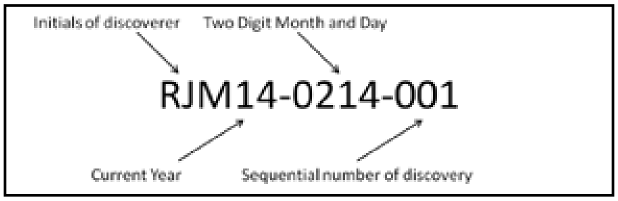

FIGURE 3. Example locality naming convention that incorporates the initials of the discoverer, month, day, and year of discovery, and the sequential number of the discovery occurring on that date. These features allow the locality to be tied to a specific field book (based on initials and year) and section within (based on date and locality number).

a sketch map. However, orientation should be noted in field notes as well. Preferred orientation, or alignment, of fossils should also be noted.
- Degree of articulation: Are the elements articulated or associated, and to what degree?
- Number of individuals: Can the number of individuals be assessed?
- Quality of preservation: Are the elements well preserved, strong, stable, with all detail preserved, or are the elements 'rotten', abraded, exfoliated, and otherwise weak or unstable? Are the elements three dimensional or flattened, undeformed or deformed?
- Fragmentation/breakage: Preservation may be good, but the elements may be fragmented because of weathering, movement down-slope, or crushing during diagenesis.
- Size of accumulation (m2, m3): What are the dimensions of the locality or accumulation?
- Bone modification
  - Weathering
  - Polish/abrasion (water transport wind abrasion)
  - Scratches/tooth marks (feeding or scavenging traces)
  - Borings/root traces
- Mode of preservation
  - Alteration halos in the matrix immediately surrounding the bone
  - Mineral crusts or concretionary material
  - Bioturbation

Geology

Lithology—Lithology, including composition of a rock layer, is determined at deposition and is therefore less likely to be influenced by opinion. Therefore, documentation of the precise lithology at a site is perhaps more important than the documentation of Group, Formation, Member, stratigraphic levels. Documentation through section measurement and lateral mapping provides the best stratigraphic context for fossil occurrences in the vertical dimension. Nearly every outcrop exhibits uniqueness, and capturing that unique color, structure, lithological succession and juxtaposition in relation to a fossil occurrence is essential. The following represents some of the criteria that should be noted in the description of lithology:
- Rock type: Whether sedimentary (detrital or of chemical origin) or extrusive igneous (tephras, flows, etc.)
- Composition: Carbonate (limestone, dolomite) or detrital (conglomerate, breccia, sandstone, siltstone, claystone
- Texture: Gravel, sand, silt/clay=mudstone as silt and clay sizes can seldom be differentiated in the field
- Parting: Massive, blocky, flaky, platy, fissile
- Color (fresh): Color of broken surface, often wet (Munsell Color Chart)
- Color (weathered): Color of weathered surface in field (Munsell Color Chart)
- Crystalline structure: Coarsely, medium, or finely crystalline
- Grain size: Boulder, cobble, pebble, very coarse-grained, coarse-grained, medium grained, fine-grained, very fine-grained, siltstone/claystone=mudstone as silt/clay sizes can seldom be differentiated in the field. The use of grain size charts may facilitate determinations in the field.
- Sorting: Poor, medium, well
- Induration: Poorly, moderately, well indurated
- Cement type: Calcareous, argillaceous, siliceous, ferruginous, gypsiferous, etc.
- Roundness: Angular, subangular, subrounded, rounded, well rounded
- Sphericity: Subspherical, spherical, non-spherical
- Sedimentary structures: Types of cross-beds, graded beds, soft-sediment deformation, mud cracks, types of ripple marks
- Thickness: Vertical range of unit
- Diagenesis Post-depositional alteration such as silicification, dolomitization, replacement, gypsum, etc.
- Specific datums or marker horizons: Particularly tephras/ashes when present
- Interbeds and thickness: Types of interbeds and range of thickness of each
- Description of contacts: Whether gradational, sharp, diastemic, or unconformable
- Types of unconformities: Disconformity, nonconformity, or angular unconformity
- Paleoenvironmental interpretation: Marine (beach, shallow water, deep water), brackish water, riparian (channel, flood plain), lacustrine, aeolian, etc.

Stratigraphy—Documentation of the stratigraphic position of fossil resources is essential. Without precise stratigraphic data, the specimen loses much of its scientific significance and the element of time, essential in the study of paleontology, becomes lost or compromised. The layered succession of surface-deposited sediments provides the basic framework for biostratigraphic studies that ultimately provide order to the successive occurrences of fossil organisms.

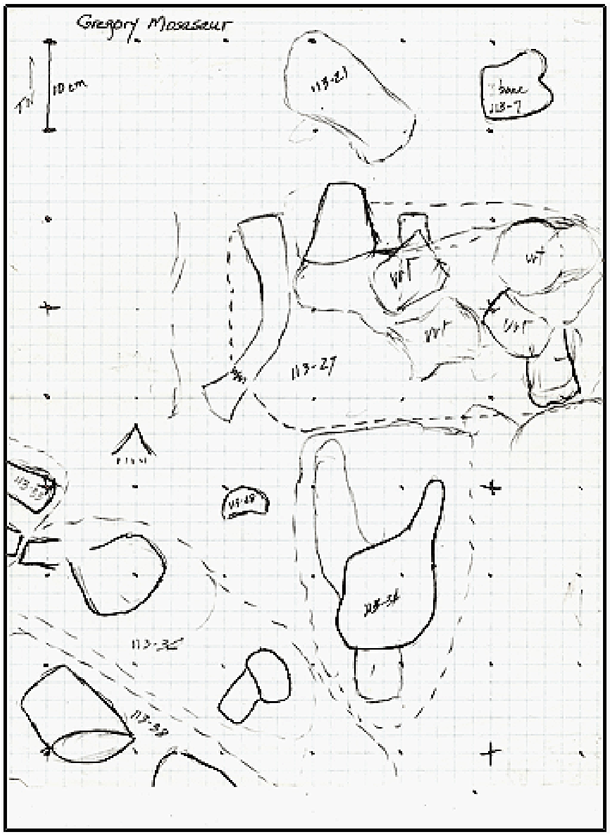

FIGURE 4. Example field sketch map of a specimen in the field. In this sketch, individual elements are drawn and labeled (when known). Field Jacket blocks are noted with dashed lines and each jacket is labeled with a field number (e.g. abbreviated numbers 113-27, 113-36, and 113-8). Used by permission of J. E. Martin.

By convention, stratigraphy is divided into a hierarchical system, whose basic unit according to the North American Code of Stratigraphic Nomenclature is the formation. Formations are bodies of rock that are separated based upon changes in lithology. However, not everyone agrees on where or when changes occur, particularly if they are gradational changes. Therefore, the boundaries of formations change, their hierarchy changes, and they may even be abandoned. Thus, a more basic unit, the layer or lithostrome, is recommended as the basic unit in field documentation of fossil occurrences. This unit is much more local, of finer resolution, and defined on consistent lithology. The following methods should be followed when measuring a stratigraphic section.

Methods for measuring and describing stratigraphic sections:

- Measured sections should be routed through well-exposed, structurally undeformed rock exposure (Rogers, 1994) when practicable. This may mean that the section will have to be measured in an area not immediately in the vicinity of the fossil. However, after the section has been measured, the fossil can be correlated into the section by carefully tracing stratigraphy laterally.
- The first step in measuring a stratigraphic section is to determine the basal unit (layer) (Rogers, 1994).
- Informal units should be defined by obvious changes to the lithologic criteria.
- Once the upper and lower contacts of the units are determined, the unit thickness can be measured and the geology and paleontology of the unit can be described and documented in a field notebook. Before taking direct measurement of the lithologic units, one must first determine the structural dip of the formation and compensate for this while measuring. See Compton (1985) for a thorough explanation of stratigraphic section measurement and description, determining structural dip, and adjusting for dip while measuring a section.
- Lithology and sedimentology should be thoroughly documented when measuring the section. Creating a graphic representation that generally depicts general outcrop form and includes lithologic depictions, descriptions, and unit thicknesses is a useful manner in which to capture the data required (Fig. 5).
- The nature of the contacts (sharp, undulating, gradational, unconformable, diastemic) should be determined and documented.
- Plot the position of the fossil occurrence on the stratigraphic section.
- Tools required for properly measuring a stratigraphic section include the following:
- Compass with inclinometer (e.g. Brunton, Sunto): for determining structural dip of bedding, and for use as a hand level;
- Jacob's staff (or other metrically calibrated pole): for quickly measuring a section of slopes that are traversable;
- Steel tape: for measuring bed thicknesses on cliffs and ledges;
- Rock hammer and/or shovel: for collection of hand samples for analysis, and for exposing fresh outcrop;
- Hand lens: for observing rock texture and small-scale features.

