VERTEBRATE PALEONTOLOGICAL RESOURCES FROM NATIONAL PARK SERVICE AREAS IN NEW MEXICO

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Abstract—Vertebrate paleontological resources are well documented from three National Park Service areas in New Mexico. Baseline paleontological resource inventories undertaken at Carlsbad Caverns National Park, Chaco Culture National Historical Park and White Sands National Monument have yielded important information on each park's vertebrate fossil record. Late Cretaceous marine and terrestrial vertebrates are preserved at Chaco Culture National Historical Park. Important assemblages of Pleistocene and Holocene vertebrate fossils are well documented from caves at Carlsbad Caverns National Park. An extensive Late Pleistocene megatracksite, consisting of thousands of vertebrate ichnofossils, has been documented in and around White Sands National Monument. A fourth NPS unit, Salinas Pueblo Missions National Monument, may have yielded mammoth remains, but the report is equivocal.

INTRODUCTION

The vertebrate paleontological resources in the national parks and monuments of New Mexico shed light on the fossil record of the American Southwest. Fossils are recognized as non-renewable resources that possess both scientific and educational values. The National Park Service (NPS) manages fossils together with other natural and cultural resources for the benefit of the public. All fossils from NPS areas are protected under federal law, and their removal, excavation or collection is prohibited except under the terms of a research permit.

A 10-year inventory of paleontological resources was completed for the National Park Service in 2012. This project was designed to identify the scope, significance, distribution and management issues associated with NPS fossils. Through this servicewide effort, paleontological resources were documented from within 240 NPS areas, uncovering a diversity of fossil plants, invertebrates, vertebrates, ichnofossils and microfossils. The focus of this report is the fossil vertebrates from the NPS areas in New Mexico. Based on the service-wide inventory, fossil vertebrates have been documented from three parks in New Mexico (Fig. 1): Carlsbad Caverns National Park, Chaco Culture National Historical Park and White Sands National Monument. A fourth NPS unit, Salinas Pueblo Missions National Monument, is associated with an equivocal report of a mammoth.

These vertebrate fossils have been the focus of scientific research, and new discoveries continue to emerge in New Mexico parks. Field inventories at Chaco Culture National Historic Park during the past decade have resulted in the identification of many Late Cretaceous fossil vertebrate localities. A new turtle was discovered and excavated from the Menefee Formation and is currently being studied for description. The caves of the Guadalupe Mountains and within Carlsbad Caverns National Park preserve important and rich assemblages of Pleistocene fauna. The discovery of fossil mammal tracks from the Tularosa Basin has expanded to include large areas within and outside of White Sands National Monument. Thousands of proboscidean, camelid, carnivoran and other mammalian ichnofossils collectively constitute a Late Pleistocene megatracksite in the Tularosa Basin.

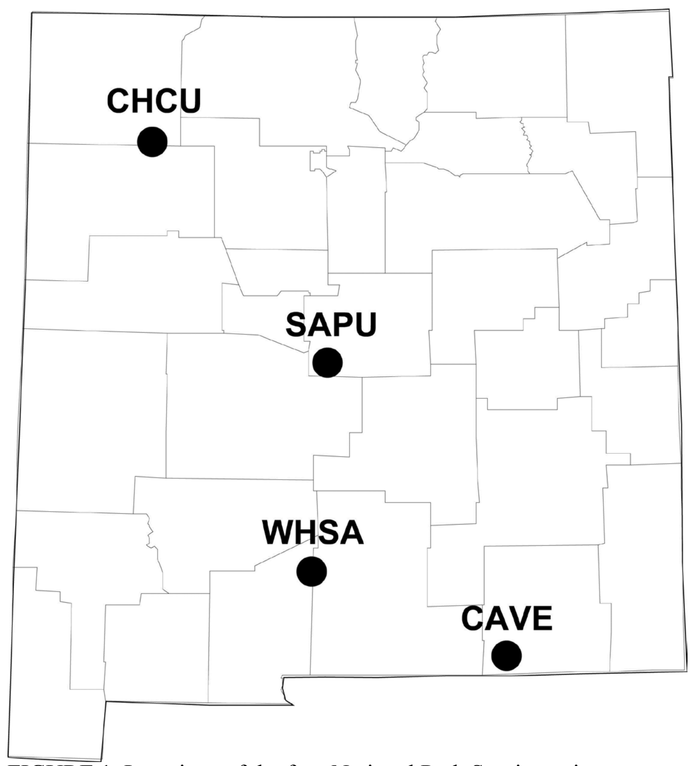

FIGURE 1. Locations of the four National Park Service units mentioned in the text. CAVE = Carlsbad Caverns National Park; CHCU = Chaco Culture National Historical Park; SAPU = Salinas Pueblo Missions National Monument (placement represents the shared center of the three units of the monument); WHSA = White Sands National Monument.

CARLSBAD CAVERNS NATIONAL PARK

Introduction

Carlsbad Caverns National Park (CAVE) was established October 25, 1923 to preserve an outstanding system of caves, the most famous being the namesake Carlsbad Cavern. The park contains 119 known caves with over 290 km of passages and rooms. CAVE includes 18,925 ha, of which 13,405 ha are designated wilderness. At the surface, CAVE elevations range from 1,095 to 1,985 m and include uplands derived from ancient Permian reefs and diverse incised canyons. CAVE was designated a World Heritage Site on December 6, 1995, based upon the remarkable geology exposed both above and below the surface.

