AN OVERVIEW OF THE PALEONTOLOGY OF UPPER TRIASSIC AND LOWER JURASSIC ROCKS IN ZION NATIONAL PARK, UTAH

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Abstract.—The spectacular rocks exposed in Zion National Park in southwestern Utah include fossiliferous units of Late Triassic and Early Jurassic age. In cooperation with the Utah Geological Survey, several National Park Service interns have recently completed a comprehensive inventory of paleontological resources within the park. We have identified over 100 new sites as a result of this project. Terrestrial vertebrate body fossils, including the remains of phytosaurs, aetosaurs, and metoposaurs have been found in the Shinarump and Petrified Forest Members of the Chinle Formation. Dozens of new dinosaur tracksites have been discovered in the Whitmore Point Member of the Moenave Formation, the Kayenta Formation, and the Navajo Sandstone.

The vast area of exposure of these formations in the cliffs and canyons of Zion provides an important resource for ongoing investigations of the paleontology of the St. George region. A number of different modes of track preservation are present, including true tracks, under tracks, natural casts, and track infills. Most of the dinosaur tracks documented are attributable to theropod dinosaurs of the ichnogenera Eubrontes and Grallator, although others, including bird-like tracks and four-toed tracks, are also present. Lacustrine rocks preserving the scales of semionotid fish and dinosaur swim tracks are found in both the Whitmore Point Member of the Moenave Formation and the Kayenta Formation.

INTRODUCTION

Zion National Park is a geological wonderland with over 2100 m (7000 ft.) of sedimentary strata exposed within its cliffs and canyons. These strata were deposited over a period of 275 million years, and record a multitude of environments, including shallow-marine, coastal, desert sand dunes, rivers, and lakes. Many of the rock units at Zion contain fossils. The arid environment of southwestern Utah, coupled with a long history of tectonic activity, means that much of the rock is exposed, allowing paleontologists to find the fossils preserved in these rocks. However, while the amount of rock exposed in Zion is truly enormous, the park is generally not known for its fossils. This is due, in part, to the fact that the large cliffs of Navajo Sandstone, the thickest rock unit in the park and the one primarily responsible for giving Zion its name, and are housed in the park’s natural history collection.

Bones and scutes (dermal armor) belonging to metoposaurs and phytosaurs were collected by Helmut Ehrenspeck from mudstones in the Petrified Forest Member of the Chinle Formation near Cougar Mountain, and are housed in the park’s natural history collection.

The Lower Jurassic Moenave Formation contains scales and bones of the fish Semionotus kanabensis, some of which were recovered from outcrops next to Highway 9 near the bridge over Pine Creek (Hesse, 1935; Schaeffer and Dunkle, 1950; Day, 1967). Stokes and Bruhn (1960) reported dinosaur track fossils from the overlying Kayenta Formation from a site along the Left Fork of North Creek. This site is well known; it is reported in several trail guides and is located along the popular “Subway” hike. The prominent cliff-forming Navajo Sandstone has been reported to contain a few bits of poorly preserved fossil wood and a dinosaur tracksite along the trail to Observation Point (Santucci, 2000). Marine invertebrates including crinoids, pectens, oysters, and other bivalves are known from limestone beds in the Middle Jurassic Carmel Formation (Gregory and Williams, 1947; Santucci, 2000).

Cretaceous sedimentary rocks are found in a small exposure on top of Horse Ranch Mountain in the northwest portion of the park. These rocks have been assigned to the Dakota Formation (Hamilton, 1978), and, more recently, to a possible Cedar Mountain Formation equivalent (Biek et al., 2003). Freshwater bivalves and plant impressions have been reported from this unit on Horse Ranch Mountain (B. Biek, personal commun., 2002). East of the park, the Dakota Formation is known to contain important vertebrate remains (Eaton et al., 1999, 2001). One of the most complete sequences of marine and terrestrial rocks of Cretaceous age is found in the region east of the park (Eaton et al., 1999, 2001); the importance of this sequence was a factor in the establishment of the nearby Grand Staircase-Escalante National Monument in 1996 (Proclamation 6920, 1996). This sequence is not, however, preserved within Zion National Park.