SCIENTIFIC SIGNIFICANCE ASSESSMENT

Scientifically significant paleontological resources may be defined as any paleontological resource that is considered to be of scientific interest. As suggested by the BLM (2009), a paleontological resource is considered to be scientifically important because it is a rare or previously unknown taxon, it is of high quality or well-preserved, or it preserves a previously unknown anatomical characteristic. Additionally, the resource may be scientifically significant if it provides new information or insight, or has identified educational or recreational value (BLM, 2009). Scientifically significant paleontological resources generally include most vertebrate fossil remains. However, vertebrate traces and rare or unusual invertebrate and plant fossils are also considered scientifically significant (BLM, 2009).

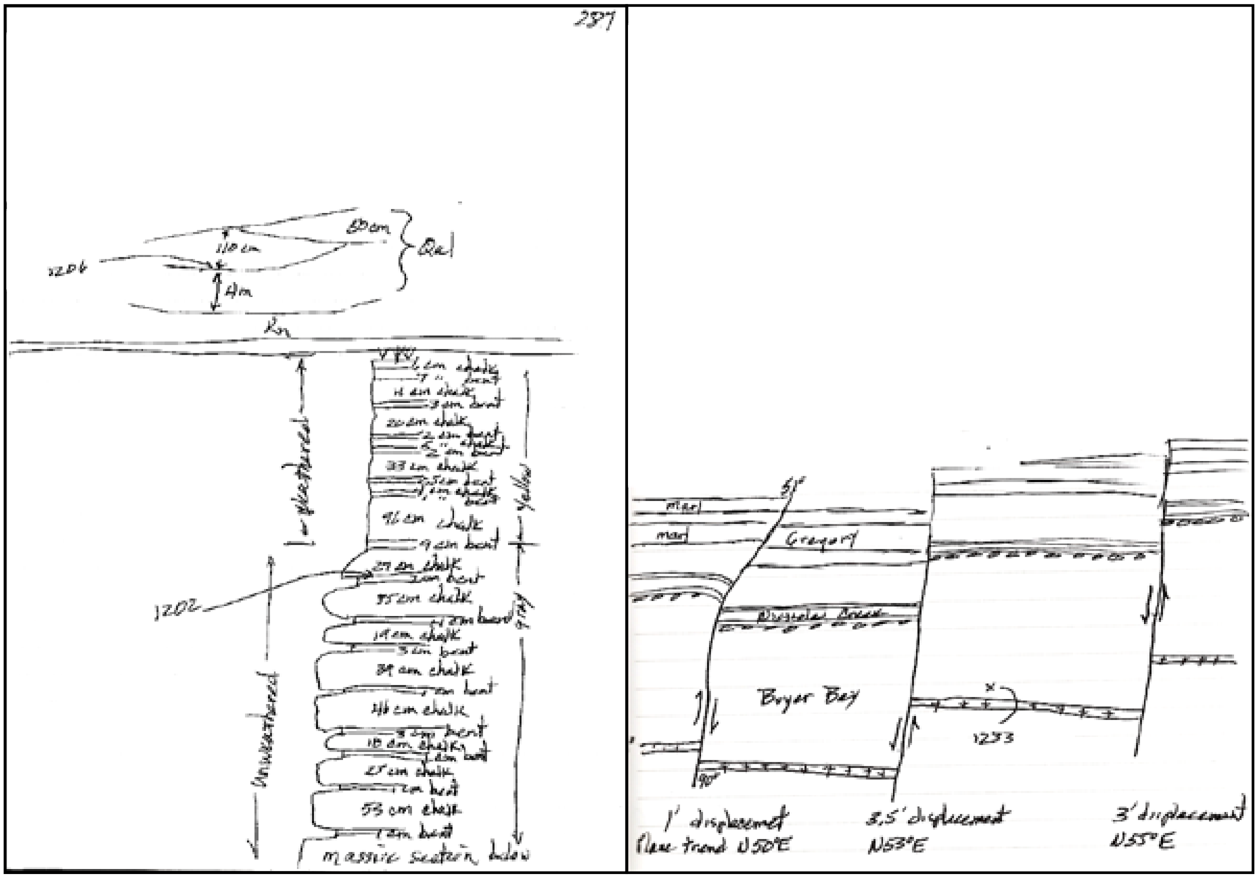

FIGURE 5. Graphic representation of measured sections taken from field notes with lithologic descriptions, unit thickness, and structural relationships. The stratigraphic position of paleontological resources is also depicted in the sketches. Used by permission of J. E. Martin.

Paleontological resources that may generally be considered non-significant include those that lack provenience or context or lack physical integrity because of decay or natural erosion (BLM, 2009). Other fossils that are excessively abundant or are otherwise not useful for research may also be considered non-significant. The determination of scientific significance is a task that only a Qualified Professional Paleontologist should make.

COLLECTING

If paleontological resources are at risk of theft or damage (by ground disturbance and/or natural processes), data collection alone does not constitute mitigation. All significant (as defined above) fossils that may be damaged or destroyed during project activities should be collected or otherwise protected, and all relevant contextual and locational data should be documented (BLM, 2009). Generally, common remains such as isolated gar scales, turtle carapace or plastron fragments, crocodilian and fish teeth, and unidentifiable bone fragments need not be collected. However, the context (assemblage, or geological) of these types of fossils should be considered. The occurrence of these seemingly non-significant specimens may well represent rare occurrences or unusual faunal associations. Therefore, they may be scientifically important and must be documented and collected or sampled, where appropriate. Furthermore, occurrences of plant or invertebrate fossils should be recorded and representative samples collected. Plants and invertebrates are great environmental indicators and are often key to reconstructing paleoenvironments. Additional mitigation measures may be warranted in some cases for these types of localities. A PI should carefully evaluate all paleontological occurrences for scientific significance and adjust mitigation plans accordingly.

Recommendations for collecting specimens:

- With few exceptions, all field documentation must be accomplished before the specimen is removed from the field.
- Avoid over-preparing a specimen in the field. Only remove enough matrix to determine the extent of the fossil(s) and determine that no other fossils are present. Preparation is a delicate task that should be left for more experienced preparators under controlled conditions with proper tools. Furthermore, matrix can be used to cushion and support fossils during transport. The goal is to remove enough matrix that the resulting field jacket is not overly heavy, while leaving enough matrix

to support the specimen and/or prevent excessive loss of contextual data.

• Avoid gluing all the fragments back together in the field. This task requires much time and is better suited for a preparation under controlled laboratory conditions. Furthermore, if application of a consolidant is required in the field to stabilize a specimen, avoid over-application. Over-application can cause adherence of surrounding matrix and make preparation very difficult.
    ▫ Use an appropriate alcohol- or acetone-based consolidant, such as VINAC (B-15) or BUTVAR (B-76) when stabilization is necessary.
    ▫ Never use cyanoacrylates (super glue) as a consolidant. Although super glues may have a purpose for gluing fragments back together, these products are only marginally reversible and exceedingly difficult to remove or clean up in the laboratory.

• Small specimens, once stabilized, may be carefully wrapped in tissue. Use a small amount of tape or moisture to keep the wrapping together and place into a vial or zip-lock bag. Keep all associated fragments together as much as possible. Make sure that a specimen label is included in the vial and/or bag and that the container is labeled on the exterior.

• Medium-sized and particularly fragile specimens may need additional protection and support. Plaster casting bandages are a particularly effective product for quick field jacketing of small-medium size specimens. Plaster casting bandages are plaster-of-Paris-impregnated strips or rolls of woven cloth. Strips or rolls can easily be cut or ripped to any desired size. Only a small amount of water is required to hydrate and activate the plaster. Remember to use tissue paper as a separating layer between the bone and the plaster bandages. Note: plaster casting bandages should not be used on large specimens. Casting bandages lack the strength required to support larger fossils.