Geology

The extensive Permian reef complex exposed in the cliffs and canyons of the Guadalupe, Apache, and Glass Mountains developed between 260 and 270 million years ago. The principal reef is referred to as the Capitan Reef and is exposed both above and below the surface at Carlsbad Caverns National Park and at the surface at Guadalupe Mountains National Park to the southwest in Texas. The reef limestone is named the Capitan Limestone. It is up to 550 m thick, and is expressed at the surface as a landform hundreds of km long and 3 to 5 km wide. The Capitan Limestone reef consists of a framework of algae, sponge and bryozoan fossils supporting a matrix of unbedded fine-grained limestone. This barrier reef formed around the perimeter of the Delaware Basin during the Permian, continuing for over 480 km. Behind the barrier, back-reef limestones formed; these are now the Artesia Group (including the Tansill, Yates, and Seven Rivers formations). They are prominently bedded and contain a high percentage of locally eroded silt as well as gypsum (Palmer, 1995). The geology and paleontology of the Capitan Reef of the Guadalupe Mountains has been the focus of intensive scientific research (e. g., Girty, 1908; Crandall, 1929; Lloyd, 1929; Blanchard and Davis, 1929; King 1942, 1948; Adams and Frenzel, 1950; Newell et al., 1953; Hayes, 1964; Hill, 1987, 1996).

Vertebrate Paleontology

A large diversity of Pleistocene/Holocene vertebrates has been documented from the caves within Carlsbad Caverns National Park (Santucci et al., 2001, 2007). Fossil remains are known primarily from Carlsbad Cavern, Lechuguilla Cave, Slaughter Canyon Cave, and Muskox (or Musk Ox) Cave. Thirty-six species have been identified from the park caves, including 16 species that are now extinct or locally extirpated. Remains of Pleistocene shrub oxen, pronghorns, an extinct cheetah-like cat, mountain goats, dire wolves, shrews, marmots, horses, an extinct vulture, and numerous other vertebrates are among the bones found in the caves.

Many specimens, representing numerous bat species, have been discovered in Lower Cave, the scenic rooms, the Big Room and a number of other areas within Carlsbad Cavern (Baker, 1963). Disarticulated ribs, vertebrae, and foot bones of a juvenile ground sloth (*Nothrotheriops shastensis*) (Shasta ground sloth) were discovered in 1947 within the Lower Devil's Den section of Carlsbad Cavern, and identified by paleontologist Charles Gazin (Smithsonian) in 1948. Additional juvenile ground sloth bones were collected from the same location in 1959 and are believed to be part of the same individual. This bone material provides a uranium series age of approximately 0.1119 Ma (Hill and Gillette, 1987). Although the fossil record of ground sloths in the American Southwest extends back nearly eight million years, into the Hemphillian, the Carlsbad specimen has provided the oldest numerical age for any sloth material. Accumulations of fossils have also been found at the entrance to Carlsbad Cavern. They may have been brought there by Native Americans, and include a variety of mammal ribs and limb bones, rodent skulls and teeth, and skeletal remains of bats and birds (Black, 1953). Radiocarbon ages on organic carbon derived from guano obtained from an old bat roost within the Big Room showed an average age of 45,830 ± 1,366 years before present (B.P.) (Jablonsky, 1999).

There are several reports of fossil vertebrates from Lechuguilla Cave. During January 1988, members of the Lechuguilla Cave Project expedition discovered an articulated and extensively calcified skeleton of *Bassariscus astutus* (ringtail cat) (P. Jablonsky, personal commun., 1993). More recently, approximately 100 bat specimens, including 50 complete skulls, were collected from Lechuguilla Cave between 1990 and 1996 (Jablonsky, 2004). These bat bones date to less than 10,000 years B.P. Seven species from four genera were identified. All of these specimens represent the family Vespertilionidae. *Myotis ciliolabrum* (Western small-footed myotis) was the most abundant inhabitant of Lechuguilla Cave. Interestingly, *Myotis ciliolabrum* has not been found at Carlsbad Cavern, which is 5 km southeast of Lechuguilla Cave. One of the species, *Lasiurus cinereus* (hoary bat), is not commonly found in caves. *Corynorhinus townsendii* (western big-eared bat) prefers shallow gypsum caves or roosts in entrances of caves or mines. *Myotis volans* (long-legged bat) prefers rock crevices or trees.

Slaughter Canyon Cave, also known as New Cave, is the source of the holotype (Museum of Comparative Zoology 49076) of the extinct Pleistocene bat *Tadarida constantinei* (Constantine's free-tailed bat) (Lawrence, 1960). To date this bat is known only from Slaughter Canyon Cave. The remains of *Navahoceros fricki* (mountain deer) and other vertebrates have also been collected and identified from Slaughter Canyon Cave. Recent excavations in Slaughter Canyon Cave have recovered thousands of *Tadarida constantinei* bones and fossils of other vertebrates, including the desert tortoise *Gopherus agassizii*, the giant short-faced bear *Arctodus simus*, and *Capromeryx minor*, a miniature pronghorn (Morgan, 2002). A flowstone cap above a trench where bat guano was removed yields an uranium series age of 0.21 Ma on calcite, showing a long history of vertebrates occupying the cave (Polyak and Asmeron, 2002).