The most recent chapter in the fossil history of Zion is recorded in a series of Quaternary lake deposits. Tracks preserved in these sediments include those of a large heron-like bird and an artiodactyl, possibly a camel (Hamilton, 1995). A single bison vertebra was collected near Trail Canyon (Santucci, 2000). Snails have been collected from lake sediments.
(Hamilton, 1979), and Hevly (1979) analyzed pollen and spores from these sediments.

PRESENT STUDY

In 1997, Aimee Painter and Rex Taylor, two students from Southern Utah University in Cedar City, UT, relocated several paleontological sites in Zion National Park (Anonymous, 1999). Their work was the impetus for further inventory work within Zion.

In the summer of 1999, an additional inventory of paleontological resources within the park was initiated by one of us (JAS, then a National Park Service [NPS] intern and presently a graduate student at the University of Utah). This work continued in the spring of 2000, and again over several weeks in the summer of 2002 to assist another of us (DD, of the Utah Geological Survey [UGS]). Because most of this work was done during the hot summer months, the work was concentrated in the cooler confines of Zion Canyon, with visits to Parunuweap Canyon and the Left Fork of North Creek. In the spring of 2003, the NPS hired another of us (JM, a recent Duke University graduate) as a paleontology intern for three months to continue the inventory work; she was assisted by DD and JK (UGS) for several weeks as well as by volunteers from the Utah Friends of Paleontology. Our work in 2003 took advantage of cooler spring temperatures to concentrate on some of the stratigraphically lower formations, especially the Chinle Formation. Through these collaborative efforts, over 120 new fossil localities have been located within the park. These sites provide avenues for further scientific work, and enable us to make informed predictions about the distribution of fossils in the park’s sedimentary rocks.

GEOLOGIC SETTING

Zion National Park covers 593 km² (229 mi²) in southwest Utah (Figs. 1, 2). The park lies in the transition zone between the Colorado Plateau and the Basin and Range physiographic provinces, within a structural block bounded to the east by the Sevier Fault Zone and to the west by the Hurricane Fault Zone. Structurally, the main portion of the park is rather simple, containing relatively horizontal beds. Joints are mostly responsible for the orientation of the canyon network throughout the park. In the canyons of the Kolob District, strata are folded to form the Kanarra Anticline, and thrust faults are present, causing the duplication of formations in several places. Over the past 2 million years, regional uplift, coupled with downcutting by the Virgin River, has carved out Zion Canyon, exposing strata that were deposited over hundreds of millions of years. The vast majority of strata in the park consist of sedimentary rocks (Figs. 2-4) and therefore may contain fossils. These rocks were formed in a variety of paleoenvironments, and we discuss each formation in greater detail below. Numerous books and papers have been written about the geology of Zion, most recently the excellent overview given in Biek et al. (2003).

GEOLOGY AND PALEONTOLOGICAL RESOURCES OF UPPER TRIASSIC AND LOWER JURASSIC ROCKS IN ZION NATIONAL PARK

We herein give a brief summary of the Upper Triassic and Lower Jurassic geologic formations found within Zion National Park. The descriptions include rock type, inferred depositional environment(s), fossils found in these rocks, and potential for important paleontological discoveries.

Chinle Formation (Late Triassic, ~226-210 Ma)

Of all of the strata in Zion National Park, the Chinle Formation has the highest potential for containing significant paleontological resources. The Chinle is famous for the fossils it contains, including some of the earliest known dinosaurs. Much of what we know about Late Triassic terrestrial ecosystems in North America comes from fossils found in the Chinle Formation of the Colorado Plateau. However, the rugged exposures in southwestern Utah have received less attention than those in Arizona, New Mexico, and Wyoming, and consequently have yielded fewer fossils to date.