• Large or oversized specimens should always be field jacketed using burlap, or similar strength material, and plaster. Reinforcing material, such as lumber, branches, or even steel or aluminum, can be incorporated into the jacket for additional support and rigidity.
    ▫ Substantial planning and time is usually required for large and oversized specimen removal. The proponent should be made aware of a situation that requires large specimen salvage as soon as possible. Coordination between the paleontology crew and the proponent is necessary to accomplish this task and all attempts should be made to maintain the construction schedule.
    ▫ Refer to Leiggi et al. (1994) for in-depth instructions on preparing a field jacket.

• Field jackets must have specimen number and orientation relative to true north marked on outside.

Micropaleontological Collecting

• Test samples: Bulk matrix test samples of approximately 0.25-0.5 cubic meters/yards should be collected, as determined by the project paleontologist or mitigation plan. Test samples should be collected from horizons that look promising, such as paleosols and mudstone, or display indicators for potential microvertebrate or important invertebrate fossils. Indicators may include plant debris, mudstone, paleosols, abundant invertebrates, or clay-ball horizons. Test samples should be screen washed using 20/30 mesh screen (SVP, 2010). Test samples will help determine if larger samples need screen washed. Alternatively, dry screening may be used to spot check areas that look promising or matrix associated with excavation of a larger specimen. However, dry screening is most effective with dry, loose, or friable matrix and is unsuitable for damp or wet, clay-rich, or well-indurated matrices.

• Standard Sample: If test sampling indicates that there is a reasonable potential for micropaleontological fossil recovery for an area or horizon, larger standard samples should be collected (SVP, 2010). Standard samples size should be between 1 and 4 cubic meters/yards.

• The need for further micropaleontological sampling and screen washing should be determined by the project paleontologist based on the findings of the test and standard sampling, the nature of the geology, and mode of preservation.

• Bulk matrix samples may be collected into bags, buckets, boxes, or totes and transferred offsite to avoid dangerous situations and construction delays. Chemicals or light agitation (e.g., bubblers, current, or rocking) may be used to promote the breakdown of the matrix to produce a concentrate. Fossils may be recovered from the concentrate by hand-picking conducted by a technician using microscope, or by density separation techniques using heavy liquids.

• Refer to McKenna et al. (1994) for more detailed instructions and theory regarding microvertebrate collecting.

DIGITAL METHODS

Field workers are increasingly using digital methods to plan field work, collect field data, and manage the data. Mobile digital devices such as GPS, tablets, smart phones, and digital cameras are becoming more affordable and widely available. Digital data backup on computers, portable hard drives, and cloud servers are cheap and effective methods of data loss prevention. Even field notes are often scanned for digital backup. Field paleontology stands to benefit from these new technologies, provided the methods are standardized and the technology is universally available.

The development of digital field equipment and computer-based mapping, data manipulation, and analysis will certainly offer many advantages for data collection, site documentation, data management, reporting, and archival. However, the importance of paper records should not be overlooked, nor the use of paper be totally abandoned. Handwritten notes will not lose data to computer glitches and do not have a battery life, nor are they susceptible to computer virus and other malicious software. Once daily field activities have been completed, the data on any digital device must be backed up. Digital units often store data in a manufacturer-specific file format, which can be easily copied. However, these files often can only be accessed with the manufacturer's software. Data should be backed-up onto another device, such as a laptop or other portable data storage device, or onto a remote or cloud server (provided internet access is available). If possible, backup on a remote server is preferable for security purposes and for access by colleagues working outside of the field location. The format of the data can also be changed during backup. Changing the data format when backing up the data to a more useful format for reporting can save time during the reporting process. Furthermore, daily downloads of data can facilitate data review and decision-making processes by the project paleontologist.

Photograpy

Thorough photo-documentation of a locality and specimens is important. Digital photography is now one of the most abundant and affordable digital methods of documentation and data collection available to paleontologists. A modern, cheap digital camera with a standard memory card can store over a thousand photos while maintaining good image quality. Therefore, there is no reason not to take numerous photos of a fossil or locality from many different perspectives. Unacceptable photos can easily be deleted at a later time.

A critical element to field photography is scale. A photo is a three dimensional image projected onto a two dimensional surface. Accurate judgment of size and distance within a photo is impossible for the human eye without a known point of reference. The following is a list of recommendations for taking useful, quality photographs when photo-documenting a paleontological resource locality:

- The first photo at every locality should be a photo of the locality number or field form.
- A known scale, preferably a ruler with metric and Imperial units, should be placed next to the subject in every photo.
- A north arrow or some directional marker should also be used to orient the photo.
- Several photos of the locality should be taken from different distances and perspectives to show the subject individually and in the context of the surrounding area.
- Photographs that capture the fossil and its context, such as the matrix lithology or stratigraphy, are particularly useful.
- A photo log should be kept describing every photo taken, including photo number, location, locality name, and context (e.g. facing south at 20 meters distance).
- Many cameras now have built-in GPS receivers. If the camera has GPS, it should be enabled to georeference each photograph taken.

Field photography differs from all other photography in that the conditions and subject cannot be drastically altered. Light may vary day to day, or hour to hour, or even minute to minute. In addition, weather conditions may vary dramatically. Therefore, perfect photographic conditions are not obtainable. Some photos may only be possible facing the sun and other photos may only be possible in shadowed areas. The subject may be indistinguishable from the background causing the subject to be indistinguishable in the photo. The photographer must understand these complications and be aware of potential solutions. The following are useful recommendations on producing the best photographs possible in poor conditions:

- If light is too strong, the photographer must have the ability to shade the subject.
- If light is too weak, the photographer must have the ability to illuminate the subject, such as camera flash or a flashlight.
- If the subject matches the background, the photographer should use angled lighting, identifying markers, or dampen the subject with water to make it stand out against the matrix
- The photographer must keep in mind that using methods to make the subject stand out can also alter the appearance of the subject.
  - Shading can remove dimensionality and cause the subject to look flat.
  - Illumination can create shadows making small asperities appear larger.
  - Identifying markers can mask other features.
  - Dampening the subject can significantly darken and homogenize the colors.
  - Using an angle can cause distortion.
- The main question the photographer must ask is "What is important about the subject?" Often, multiple photos may be necessary to document multiple characteristics (shadows to show dimensionality, direct light to show color, dampening to show form).

MITIGATION RECOMMENDATIONS AND PLANS

Paleontological resource mitigation plans should be developed on the basis of the scientific significance of the paleontological resources and their biostratigaphic, biochronologic, paleoecologic, taphonomic, and taxonomic attributes, rather than economic concerns. Although these plans should be developed with input from the proponent and the lead agency, recommended mitigations actions and the intensity of the mitigation plan are to be made by the Qualified Professional Paleontologist (PI) (SVP, 2010). The mitigation plan establishes a framework for the mitigation program, including documentation, sampling, testing, excavation, screen washing, and other paleontological protocol (SVP, 2010). A qualified (and properly permitted) professional paleontologist must also act as program supervisor, principal investigator, and project paleontologist and is responsible for implementing the mitigation plan. The professional paleontologist is also responsible for making project-specific modifications to the paleontological resource mitigation plan with consultation from the lead agency, project proponent, and other applicable stakeholders (SVP, 2010).