An important vertebrate fauna has been reported from Muskox Cave (Logan, 1977, 1978, 1979). The fossil material represents an assemblage of Late Pleistocene vertebrates that apparently died after being trapped in a large sinkhole. This cave was first discovered and entered in 1954 by a small group led by Park Ranger Patterson. The party collected a number of bones during this first reported entry, which were identified by Charles Gazin as the remains of a horse, a small artiodactyl, a bovid, a large dog, and a bobcat-like small felid. The cave was revisited in February 1969 by a small group led by Park Naturalist Bullington, who reported "literally thousands of small disassociated bones." A few vertebrate fossils were collected from the cave and identified by paleontologist Ernest Lundelius (University of Texas, Austin) as bones of a shrub-ox (possibly *Euceratherium*), a horse, and a small pronghorn (Logan, 1979).

Muskox Cave was mapped by members of the Cave Research Foundation during 1975 and 1976, and numerous new passages were discovered. During this mapping project, a skull and associated skeleton of the shrub-ox *Euceratherium* cf. *sinclairi* was found in a small pool at the base of a breakdown slope, and a dire wolf skull was found embedded in the floor of the cave near the pool (Fig. 2) (Logan, 1977, 1979). The shrub-ox specimen and other remains from Muskox Cave are maintained in the collections of the Smithsonian National Museum of Natural History (Fig. 3). Other skeletal remains observed during visits to the cave included fossils of *Equus, Bassariscus*, *Spilogale* (skunk), and *Neotoma* (woodrat). The skeleton in the pool and other vertebrates from the cave were collected by a joint field party from the Smithsonian Institution, Texas Tech University, and the National Park Service during July 1976 (Logan, 1979). A follow-up collecting effort was undertaken in April 1977. Jass et al. (2000) reports on the discovery of an *Oreamnos harringtoni* (Harrington's Mountain Goat) from Muskox Cave.

Small numbers of bat and other vertebrate bones are known from numerous other caves within the park but have not been studied (Figs. 4–5). Other significant paleontological resources are known from caves adjacent to, but outside of, Carlsbad Caverns National Park. For example, Big Manhole Cave is on Bureau of Land Management lands just a few hundred feet from the CAVE boundary. This cave has Pleistocene fossils of birds, shrews, rodents, rabbits, carnivorans, horses, deer, pronghorns, bison, and camels (Harris, 1993), and Holocene vertebrate remains of toads, lizards, snakes, birds, insectivores, rodents, bats, rabbits, and small carnivorans (Lear and Harris, 2007; Carraway, 2010).

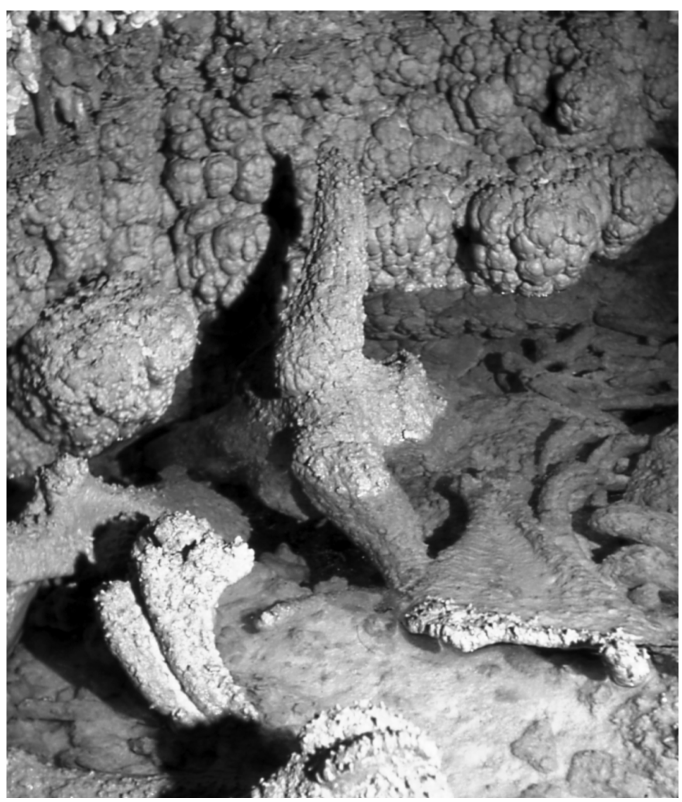

FIGURE 2. The in situ remains of a shrub-ox preserved in Muskox Cave, Carlsbad Caverns National Park (photo by Ron Kerbo).

FIGURE 3. The skull of a shrub-ox recovered from Muskox Cave, Carlsbad Caverns National Park in the collection of the Smithsonian National Museum of Natural History (photo by Vincent L. Santucci).

FIGURE 4. Fossil bat encased within flowstone at Carlsbad Caverns National Park (NPS photo).

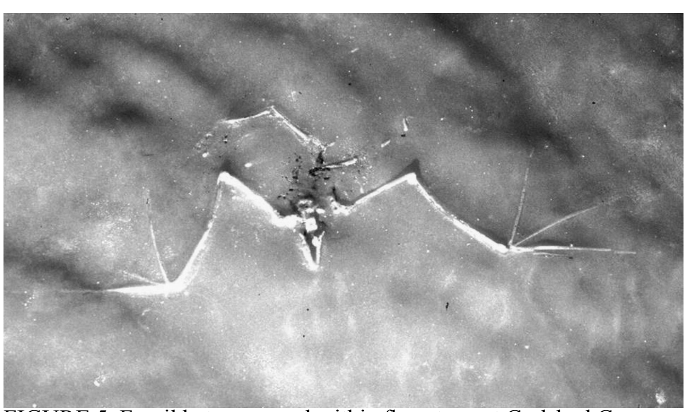

FIGURE 5. Fossil bat preserved within flowstone at Carlsbad Caverns National Park (NPS photo).