The stratigraphy of the Chinle Formation is complex, and there have been several different proposals regarding the nomenclature used in describing its constituent units. Lucas (1991, 1993) advocated raising the Chinle Formation to group status and naming the various members within...
FIGURE 3. Stratigraphic column showing rock units present in Zion National Park (from Biek et al., 2003). Note that herein we include the Springdale Sandstone Member as the basal member of the Kayenta Formation.
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Regardless of preference, the group scheme has not generally been implemented in southwestern Utah (and not adopted by the UGS), although a preliminary examination by Lucas and Heckert (see Heckert et al., this volume), identified Lucas’s (1993) Blue Mesa, Sonsela, and Painted Desert members of the Petrified Forest Formation and the overlying Owl Rock Formation, in addition to the underlying Shinarump Conglomerate in the park. Prior to this work, just two members were recognized in the Chinle Formation in Zion National Park, and as these are the mapped units in this area, these will be sufficient for our purposes.

The Chinle Formation consists primarily of sandstone, siltstone, and mudstone. The two members recognized within the Chinle in Zion National Park are the basal Shinarump Conglomerate Member and the overlying Petrified Forest Member. The Shinarump Conglomerate was deposited mainly in braided streams, whereas the Petrified Forest Member was deposited in floodplains, lakes, and stream channels in a low, wooded basin (Stewart et al., 1972; Dubiel, 1994; Biek et al., 2003). The majority of vertebrate body fossils in the park come from the Petrified Forest Member. The Chinle Formation is exposed in the Kolob Canyons District and in the southwest region of the park, notably along the Chinle Trail.

**Shinarump Conglomerate Member**

The Shinarump Conglomerate ranges in thickness from 18 to 41 m (60 to 135 ft.) within the park. This unit is well known for its petrified wood, including *Araucarioxylon* sp. and *Woodworthia* sp. (Santucci, 2000). Among the Shinarump Conglomerate’s coarse-grained sand and smooth pebbles, we have discovered chunks of silicified wood, sporadic large logs, and plant fragments, typically partially replaced by iron-manganese oxide (Figs. 5, 6). In addition to the plant material, bones and bone fragments are found in the Shinarump. A well-preserved reptile vertebra was discovered, but not collected, in Shinarump strata during this study in a dry wash north of Crater Hill (Fig. 7). In general, the fossils in the Shinarump are widely scattered and commonly are quite water-worn, indicating prolonged and/or violent transport, but they are typically protected by virtue of being encased in hard, well-cemented rock.

**Petrified Forest Member**

The Petrified Forest Member of the Chinle is named for the strata at the famous Petrified Forest National Park in Arizona, and is one of the more distinctive rock units in the park, composed of many variegated purple, gray, red, green, and brown mudstones, claystones, and sandstones. These horizons total between 136 and 152 m (450 and 500 ft.) thick (Biek et al., 2003). The rocks of the Petrified Forest Member contain bentonitic clays that swell when wet, so they weather with a distinctive “popcorn”-like profile. These clays also make this member susceptible to slumping and landslides; in many areas of the park and surrounding region these strata are covered by landslide debris. Chinle Formation strata are not found in the main canyon, but are exposed primarily in the southwest portion of the park in the area around Huber Wash.
FIGURE 6. A fossil log preserved as pyrite in the Shinarump Conglomerate in the South Fork of North Creek. This is a unique occurrence of a pyritized log because pyrite normally breaks down in the presence of oxygen. Being submerged under water has preserved this specimen. A-B, Log in situ in creek. C, Close-up of collected specimen. D, Close-up of pyrite and carbonaceous material on the log.

FIGURE 7. Reptile vertebra in Shinarump Conglomerate.

FIGURE 8. Phytosaur teeth (ZION 15681) from Al’s Tooth Site, located north of Mt. Kinesava.

FIGURE 9. Coprolites (ZION 15680) from the Petrified Forest Member of the Chinle Formation in Zion National Park.