Mitigation Mandates

Whereas avoidance stipulations may be acceptable and commonly implemented for proposed actions with regards to other resources (e.g. cultural resources and wildlife resources), avoidance of paleontological resources in general presumably does not satisfy the intent of the Paleontological Resources Protection Act (PRPA) or any other conceivable protective mandates. In all probability, avoiding paleontological resources does little to protect them in that nature (erosion and weathering) and theft can be just as effective as any development, pipeline, well pad, or other proposed undertaking at destroying a fossil (or its significance). Experience has shown that fossils rarely survive exposed on the surface for more than a few years. Also as stated earlier, data collection alone does not constitute mitigation. What purpose is served by producing inventories and photographs of hundreds of specimens in the field, followed by identification and preparation of large technical reports on all of these discoveries, only to allow natural processes (or worse yet, theft) to destroy the actual resource? Arguably, these practices do not fulfill the intent of the protective mandates for paleontological resources. Therefore, recovery of the fossil and all of its contextual data should be the primary mandate of any paleontological protections and the default mitigation measure for all proposed actions. There are some instances where avoidance or other remedy may be the only practicable solution. However, these measures should be considered a less desirable course of action. If salvage (full recovery) is the primary mitigation measure, then the following alternatives may be entertained when salvage is not practicable:

Avoidance—An alternative mitigation technique in which the course of action is to change or reroute the project location, rather than salvage the paleontological resource. The PI, lead agency, and proponent should recognize that reroutes necessitate additional field surveys in alternative areas. Furthermore, reroutes may trigger a myriad of reevaluations by other resource specialists, land surveyors, and even new engineering designs. These reevaluations are costly exercises that do not eliminate the risk that the alternative areas may too be unacceptable. The PI and proponent must carefully assess budgetary pros and cons of avoidance over salvage. In the end, it is often more cost effective to salvage the specimen than to reroute a proposed undertaking. Anticipation of this contingency prior to or during the original survey may allow for survey of an expanded area at the same time.

Protective Measures—In some cases, fossil material may have been identified but is so abundant or widespread that recovery or avoidance are not viable mitigation measures. In these cases, other means of 'protecting' the resource must be developed in order for the proposed undertaking to proceed. For example, suppose that an access road needs to be constructed (or reconstructed) in order to access key infrastructure. However, the proposed access route intersects an important, expansive, and prolific fossil site. In this circumstance, it may be more acceptable to cover the ground surface along the proposed route through the high sensitivity area with a layer of earth and protective road underlayment. Once the proposed project has been completed, the surfacing material and underlayment could be removed, if desired. Erosion would eventually reexpose the fossils at this site. Plans for protective measures are unusual remedies and require careful consideration and approval from the project proponent and the lead agency.

Recommendation Approval

Lead agencies are rarely required to follow the recommendations made by the qualified professional paleontologist. However, it is generally recognized that most agencies rarely employ adequately qualified, trained paleontologists at the local or field office level. Of course, this is where most management decisions are made regarding paleontological resources for a particular undertaking. Therefore, until such a time that the agencies employ qualified paleontologists at local or field office levels, the recommendations made by the qualified professional paleontologist should be seriously considered unless scientifically sound justification can be made to do otherwise.

Previously Surveyed Areas

It is not uncommon in cultural resources management for previously surveyed areas, such as pipeline ROW or large block survey areas, to be excluded from additional surveys during subsequent proposed developments occurring in the same area. Hypothetically, the previous survey(s) have already identified the resources in the surveyed area, therefore there is no need to resurvey. However, this practice in is not recommended for paleontological resources. First, erosion in some areas can very quickly expose fossils where once there were none. If the archeological methodology was employed, these resources may therefore go unprotected, because according to a previous survey, there are no resources in that area. Alternatively, resurvey of the same area within a year, or even five years for some areas also seems excessive. Perhaps a standard time frame should be established to help land and resource managers determine which areas require resurvey.

Lastly, it does not seem logical for existing localities to necessarily require avoidance. For example, during a survey a specimen was found in the ROW of a project. The specimen was salvaged in order to allow the project to continue along the proposed route. Several years later, a new project passes through the same area. Now, file searches reveal that a paleontological resource locality is within the proposed route. In this hypothetical situation, many lead agency resource managers would call for avoidance of the locality and a reroute of the proposed action. However, in this case the specimen, which is the paleontological resource that is being protected, has already been removed. The locality is not a paleontological resource, and does not (by itself) warrant protections. Clearly, if there are additional specimens discovered at the locality or it has some other contextual significance, then avoidance may be reasonable. Otherwise, there should be no reason to treat a locality as if it were a paleontological resource.

CONCLUSIONS

Paleontological resources are our unique and non-renewable natural heritage. These resources have contributed to our scientific knowledge and our imaginations. Agencies, and perhaps even society, are beginning to recognize that these residues of biology and geology warrant protection and preservation. The growing practice of mitigation paleontology demonstrates the increasing recognition that these resources are invaluable. As in all growing practices, there comes a juncture at which standards and best practices must be developed in order to ensure that necessary tasks are completed appropriately and that all required data is properly documented. The importance of having qualified individuals conducting field assessments and properly collecting the paleontological resources and critical contextual data cannot be stressed enough. With hope, this document, and indeed this volume, will begin to establish the basic standards with which to conduct mitigation paleontology.

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ARTICLE

THE DEMOGRAPHICS OF MITIGATION PALEONTOLOGY: RESULTS OF AN ONLINE SURVEY

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Mitigation paleontology is a rapidly evolving subfield of paleontology which is focused on the management, recovery, and preservation of fossils and associated data threatened by human activities. In order to discuss the need for and benefits of developing best practices in mitigation paleontology, a meeting of over 40 individuals with interest and/or employment in this field was held at the 2013 annual meeting of the Society of Vertebrate Paleontology (SVP) in Los Angeles, California. During this meeting, there was discussion of the need for a survey of those involved in mitigation in an attempt to learn more about the demographics of mitigation paleontologists. The purpose of the survey was to gather information that will be useful to mitigation paleontologists, land managers, and policy makers, including current practices, development of best practices, and interest in forming a professional organization. An overview of the survey results is shared here for those who are interested in learning more about mitigation paleontology, its contributions to the science of paleontology, and its growth as a source of employment for paleontologists.

The survey questions were developed, put into SurveyMonkey, and reviewed by the authors as well as by other members of the Mitigation Paleontology Working Group. The online survey request was sent via e-mail to over 100 individuals that were identified as being involved with mitigation paleontology as a consultant, museum or agency employee, and/or land manager. Those that were identified as consultants primarily consisted of mitigation paleontologists that perform a large range of paleontological resource activities (i.e. field work to technical report review); the larger group of field technicians/field monitors was not the primary target of this survey. This survey, conducted from December, 2013 to January, 2014, consisted of 32 questions which were designed to cover the following topics: contact information (Q1), individual education and experience/expertise (Q2–Q6), the level of expertise field mitigation paleontologists should have (Q7), firm/independent details including states worked, number of employees and projects, bulk matrix and fossil collection and repository details (Q8–Q23), questions about a professional mitigation paleontology organization and licensing (Q24–Q29), and requests for additional information including contact information for other mitigation paleontologists, details about publications including fossils from mitigation projects, and general comments (Q30–Q32).

A total of 70 persons responded to the survey, a high rate of return, which we interpret to be a the result of a high interest level in the topic.. Eight respondents chose to participate anonymously. Individual answers for the anonymous respondents were included in the survey results reported here except for one individual who left the majority of the questionnaire blank and three who did not identify themselves as Mitigation Paleontologists (MPs) and whose affiliation could not be determined. Information relating to company (firm) data was excluded from all but two of the eight because it was either incompletely or erroneously answered. When more than one response was received for a firm, the response for the most senior staff member (or firm representative) was used. For all individuals who answered “I am NOT a mitigation paleontologist, but I work in a related field (such as student, government agency, museum curator, etc.)”, their responses were not included in the company responses below (which include independent consultants). It should be recognized that while a number of agency paleontologists engage in mitigation-related activities for federal or state lands including but not limited to surveys and reporting, the responses by this group were not consistent and difficult to compare with those of privately employed MPs. Details from portions of surveys that were not fully completed were excluded. For example, if pounds of matrix screen washed in 2013 were included, but the firm representative did not report projects, the bulk matrix data was not included; or if a firm representative stated there were 0 projects in 2013, the number of employees was not included since they did not technically work on mitigation paleontology projects in 2013. Percentages provided below were determined based on the number of individuals that answered the question or series of questions, not on the number of surveys completed.