CHACO CULTURE NATIONAL HISTORICAL PARK

Introduction

Chaco Culture National Historical Park (CHCU) was established to protect hundreds of sites built by the ancestral Puebloans. Chaco Canyon was a major cultural center from approximately 900 to 1150 A.D., and construction includes multi-story great houses with hundreds of rooms (Fagan, 2005). CHCU was proclaimed as Chaco Canyon National Monument March 11, 1907, and was redesignated as Chaco Culture National Historical Park December 19, 1980. It became a World Heritage Site December 8, 1987. CHCU encompasses 13,743.20 ha. The great majority of the land is found in one main unit, with three smaller units. The nearest of these is the Kin Bineola unit, 5.5 km to the west-southwest of the main part of the park, followed by Pueblo Pintado, 16 km to the southeast, and Kin Ya'a, 37 km to the southwest. Because the main unit of CHCU is so much larger than these outliers, references will be to this unit unless otherwise stated.

Geology

CHCU is located in northwestern New Mexico near the southwestern margin of the San Juan Basin. The San Juan Basin is an early Cenozoic structural basin formed over part of a larger Cretaceous depositional basin (Molenaar, 1977). CHCU is about 72 km southwest of the center of the basin (Scott et al., 1984). The geology and paleontology of CHCU and surrounding Chaco Canyon have been described in a number of publications (e. g., Bryan, 1928, 1954; Lease, 1971; Siemers and King, 1974a, b; Love, 1977, 1979; Hall, 1977; Betancourt and Van Devender, 1980a, 1980b, 1981; Schneider and Mytton, 1981; Mytton, 1982; Betancourt et al., 1983; Gillespie, 1984; Miller, 1984; Harris, 1988; Donselaar, 1989; Betancourt, 1990; Benson et al., 2003; Force and Vivian, 2003); maps (e. g., Scott et al., 1984; Mytton and Schneider, 1987; National Park Service, Geologic Resources Division, 2007), dissertations and theses (e. g., Vann, 1931; Hall, 1975; Love, 1980), and National Park Service documents (Gould, 1938; KellerLynn, 2007; Tweet et al., 2009).

During the Late Cretaceous, multiple marine transgression-regression cycles of differing durations and extents occurred, forming the Western Interior Seaway of western North America (Aubrey, 1991). The San Juan Basin subsided in several pulses tied to a contemporaneous Laramide orogeny mountain-building event after 80 Ma (Cather, 2003). The waters that submerged the San Juan Basin were warm and advanced from the south, differing from the cool, lower salinity waters moving in from north of the continent (Olesen, 1991). Water depth during the most extensive marine transgression was on the order of 90 to 120 m in the Basin (Molenaar, 1977). Deltas prograded into the seaway over time. The Mesaverde Group, which makes up the majority of the rocks exposed at the surface of CHCU, represents one such large deltaic wedge (Fassett, 1974; Aubrey, 1991). A final period of regression, which ended marine deposition in New Mexico, occurred from 76 to 73.5 Ma, and is partially recorded in rocks present at CHCU (Ambrose and Ayers, 2007). The mountain-building of the Late Cretaceous to early Paleogene Laramide orogeny caused the seaway to withdraw and initiated the formation of the present-day Rocky Mountains (Aubrey, 1991).

Most of the Cenozoic is not represented at CHCU, due to erosion or lack of deposition. Chaco Canyon was incised into the landscape in several stages over the past 300,000 years (Scott et al., 1984). In general there are few traces of humans or megafauna in the Basin from 18,000 years ago until comparatively recently (O'Neill, 1992). Humans are first known in the Basin about 13,000 years ago (Love, 1977), and entered Chaco Canyon before 7,000 years ago (Gillespie, 1984), but the most famous structures at CHCU were constructed much later, between 800 and 1150 AD (Force and Vivian, 2003).

Vertebrate Paleontology

Mesaverde Group: Menefee Formation (Upper Cretaceous)

The Menefee Formation is a heterogeneous rock unit largely made up of sandstone, shale, and coal (Beaumont et al., 1956). It represents a sustained period of continental exposure during the transgressive-regressive cycles of the Western Interior seaway (Aubrey, 1991). The Menefee Formation is time-transgressive, and was deposited approximately 80 Ma at CHCU (Scott et al., 1984). At CHCU the main body of the Menefee Formation is over 50 m thick (Mytton and Schneider, 1987). It is exposed in the valleys of the main CHCU unit (Scott et al., 1984), and forms slopes and ledges in the eastern part of the park (Schneider and Mytton, 1981). The Menefee Formation is also exposed in the western part of the park near Kin Klizhin and to the west, south and southwest of West Mesa, where this unit has eroded into badlands terrain, and in the Kin Bineola unit (National Park Service, 2007).