The Moenave Formation lies above the Petrified Forest Member of the Chinle Formation and is separated from it by the J-O unconformity, thought to represent roughly 10 million years (Pipiringos and O’Sullivan, 1978). The Moenave Formation is a continental deposit 71 to 118 m (235 to 390 ft.) thick in the Zion region. Historically, the Moenave has been divided into three members: the Dinosaur Canyon, Whitmore Point, and Springdale Sandstone (Fig. 10). Lucas and Tanner (this volume)
make a strong case for placing the Springdale Sandstone as the basal member of the overlying Kayenta Formation, which we follow herein. Evidence from a number of fossil groups, including fishes (Olsen et al., 1982), crocodylomorphs (Clark and Fastovsky, 1986), pollen (Litwin, 1986; Cornet and Waanders, this volume), dinosaurs (Lucas and Heckert, 2001), and fossil tracks (Olsen and Padian, 1986) have been used to help date this member as Early Jurassic.

Dinosaur Canyon Member

The basal Dinosaur Canyon Member is composed of slope-forming, reddish-brown, fine-grained sandstone and siltstone deposited in a river and floodplain environment (Biek, 2000). Despite its name, the Dinosaur Canyon Member contains few fossils. Nevertheless, several paleontological sites have been found in this member in the park and environs. These are primarily trace fossils including invertebrate burrows and tridactyl dinosaur tracks. A recently discovered track horizon in St. George, Utah (Kirkland et al., 2002; Milner et al., 2004, this volume a) indicates the further potential for tracks in this unit. However, its slope-forming weathering profile in the park limits the exposure needed to discover significant tracksites. We noted mollusks, plant fragments, and trace fossils in this unit in Zion. Our surveys discovered a site in the Kolob Canyons District that contains the remains of plants (Figs. 11, 12), some of which may be complete enough to be identified.

Whitmore Point Member

The Whitmore Point Member is a distinctive unit that, along with reddish-brown sandstone and siltstone beds found in the underlying Dinosaur Canyon Member, also contains reddish-purple to greenish-gray mudstone and claystone beds as well as thin dolomitic limestone beds (Biek, 2000, Biek et al., 2003). The Whitmore Point Member was deposited in a river and floodplain environment that also included lakes, particularly an extensive lacustrine system called “Lake Dixie.” In Zion, it appears to be less lacustrine-dominated than it is to the south and southwest. This unit is best known for its ichnofauna (Kirkland et al., 2002; Milner et al., 2004, this volume a, b).

As part of our survey, we attempted to relocate the well-known site along Highway 9 near the bridge across Pine Creek that produced fossils of Semionotus kanabensis (Hesse, 1935; Schaeffer and Dunkle, 1950; Day, 1967), but were only able to find a few isolated fish scales. Perhaps earlier workers recovered the best material from this site, or the site may be buried below the grade of the road, which appears to have been raised in the course of repaving. Several other sites that contain fish remains were located in the unit, but are only isolated scales and bone fragments that are not very informative. In the Zion Natural History collection (prefix ZION), there is a nice specimen of a partial fish, including a section of articulated scales (ZION 667, Fig. 13). Although this specimen is labeled as coming from the Chinle Formation, it should be noted that early geologists (e.g., Gregory, 1950) did not recognize the Moenave as a distinct unit (the Moenave was not named until Harshbarger et al., 1957), and lumped all of its strata, along with parts of the overlying Kayenta Formation, into the Chinle Formation. Based on what is presently known, the fish specimen is likely from the Whitmore Point Member of the Moenave Formation.

Plant fossils are also present in the form of disseminated plant fragments and rare sections of petrified wood. These fossils are of interest mainly for what they tell about the conditions under which these sediments were deposited. In addition, many horizons, primarily thin dolomitic beds, display algal structures that probably represent the remains of shallow lakes.