Of the 66 responses summarized here for individual information, 23 did not identify themselves as MPs, but rather as persons who work in a related field (such as student, government agency, museum curator, etc.) (Fig.1). A total of 43 individuals (62%) identify themselves as pro-

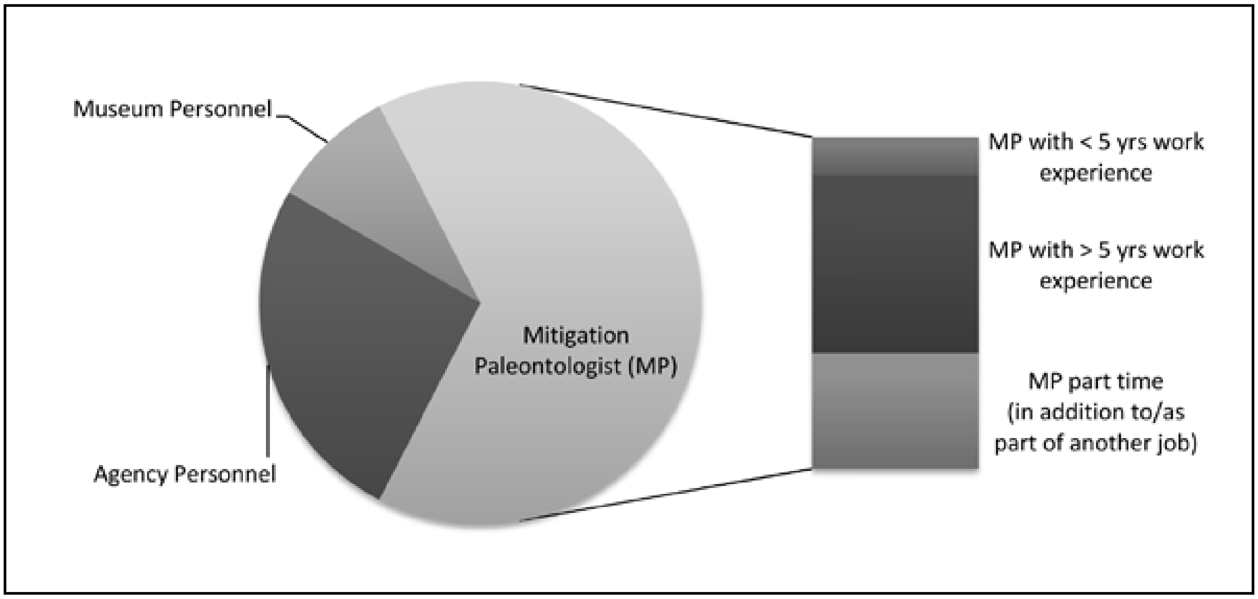

Figure 1. Survey respondent's job demographics and experience levels.

fessional MPs: with more than 5 years of full-time work experience (N=23), with fewer than 5 years of full-time work experience (N=5), or as working in mitigation paleontology in addition to, or as part of, another job such as museum curator or professor (N=15). Overall for MPs and non-MPs, 41% of the respondents (N=27) have doctoral degrees, 42% (N=28) have master's degrees, and 15% (N=10) have bachelor's degrees (Fig. 2). These percentages are similar for only MPs at 44%, 42%, and 12%, respectively. Interestingly the question "In what discipline/field is your highest degree?" was one of the most difficult to summarize. Even individuals with similar university backgrounds responded to the question slightly differently. The majority (58%) of the 66 respondents indicate the discipline/field of their highest degree as geology or geology/paleontology (each 29%), 12% indicate biology or biology/paleontology, 11% indicate paleontology, and 9% anthropology or archeology. Other fields/disciplines include electronic technician, teaching, history, mathematics, and museum science. For the 43 MPs that responded, the results were generally similar, although a higher percentage reported paleontology (16%) and biology (14%) and a lower percentage reported anthropology or archeology (7%).

When indicating their specialty in paleontology, 27% (N=18) of respondents selected more than one specialty, some chose to write in a response, and 8% (N=5) did not select a specialty. The majority of respondents (~83%, N=55) consider one of their specialties to be vertebrate paleontology, followed by invertebrate paleontology (~20%, N=13), micropaleontology (~15%, N=10), and paleobotany (~2%, N=4) (Fig. 3). Other 'specialties' that were written in include: ichnology, preparation, stratigraphy, biostratigraphy, fossil geochemistry, as well as public land and/or resource management and protection. For MPs only, the percent of respondents selecting each of the specialties varied slightly: ~73% (N=38) vertebrate paleontology, 15% (N=8) micropaleontology, ~8% (N=4) invertebrate paleontology and ~4% (N=2) paleobotany. A review of the results suggests that 'micropaleontology' was likely interpreted in multiple ways. Micropaleontology was intended to cover microscopic fossils (i.e. forams); but in some cases respondents interpreted micropaleontology to include 'screenwash' specimens.

Not surprisingly, the education and expertise of the respondents, as outlined above, correlates closely with the training and experience respondents think are necessary for mitigation paleontology field personnel (paleontological monitors/surveyors). Sixty-two percent think that training and experience in vertebrate paleontology necessary to identify vertebrate specimens to element and higher level taxonomy (Order or Class) is needed, and 38% think that lower levels of training and experience are adequate. For invertebrate paleontology those numbers are 48% vs. 52%, and for paleobotany they are 31% vs. 69%. In addition, 79% of respondents think field paleontologists need to have the training and experience necessary to measure a detailed stratigraphic section, and a number of detailed comments supported this opinion with additional details and examples. When the results of only the MPs are considered, the general trend remains. However, for each of the four categories, the percentage that thinks a 'higher' level is needed decreased slightly: 54%, 34%, 20%, and 77% respectively; whereas within non-MP respondents (i.e., museum and agency personal), the percentage increases in each of the four categories, with at least 50%

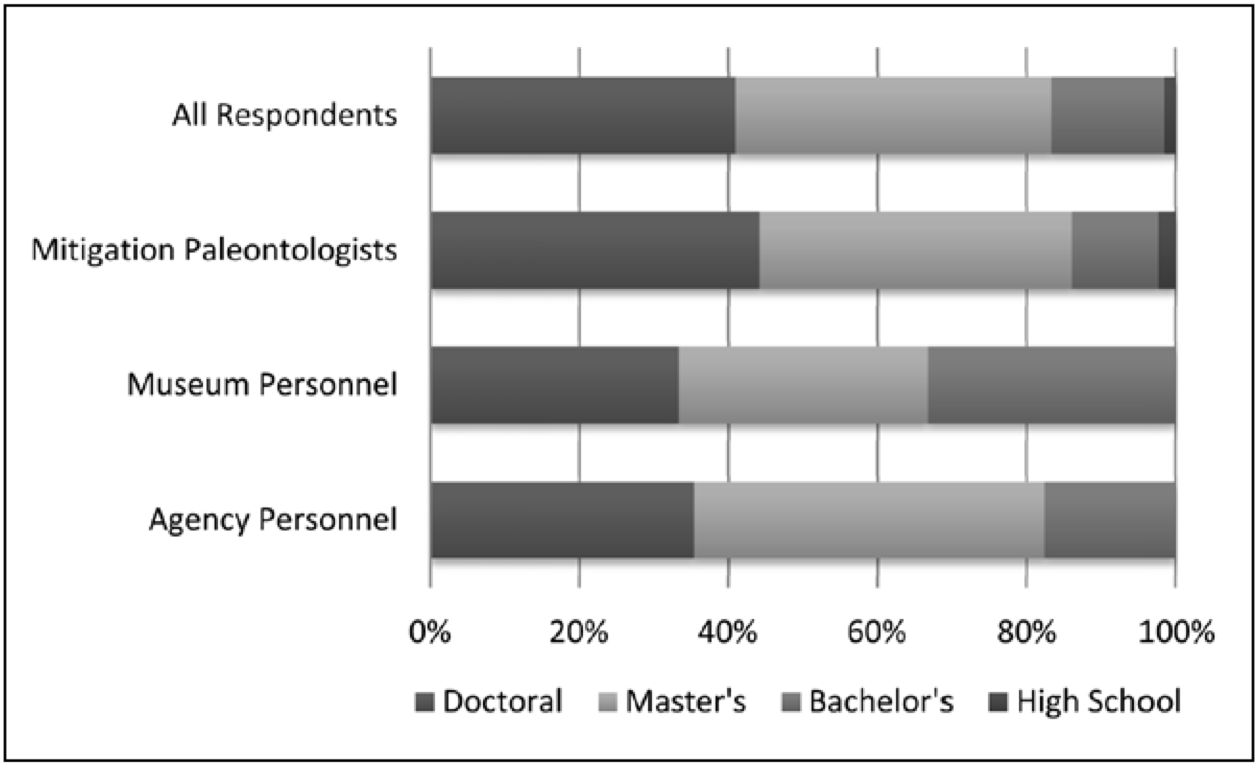

Figure 2. Highest degrees earned by professional category.

of respondents selecting that a 'higher' level is needed.