The Menefee Formation of the CHCU area is divided into the Cleary Coal Member and overlying Allison Member. The Allison Member is further divided into three parts, in ascending order the unnamed lower beds, Juans Lake Beds, and La Vida Beds. The lower beds are heterogeneous and lack coal. The Juans Lake Beds are a sandstone-mudstone unit with some large limy concretions, petrified wood, plant debris, amber, coal and vertebrate bone fragments. The La Vida Beds are also a sandstone-mudstone unit. Petrified wood chunks are common in the La Vida Beds, and coal is present in the upper and middle sections (Miller, 1984). Depositional environments range from fluvial, to swampy deltaic coastal plain, to lagoonal and deltaic at the top (Donselaar, 1989). The upper Menefee Formation at CHCU intertongues with the overlying Cliff House Sandstone (Mytton, 1982).

The terrestrial vertebrates of the Menefee Formation are of interest because of the rarity of nonmarine vertebrates in rocks of similar age in North America (Williamson, 1996; Lewis et al., 2006). Vertebrate fossils were initially discovered in the Menefee Formation at CHCU by Tom Lyttle and Donna Smith (KellerLynn, 2007) and additional material was discovered during the 2011–2013 field seasons. Almost all fossil finds are confined to specific levels of the Juans Lake Beds of the Allison Member. Within the Juans Lake Beds, there are three cycles of mudstone beneath silty sandstone with a calcified or sideritic cap, with the middle cycle being most fossiliferous. Vertebrate fossils are found in mudstones associated with a concretionary zone. The silty sandstone is interpreted as fluvial, while the mudstone is interpreted as delta plains and coastal swamps (T. Lyttle, pers. commun., 2009). The most notable vertebrate fossil known to date is a partial turtle plastron discovered by Lyttle and Smith in 2007 (Fig. 6). It pertains to a pelomedusid (side-necked turtle), and is the first known from the Menefee Formation (T. Lyttle, pers. commun., 2009). The fossil turtle is now stored at the NPS collections facility of the Hibben Center at the University of New Mexico in Albuquerque, New Mexico. Other fragmentary vertebrate fossils have been documented from the Menefee Formation at CHCU, including a rib approximately 40 cm (16 inches) long and some vertebrae (T. Lyttle, pers. commun., 2009; P. Varela, pers. commun., 2014).

FIGURE 6. Freshwater side-necked turtle (Testudines, Pelomedusidae) from the Late Cretaceous Menefee Formation at Chaco Culture National Historical Park (NPS photo).

Mesaverde Group: Cliff House Sandstone (Upper Cretaceous)

The Cliff House Sandstone is a transgressive sandstone recording a time of marine encroachment over the Menefee Formation coastal plain (Miller et al., 1991). It forms the top of the Mesaverde Group's northeast-pointing wedge of sediments (Fassett, 1974; Aubrey, 1991) and represents a shifting strandline (Siemers and King, 1974a). The Cliff House Sandstone records rapid transgression at its base and top, and a relatively stable shoreline in the intervening time (Fassett, 1977). Cycles of lagoons and shorefaces of a barrier island system are present in the southern San Juan Basin (Donselaar, 1989). It is about 77 million years old at CHCU (Siemers and King, 1974a). Four divisions of the formation are present at the park. In ascending order, they are: a 3–30 m thick marine sandstone that forms the cliffs over the ruins on the north wall of Chaco Canyon; a 37 m thick marine sandstone with thin marine shales; a 24–40 m thick sandstone that forms cliffs and ledges; and a 9–18 m thick sandstone, present only south of the canyon (Mytton and Schneider, 1987).

Vertebrate fossils from the Cliff House Sandstone at CHCU include shark teeth, numerous small vertebrae, a turtle plastron (lost to erosion in the late 1990s) and other bone fragments (Siemers and King, 1974a). Shark teeth (Fig. 7) are also common in the intermediate unit, and numerous fragmentary bones from terrestrial vertebrates have been recovered. Cliff House Sandstone fossils at CHCU come from four assemblages: transported beach zone, shallow marine, shallow marine sands, and possible tidal channel fill (Siemers and King, 1974a, b). The beach zone rocks have the most diverse fauna (Siemers and King, 1974a). The current paleontological inventory at CHCU has been able to replicate much of Siemers and King's work. Fossil invertebrate shells, some shark teeth and small bone fragments are contained within a tough concretionary layer (T. Lyttle, pers. commun., 2009).

Lewis Shale (Upper Cretaceous)

The Lewis Shale of the San Juan Basin and surrounding areas is not to be confused with the "Lewis Shale" of northwestern Colorado and Wyoming, which had been named as such because it was mistakenly thought to be correlative (Molenaar, 1977). The San Juan Basin's Lewis Shale is a sandy fossiliferous shale, with a greater sand content as it transitions into overlying and underlying sandstone units (Donselaar, 1989). Limestone concretions are also present (Fassett, 1974), as well as abundant thin bentonite layers from volcanic ash (Scott et al., 1984). At CHCU, the formation is about 30 m thick, and outcrops are mostly shale, with some claystone, siltstone, sandstone, and fossiliferous limestone (Mytton and Schneider, 1987). The Lewis Shale is the offshore marine equivalent of the underlying Cliff House Sandstone (Donselaar, 1989). The Lewis Shale interfingers with the Cliff House Sandstone (Scott et al., 1984), and transitions into the overlying Pictured Cliffs Sandstone through a series of interbedded

FIGURE 7. Cretaceous shark teeth from the Cliff House Sandstone at Chaco Culture National Historical Park (NPS photo).

thin sandstones, siltstones, and shales (Mytton et al., 1981). A widely-distributed bentonite bed within the Lewis Shale, the Huerfanito Bentonite Bed, has been dated to 75.76 ± 0.34 Ma, showing the shale to be Late Campanian in age (Cather, 2003).

Limestone beds in the Lewis Shale at CHCU are fossiliferous (Mytton and Schneider, 1987). A vertebrate tooth and bone fragments are known from the Pueblo Pintado unit, where the exposures are mostly Lewis Shale (T. Lyttle, pers. commun., 2009).

Other

Hay (1908) described the turtle *Naiadochelys ingravata* based on a fragment of xiphisternum (AMNH 6078) recovered from Chaco Canyon, from what he supposed to be Laramie beds (Upper Cretaceous). This specimen may have come from what is now CHCU, but the locality information is too vague to be certain of the location, and Hay received it at least third-hand. Hay (1908) also described another turtle from Chaco Canyon, *Aspideretes singularis*, but this specimen must have come from an area of the canyon outside of CHCU because it is from Paleocene rocks (Torrejon beds, now known as the Nacimiento Formation). It is however of interest in illustrating the history of fossil collection in the area, having been collected by David Baldwin for Edward Drinker Cope in 1883 (Hay, 1908).

Paleontological Collections

There are thousands of fossil specimens in the CHCU natural history and cultural resources collections, the vast majority in the cultural resources collections. The natural history collection has 161 objects under 20 catalog numbers. Of these objects, 130 are fossil shark teeth, ten are unknown fossil bones or teeth, two are fossilized bony fish fragments, and one is a possible mosasaur tooth. Unfortunately, the locality and geologic formation from which these specimens were collected are not available for most of these specimens. 131 of the specimens are cataloged in a single lot of confiscated items (CHCU 95143), and three specimens under two catalog numbers were turned in by visitors (CHCU 79452 and 95433) (K. Beckwith, Western Archeological and Conservation Center registrar, pers. commun. to A. Mims, 2008).

The fossils collected by Siemers and King (1974a) had been housed by the University of New Mexico, Albuquerque, but may have been discarded in the 1980s (KellerLynn, 2007). Barry Kues (Department of Earth and Planetary Sciences, University of New Mexico) could not locate them in the collections of the University of New Mexico in February 2009, and suggests that they were either discarded or removed by Siemers when he left the University in the late 1970s (B. Kues, pers. commun., 2009).

SALINAS PUEBLO MISSIONS NATIONAL MONUMENT

Introduction

Salinas Pueblo Missions National Monument (SAPU) preserves notable examples of 17th-century Spanish Franciscan mission churches and conventos as well as three large Pueblo Indian villages. It was proclaimed as Gran Quivira National Monument November 1, 1909, and renamed Salinas National Monument December 19, 1980. On November 2, 1981, Abó State Monument and Quarai State Monument were incorporated with Salinas National Monument, which in turn was renamed Salinas Pueblo Missions National Monument October 29, 1988. It encompasses 433.59 ha. SAPU is comprised of three units: Abó, Quarai, and Gran Quivira. Measuring from Gran Quivira (the largest unit), Abó is 32 km to the northwest and Quarai is 40 km to the northwest.

Geology

The geology of SAPU has been described in several documents (Chronic, 1987; McLemore, 2000; Ball et al., 2006; Oviatt, 2011, 2012). SAPU is located in central New Mexico, east of the Rio Grande rift. Exposed rocks and sediments in the three SAPU units mostly pertain to Permian sedimentary formations and Quaternary alluvium. Permian rocks exposed at SAPU document shifting environments, from fluvial, to eolian and tidal flat, to shoreface, to shallow marine (Lucas and Ziegler, 2004), over a period of time from ~300 Ma to ~270 Ma (Baars, 1961). Before the sea encroached, early amphibians, reptiles, and synapsids roamed New Mexico (Lucas et al. 2004). The sea retreated shortly after the deposition of the youngest Permian rocks (San Andres Limestone) at SAPU (Harbour, 1970).

A significant unconformity at SAPU eliminates the Mesozoic and most of the Cenozoic. There are Oligocene mafic dikes in the Gran Quivira area (Oviatt, 2012), but for the most part geologic history at SAPU itself does not resume until nearly the present. Between approximately 45,000 and 12,000 years ago a succession of water bodies occupied the Estancia Basin, becoming Lake Estancia after major expansion beginning 24,000 years ago. This lake fluctuated in size several times until it finally desiccated (Allen, 2005). All three units of SAPU would have been close to the western or southern shorelines of Lake Estancia.

Vertebrate Paleontology

During 1939 and 1940, workers with a joint Museum of New Mexico and Works Project Administration archeological and stabilization project at Quarai reportedly uncovered and excavated a complete disarticulated mammoth (Hurt, 1990). This specimen, found during road construction northeast of Quarai (Hurt, 1990), has apparently vanished (Morgan et al., 2001). It is unclear if the site was within SAPU boundaries, and without further documentation, it cannot be included without reservation. It is of interest to note that Pleistocene bones, including those of mammoths, were reportedly common near Punto de Agua, about a kilometer northeast of Quarai (Hibben, 1941).