Of the 43 individuals that identify themselves as MPs or part-time MPs, all expressed experience with at least one of the mitigation paleontology activities listed (Fig. 4). These, activities order from most to least by number of individuals, are: conducting field surveys (N=42), paleontological monitoring (N=41), laboratory preparation (N=39), salvage of specimens discovered during construction (N=39), preparation of pre-construction paleontological resource impact assessments (N=38), preparation of post-construction final reports of paleontological resource mitigation programs (N=36), museum accessioning and curation of salvaged specimens (N=35), project management (N=33), review and critique of final reports of paleontological resource mitigation programs (N=29), and preparation of NEPA/CEQA documents (N=28). This information, along with responses to education, and number of employees per firm, suggests that the survey was primarily completed by MPs that are not field technicians/field monitors, and are at least in part responsible for managing projects and/or other employees.

As anticipated, the state where the highest number of firms have conducted fieldwork is California (N=12), followed in order by Nevada; Wyoming; Utah and Arizona; Montana and Colorado; New Mexico; Idaho; Oregon, North Dakota, and South Dakota; Washington; Nebraska and Texas. Unexpectedly, the number of firms that have conducted non-field based projects was similar, only fluctuating by one firm in most states (NV, WY, AZ, CO, OR), by two in SD, and by three in NM. In addition, Oklahoma was added to the list for non-field based projects. Three firms have worked on field- and non-field-based paleontological resource mitigation projects outside of the United States; one in seven Canadian provinces, one in South America and Central America, and one specifically in Chile. Over the past five years (2009-2013), the total number of projects (402, 547, 631, 565, and 490 respectively) and active firms (15, 13, 14, 16 and 17 respectively) has fluctuated. The approximate number of projects per firm has varied as well, from an average of 26 projects per firm in 2009 to 45 projects per firm in 2011. Interestingly, this past year, 2013, was on the low end with roughly 28 projects per firm. It must be pointed out that project size is significantly variable (likely a few acres up to thousands of acres). Therefore, the implications of these numbers must be taken with a grain of salt. In addition, there are at least two areas (the Uinta Basin of UT and Piceance Creek Basin of UT and CO) that skew the data because the majority of projects are single well pads or small linear projects, and there has been a lot of work in these areas during the past five years as a result of increased oil and gas drilling. Generally, active mitigation firms worked on an average of 27 (2009) to 45 (2011) separate projects per year; or 16 (2009 and 2013) to 20 (2011) separate projects per year if the 'Uinta/Piceance' type projects are modified to a more realistic level by removing a percentage (~85%)

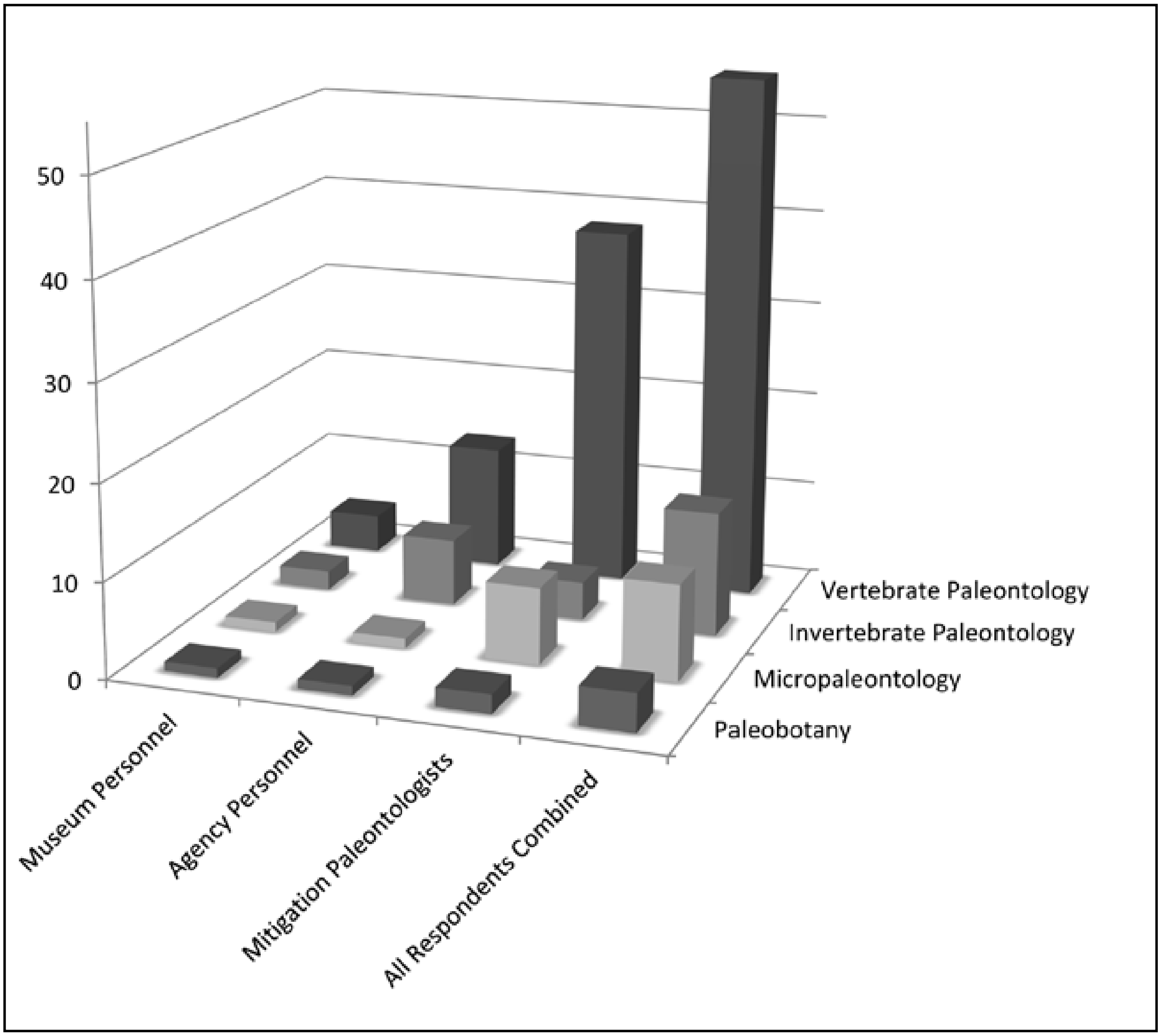

Figure 3. Respondent's top four paleontological specialties.

of projects from the two firms with the highest number of projects in this area. The data obtained from this survey indicates that 2010 and 2011 were the busiest of the years sampled in the 'Uinta/Piceance basin' area.

Of the 17 firm representatives that reported projects in 2013, the number of individuals who worked part-time or full-time doing only mitigation paleontology was approximately 103, and 50 additional individuals did some mitigation paleontology but another discipline made up the majority of their workload. This number of employees (N=153) equates to roughly six part- or full-time MPs and three other individuals per firm.

In 2013, more than 300,000 pounds of bulk sedimentary matrix was collected to process (screenwash) for small fossils. Five (29%) of the 17 firm representatives with projects in 2013 did not collect matrix for screen washing. The amount (pounds) collected by representatives of the other 12 firms ranged from 5 to 250,000 pounds, with the majority of the respondents reporting a few hundred to a few thousand pounds. As with a number of other questions within this survey, the data may vary drastically by year, based on ongoing projects, the economy, weather, and other factors. Specifically in regard to questions about bulk sampling, the 250,000 pound entry stands out. From a review of this individual record it is apparent that this represents an 'unusual' large project that required the collection of large amounts of sediment. While projects like this occur from time to time, they are unusual. The number of scientifically important fossils obtained via wet-screening efforts in 2013 from the 12 firms with employees that collected some bulk matrix varied from none (2 or 16%) to >1,000 (4 or 33%).