WHITE SANDS NATIONAL MONUMENT

Introduction

White Sands National Monument (WHSA) was established on January 18, 1933, in order to preserve the world's largest gypsum sand dune fields. The gypsum dune field is within the Tularosa Basin of south-central New Mexico, at the northern end of the Chihuahuan Desert. WHSA encompasses 58,167 ha in the southern part of the dune field.

Geology

Herrick (1900) provided one of the earliest descriptions of the geology of the Tularosa Basin and the origin of the White Sands. Jicha (1954) and Kiver and Harris (1999) presented more recent geologic interpretations of the White Sands, and Herrick (1961) produced a geologic map of the White Sands area. The gypsum dunes have accumulated in a large graben that extends southward to the Texas border and northward to the Malpais basalt flows. The graben is related to a major structural feature known as the Rio Grande rift. The local graben is referred to as the Tularosa Basin graben and is bounded by the San Andres Mountains on the west and the Sacramento Mountains on the east (Baldridge and Olsen, 1989). The Tularosa Basin graben is 60 km wide. The basin is a true bolson, a desert area with internal drainage and no discharge outside of the basin (except through groundwater flow into the Hueco bolson to the south).

The source of the gypsum has been the subject of some scholarly debate. The most likely source seems to be the local Paleozoic formations (LeMone, 1987). During the Paleozoic shallow seas advanced and retreated over the New Mexico area. Thick evaporate deposits were deposited, including the Permian-age Yeso (Spanish for gypsum) Formation, which consists of over 152 m of gypsum. The Yeso Formation is suggested by LeMone (1987) as the most reasonable source of gypsum. The gypsum sand is primarily medium-grained, ranges from angular to subrounded, and has fair to good sorting (LeMone, 1987). A wide variety of dune morphologies are documented at the Monument, including dome-shaped, blowout, parabolic, barchan, and transverse dunes. Dune heights and rates of movement are directly related to morphology. The tallest dunes rise to 20 m in some areas. Winds blow almost constantly from the southwest with velocities reaching gusts of 88 kmph. The northern part of the White Sands dune field grades into yellowish, wind-deposited, quartz sands.

Vertebrate Paleontology

The earliest reference to fossil vertebrates from within White Sands National Monument is a report by Vandiver (1936), who noted the possible occurrence of fossil bones and teeth of a mammoth. Vandiver visited the purported mammoth locality and was able to find only fragmentary bones.

Fossil vertebrate footprints were first reported from the Tularosa Basin in 1932. At that time the traces were proposed to be the tracks of giant humans (Lucas et al., 2002). A fossil track locality on the White Sands Missile Range, the "Big Footprints" site, was investigated on September 11, 1981 by geologists John Hawley, David Love, Donald Wolberg and Adrian Hunt, all then of the New Mexico Bureau of

Geology and Mineral Resources. The field party identified three different types of vertebrate tracks that were preserved as extremely fragile and ephemeral pedestals in convex relief above the ground surface. The tracks were determined to be mammalian and ascribed to camel, proboscidean, and an undetermined mammal (Lucas et al., 2002, 2007; Morgan and Lucas, 2002; Allen et al., 2006).

In 2006, researchers documented extensive mammoth trackways in Pleistocene lake margin sediments within White Sands National Monument (Fig. 8). Many of the tracks were preserved in convex relief. Erosion of the soft gypsum matrix causes rapid deterioration of the tracks. The circular proboscidean tracks from the Tularosa Basin were assigned by Lucas et al. (2007) to the ichnotaxon *Proboscipeda panfamilia*.

Beginning in 2011, a systematic field documentation of vertebrate tracks, representing a megatracksite, was initiated at White Sands National Monument. Hundreds of proboscidean tracks and extensive trackways were discovered and photogrammetrically documented on the southern shore of Lake Lucero in the monument. Additionally, camelid tracks (Fig. 9), a few unidentified artiodactyl tracks, and large and small carnivore tracks (Figs. 10, 11a-b) were also photogrammetrically documented during field inventories.

In 2014, an interagency team of paleontologists, resource managers and aviation specialists from the NPS, BLM, USGS and Department of Defense (DOD) joined together in an effort to document fossilized

FIGURE 8. Late Pleistocene proboscidean trackway at White Sands National Monument (NPS photo).

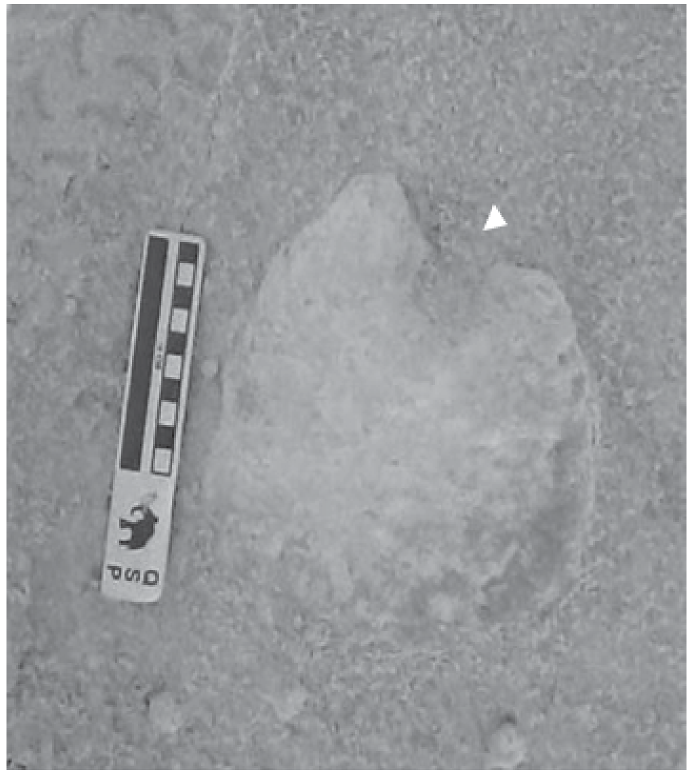

FIGURE 9. Late Pleistocene camelid footprint at White Sands National Monument (NPS photo).