Overall, in 2013, more than 5,000 fossils were salvaged during mitigation paleontology projects. Four of the 17 firms that responded to this question reported zero specimens curated, four firms reported fewer than ten speci-

Institution	City	State or Provence
Buena Vista Museum of Natural History and Sciences	Bakersfield	California
California Academy of Sciences	San Francisco	California
John D. Cooper Center	Santa Ana	California
Natural History Museum of Los Angeles County	Los Angeles	California
San Bernardino County Museum	Redlands	California
San Diego Natural History Museum	San Diego	California
University of California	Merced	California
University of California Museum of Paleontology	Berkeley	California
Western Science Center	Hemet	California
Denver Museum of Nature and Science	Denver	Colorado
Museum of Western Colorado	Fruita	Colorado
New Mexico Museum of Natural History and Science	Albuquerque	New Mexico
Florida Museum of Natural History	Gainesville	Florida
South Dakota School of Mines Museum of Geology	Rapid City	South Dakota
Tate Geological Museum, Casper College	Casper	Wyoming
Natural History Museum of Utah	Salt Lake City	Utah
Utah Field House Museum of Natural History	Vernal	Utah
Royal Alberta Museum	Edmonton	Alberta
Royal Tyrrell Museum of Paleontology	Drumheller	Alberta

Table 1. Institutions where mitigation fossil collections were reposited (curated) during 2013.

mens curated, three firms reported between 11 and 100 specimens curated, and six firms reported greater than 100 specimens curated (this includes the 4 firms listed above that had more than 1,000 fossils from screen washing). This very roughly equates to six scientifically important fossils curated per project in 2013. However, realize that this does not account for all important (or significant) fossils found since some projects do not allow collection due to ownership (some tribal and private land) or resource avoidance strategies and includes at least four firms that reported large collections from screen washing operations. A likely more realistic look at this information would come from individual firm responses, but that is also difficult to tease apart. The specimens collected in 2013 by MPs were curated into 19 institutions (Table 1). It should be noted that a number of other institutions are known to accept fossils from mitigation projects, but were not included in the survey results as they did not receive specimens in 2013.

While an estimate of the amount paid for museum repository/curation/storage in 2013 was requested, the results are difficult to interpret and summarize in a meaningful way. It can be noted that for the 13 firms that curated fossils, the fees charged varied greatly (roughly $0 to $15,000 per firm) based on a large number of factors. While these were not clear in the responses, they likely include the number of fossils, their condition and size, the details of the curation agreement, and the needs and locations of curation facilities. According to 10 of the 20 firms that responded, some of the institutions that curate mitigation paleontology collections (including facilities in addition to those listed above) do not require fossils to be fully prepared prior to delivery and others require no preparation at all. The details about preparation requirements are variable. A few specific notes on institutional preparation requirements include the following: full preparation is required; prepared to the point of identification (some specifically state to the family and or generic level); provide fossils in field jackets unprepared (for volunteers to prepare); details may be negotiable.

Ten firms (43%) have completed field-based mitigation paleontology projects on privately owned lands outside of California. Five of these firms stated that for non-California projects, the private land owners were (at least sometimes) involved in mitigation decisions (salvage, avoidance, curation, etc.); two firms did not indicate if the land owners were involved or not. For the five firms with projects where land owners involved, the estimated percent of land owners who decided to donate the recovered fossils to a public museum varied dramatically from approximately 5% to 100%. While not addressed specifically by survey questions, it is expected and inferred from other survey answers that this decision commonly varies by project location (i.e., state) and possibly year the surveys were conducted.

The majority of respondents (93% of MPs and 83% of others) reported that they would likely participate in an organization of professional mitigation paleontologists. More than half (54%) think that this organization should be an independent organization affiliated with the Soci-

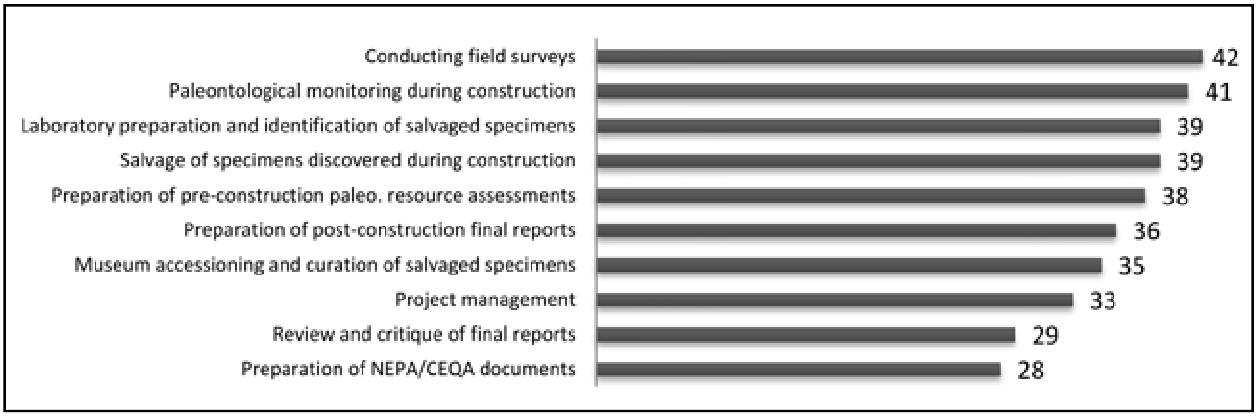

Figure 4. Mitigation paleontologists' (N=43) experience in common mitigation paleontology work categories.

ety of Vertebrate Paleontology (SVP), Geological Society of America (GSA), Paleontological Society (PS), and/or other scientific societies, whereas 44% think that this organization should be a sub-organization within SVP, and 2% think it should be a sub-organization within a society other than SVP. While results about participating within an organization were similar between MPs and others, the preferred venue for the organization varies significantly between MPs and others as the large majority (75%) of museum personnel prefer an independent organization over a sub-organization.

Of the 40 MPs that responded, 36 (90%) indicated that, if sponsored by an organization of mitigation paleontologists, they would likely participate in a voluntary certification or registration of professional mitigation paleontologists. Of other respondents, 67% of agency personnel and 100% of museum personnel indicated that they would participate in such an organization. Eight respondents, five MPs with greater than five years' experience (or 13% of all MPs) and 20% of agency personnel, report that they are registered professional geologists in one or more of the following states: California (2), Kansas (1), Oregon (1), Utah (4), and Wyoming (3). Eleven of the fifty-eight respondents (19%) think that mitigation paleontologists should be registered professional geologists. However, this is variable by respondent type and includes no MPs with less than five years of experience, one museum person, five experienced MPs, and five agency people.

In addition to the survey responses summarized above, this project also initiated an effort to compile a comprehensive database of peer reviewed scientific publications, theses, and dissertations that include fossils collected from impact mitigation projects. Respondents reported that hundreds to thousands of specimens collected via mitigation have been included in peer-reviewed, scientific publications or graduate theses and/or dissertations, and the number of such publications is estimated to be in the hundreds, although the compilation is ongoing. Additional information on this topic will be presented at a later time.

More than one half (36, or 52%) of respondents left comments, questions, or suggestions, including some lengthy commentary and some strongly worded opinions. In addition to this paper, the survey data along with topics raised by these comments will be discussed during the round-table meeting at the Mitigation Paleontology Symposium at the 10th Conference on Fossil Resources. Information and feedback provided by participants will be used to support the development of best practices in mitigation paleontology (Murphey et al. 2014) and for determining the appropriate 'home' for an organization of mitigation paleontologists.

ACKNOWLEDGEMENTS

Thanks to all those that completed the survey. In light of the anonymity of a handful of respondents and without having sought permission from the rest of the group, the authors chose not to include the names of the survey participants in this paper. Your responses to the survey questions are highly valued and are greatly appreciated.

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Index

Symbols

3D data 53

A

Adams, Jason S 278
Agenbroad, Larry D 10, 111
Aircarft Camera Blimp System 53
Alaska 199
Alaska National Interest Lands Conservation Act 199
Alberta 63
Alberta, Canada 12
Ammolite 63
Ammonite 63
ant hills 57
Antonioni, Michael 173
Archaeological Resources Protection Act 43
Armstrong, Harley J 10
Authentic Experiences 36

B

Badlands National Park 19, 44, 116
Bancescu, Jennifer M 12
Beasley, Barbara A 17
Bell, Alyssa 31
Bell, Gorden L Jr 18
Benton, Rachel 37
Bestram, Brent 73
Bilbey, Sue 57
BLM *See* Bureau of Land Management
Blodgett, Robert B 90, 207
Bovee, Marit 39
Boyd, Clint A 19, 116
Brady, Lance R 53
Bredehoeft, Keila E 20
Breithaupt, Brent H 20, 23, 36, 39, 48, 53, 72, 73, 211, 53
Brill, Kathleen A 33
British Columbia 42
Britt, Brooks B 140
Bromley, Craig 25
Bryan, Karina 25
Bugbee, Monica M 10, 111
Bureau of Land Management 10, 22, 23, 36, 43, 53, 73
Burgess Shale 42

C

California 34, 111
Callahan, Wayne R 26, 155
Campbell, Carl E 26
Canada 12, 42, 63
Casual collection 43, 47
Cedar Mountain Formation 38
Ceratopsian 51
Cerruti, Anthony D 28, 44, 67
Chadronian 19
Channel Islands National Park 10, 111
Chemical signature 28, 44, 67, 69, 73
Chesapeake and Delaware Canal 162
Chiappe, Luis M 31
Chure, Daniel J 140
climate 59
Clites, Erica C 31
Code of Federal Regulations 43
Collection Management 56
Commercial collecting 86
Commercial Collection 48
Community College 26, 31
Connors, Tim 32, 61
Cretaceous 26, 38, 47, 51, 72, 162
  Late Cretaceous 26, 155
Cummingsville Formation 105
Curation 56

D

Decorah Shale 104
Delaware 47, 162
Demere, Thomas A 58, 235
Denton, Robert K Jr 26, 155
Devil's Coulee 14
Devonian 191
Di Giacom, Mariana 34, 183
dimensionally complex subjects 53
Dinosaur 14
Dinosaur eggs 14
Dinosaur National Monument 140, 208
Disposition 63

E

Englemann, George F 140
Eocene 19
Equids 62
Ethnic minorities 31
Evanoff, Emmett 33
Exhibition 57

F

Falls of the Ohio State Park 37, 191
Farina, Richard A 34, 183
Federal Land Policy and Management Act 43
Fisk, Lanny H 34, 42, 58, 235, 294
Florissant Fossil Beds National Monument 57
Fossil Cycad National Monument 32, 36, 48, 61
Foss, Scott 35, 232
Freeman, Lisa 37, 191
frogs 20

G

Geographic Information System (GIS) 49, 50
Geologic field course 26
geometric morphometric 20
geosciences 31
Ghist, John M 36, 61, 207
Giesler, Ron 36
Glenwood Formation 103
Goldstein, Alan 37, 191
Good, Thomas R 140
Grandstaff, David E 28, 44, 67, 69
Great Bain National Park 18
Gypsum Cave 62

H

Haasl, David M 34
Hagerman Fossil Beds National Monument 59
Hall, Evan J 57
Hardes, Jonathan G 199
Hell Creek Formation 26, 51
historic photography 33
Horrocks, Rodney 61
Horses 62
Householder, Mindy 37
Howard, Matthew L 38
Hurley, Gretchen L 39

I

invertebrate fossils 31, 63

J

Jordan Sandstone 101

K

Kania, Aaron 73
Keith, Todd 42
Kisiel, James 31
Knauss, Georgia E 42, 58, 235, 294
Knight, Cassi 173
Kootenay National Park 42
Kuizon, Lucia 43

L

Lake Clark National Park & Preserve 90
Lalor, Eve F 44, 67
Lauginiger, Edward M 47, 162
Law enforcement 39, 58, 60, 69, 73
Lee, David A 38
Legislation 63
Leptomeryx 130
Lifelong Learning 36
Liggett, Gregory A 36, 48, 49, 50, 203
Lukens, W E 67
Lutz, Christina M 61

M

Maloney, David F 34
Mamalis, Jim 42
mammoth 10, 111
Manker, Craig R 62
Marks, Lisa M 39
Marshall, Charles R 31
Martin, James E 278
Matthews, Neffra A 20, 23, 49, 53, 72, 211, 53
McDonald, H Gregory 56
Meeteetse Formation 72, 211
Mehling, Carl M 26, 155
Meyer, Herb 57
microfossils 57
Minnesota 72, 99
minorities 31
Mississippi National River and Recreation Area 72, 99
Mitigation 34, 35, 42, 232, 235, 278, 235
Mitigation Paleontology 235 *See* Mitigation
Mojave Desert 62
Monaco, Patricia E 57
Montana 203
Morris, Don P 10, 111
Moses, Randolph J 278
Murphey, Paul C 33, 42, 58, 235, 294
Musteloidea 59

N

Nardinger, Joseph 58
National Parks 18
  Arches National Park 208
  Badlands National Park 19, 44, 116
  Channel Islands 10
  Channel Islands National Park 111
  Glacier Bay National Park and Preserve 208
  Great Bain National Park 18
  Kootenay National Park 42
  Lake Clark National Park & Preserve 90
  Tetons National Park 26
  Yellowstone National Park 26
  Yoho National Park 42
National Park Service 31, 43, 60, 72, 173, 199, 207
Nebraska 67
Nevada 61, 62
New Jersey 26, 155
Noble, Tommy A 53, 53
Nugget Sandstone 140

O

O'Meara, Stephanie 32
Ordovician 99

P

Pagnac, Darrin C 38
Paleoecology 59
Paleontological documentation 53
Paleontological Resources Preservation Act 20, 43, 58

Paleontological Resources Use Permit 20, 49
Paleontology Localities 10
Parris, David C 26, 47, 155, 162
Partnerships 17
Passport in Time 17
Pellegrini, Rodrigo A 47, 162
Permits 10, 63
Petrified Forest National Monument 60
photogrammetry 53, 223
Photogrammetry 53, 211, 220
PIT 17
Platteville Formation 103
Pleistocene 34, 62, 183
Pliocene 59
Poaching 28, 44, 60
Podcasts 23
Pogonomyrymex 57
Potential Fossil Yield Classification 50
Prairie du Chien Group 103
Prassack, Kari A 59
Preparation 17, 37
Prosecution 28
PRPA *See* Paleontological Resources Preservation Act
pygmy mammoth 10, 111

Q

R

Rancholabrean 62
Ranidae 20
rapid prototyping 220
Rare Earth Elements 28
Record keeping 25
Red Gulch Dinosaur Tracksite 23, 53
research 31, 38
Resource Management 37, 49, 53
Resource Protection 28, 37, 39
Reynolds, Robert E 58, 235
Robinson, Peter 57

S

Samuels, Joshua X 20
Santucci, Vincent L 31, 32, 36, 48, 60, 61, 90, 173, 207, 220
Sauce, Uruguay 183
Schaaf, Clinton A 278
Scott, Eric 61, 62
Shelton, Sally 17
Shoup, Bentley E 278
Silsbee, Laura B 50
small mammals 59
South Dakota 19, 51, 67
Spivak, Daniel N 63
Springer, Kathleen B 62
Starck, E N 37
Sternberg, Charles H 48, 86
stilt-legged Equus 62
stout-limbed Equus 62
St Peter Sandstone 103
Strauss, Justin J 58, 235

T

Taphofacies 38
Taphonomy 59
Terry, Dennis O Jr 28, 44, 67, 69
Tetons National Park 26
Trace fossils 22, 39
tracks 22, 211
Tracksite 72
Trujillo, Kelli C 58, 235
Tule Springs 62
Tweet, Justin S 72, 99

U

University of California Museum of Paleontology (UCMP) 31
Unmanned aircraft systems 53
Unmanned Aircraft Systems 223
Uruguay 34, 183
US Fish and Wildlife Service 43
US Forest Service 43
Utah 38, 140

V

vandalism 60
Visitor Interaction 37

W

Wagner, Hugh M 34
Walker, Lindsay 57
Wegweiser, Marilyn D 72, 73, 211
Welsh, Ed 19, 116
Wilkins, W Justin 10, 111
Willow Creek Hoodoos 14
Willwood Formation 73
Wood, John R “Jack” 220
Wyoming 23, 39, 67, 72, 211

X

Y

Yann, Lindsey 57
Yellowstone National Park 26
Yoho National Park 42

Z