FIGURE 10. Large Late Pleistocene carnivore track preserved at White Sands National Monument (NPS photo).

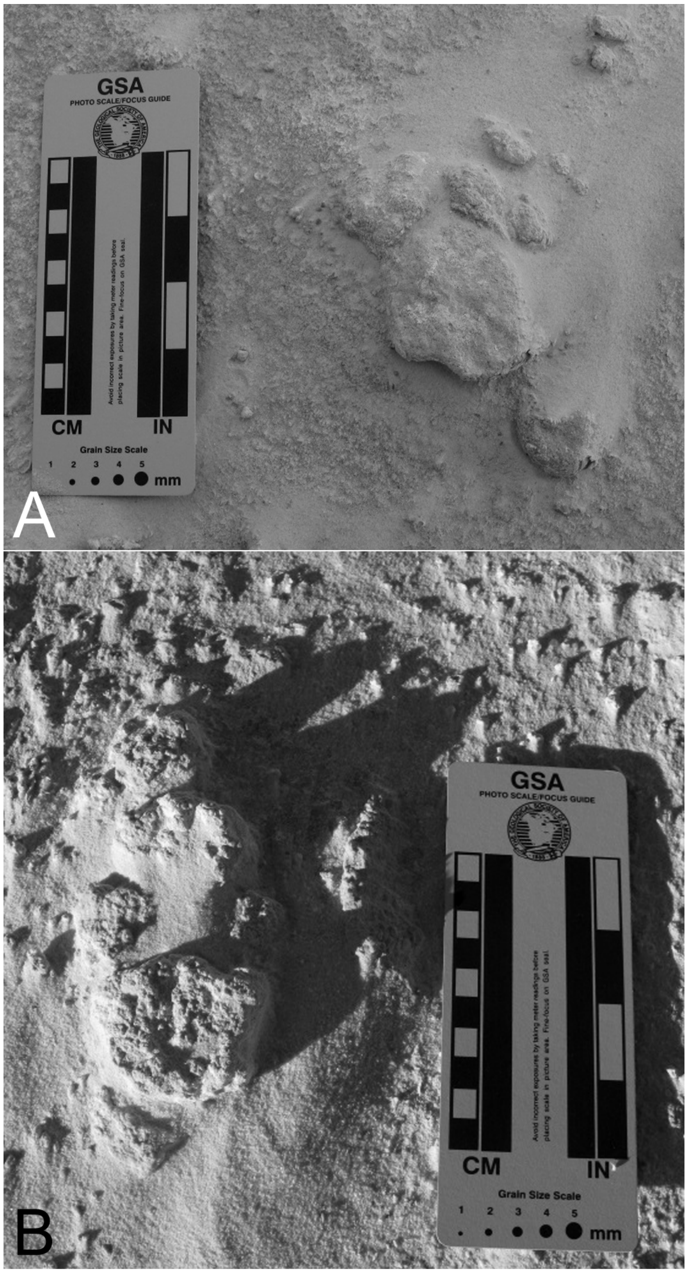

FIGURE 11A-B. Small Late Pleistocene carnivore tracks preserved at White Sands National Monument (NPS photos).

footprints within the WHSA portion of the megatracksite using remote imaging technology (Fig. 12). The DOD provided high resolution satellite imagery for the area of the monument encompassing the megatracksite and authorized the BLM flight crew to fly an unmanned aircraft system – specifically, an RQ-16 Tarantula-Hawk (T-Hawk) – in the DOD-restricted airspace over the monument. The field work in January 2014 represents the first time a T-Hawk platform has been used to support paleontological research and resource management. The aerial photography and videography enabled centimeter-scale resolution and geospatial data collection while minimizing impacts and ground disturbances to the fragile paleontological resources. Additionally, use of the T-Hawk Platform represented a significant time savings by covering larger geographic areas and reducing the need for in-depth field reconnaissance. A strategy including both aerial and on-the-ground photogrammetric documentation has proven to be very successful for this project. The ground base photogrammetry collected sub-millimeter data (equivalent to a laser scanning) of the entire trackways. The extreme precision of the ground-based photogrammetry will allow the tracks to be studied long after they have weathered away and enable the creation of exact 3-D replica models to be produced

FIGURE 12. Interagency team of scientists and technical specialists from the NPS, BLM, USGS and DOD with RQ-16 Tarantula Hawk (T-Hawk) at White Sands National Monument in January 2014. The T-Hawk unmanned aircraft system was equipped with cameras to capture air photos and videos of the Late Pleistocene megatracksite.

for future generations to enjoy and study. The 3-D models will allow millions to enjoy the tracks virtually or in person with no resource damage, truly leaving no trace and protecting the actual location of sensitive fossil localities (Wood and Santucci, 2014).

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