Trace fossils are the most abundant fossils found in the Whitmore Point Member in Zion. Invertebrate burrows are common in many horizons and can be found in virtually any exposure of this member. The most significant trace fossils found in the Whitmore Point Member are the tracks and trackways of dinosaurs (Figs. 14-18). Three-toed tracks of theropod dinosaurs are attributed to the ichnogenera *Eubrontes* and *Grallator*, although they have not received detailed study.
Such tracks are common in many horizons in Zion, and dozens of new localities have been located as a result of our survey (Smith and Santucci, 1999; Smith et al., 2002; DeBlieux et al., 2003; DeBlieux and Kirkland, 2003). The tracks of the Whitmore Point Member in Zion are one of the more significant paleontological resources within the park, second only to the tracksites of the Kayenta Formation. Tracks appear to be concen-

FIGURE 13. Fish scales of *Semionotus kanabensis* (ZION 667) typical of those found in the Moenave Formation of the Zion region.

FIGURE 14. Schematic diagram demonstrating preservational modes of fossil tracks, which can be preserved as true tracks, under tracks, natural casts, and track infills. After Lockley and Hunt (1995).

FIGURE 15. *Eubrontes* track in the Whitmore Point Member of the Moenave Formation from Zion Canyon. Pencil is 15 cm in length.

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FIGURE 16. Bird-like tracks from the Whitmore Point Member of the Moenave Formation, Zion National Park. Scale bar in centimeters.

FIGURE 17. ?*Grallator* or ?*Anomoepus* track in Whitmore Point Member strata in Parunuweap Canyon with outline in white drawn around the track. Note the imprint of the dewclaw on the lower left of the track. The GPS unit is 13 cm in length.

trated in the greenish-gray dolomitic beds. Blocks of these beds can be easily seen from a distance because of their contrast with the predominately brown and red surrounding beds.

Kayenta Formation (Early Jurassic, ~196-184 Ma)

The Kayenta Formation ranges from 194 to 258 m (640 to 850 ft.) thick in the Zion region and forms the prominent slope below the Navajo cliffs. Its base is marked by the cliff-forming Springdale Member. The Kayenta Formation is exposed in many areas of the park, including lower Zion Canyon, Parunuweap Canyon, the West Temple and Cougar Moun-
attributed to ages expose the top of the Springdale, particularly large theropod tracks on the top of the Springdale Sandstone (Fig. 19). Where streams and drainages expose the top of the Springdale Sandstone, the damage and the location of large tracks on the Springdale Sandstone forms cliffs and bedding planes are only exposed. Layers containing vast numbers of tracks are referred to as “megatracksites.” The Springdale Member/“main body” of the Kayenta contact may be considered a megatracksite.

In addition to the tracks, we have located fish scales of *Semionotus kanahensis*.

**Navajo Sandstone (Early Jurassic, ~184-180 Ma)**

The Navajo Sandstone forms the towering vertical cliffs that give Zion its distinctive scenic character. The unit ranges from 545 to 667 m (1800 to 2200 ft.) thick in the Zion region. The transition from the water-laid deposits of the Kayenta Formation to the wind-blown sands of the Navajo Sandstone is well documented in Zion. The Navajo Sandstone was deposited in a desert environment similar to that of the parts of the modern Sahara, and records a part of what is thought to be the world’s largest ancient dune field (Blakey et al., 1988; Blakey, 1994; Peterson, 1994). For a sedimentary formation of such great thickness and areal extent, the Navajo Sandstone preserves relatively few fossils. However, tracks are known from the Navajo Sandstone in Zion and elsewhere. Peterson (in Santucci, 2000) reported several dinosaur footprints in the Navajo Sandstone along the trail to Observation Point in Zion Canyon that were relocated during our survey. In addition, we found the prints of several different animals on the weathered surface of a large rock-fall boulder in a side canyon of Parunuweap Canyon (Fig. 25). Tracks in the Navajo may actually be fairly common, but the conditions required for revealing these tracks are such that most of these will never be seen. Erosion is typically needed to bring the tracks into relief. Also, the bedding planes on which tracks were made are not generally exposed because the sandstone forms cliffs, and bedding planes are only exposed on fallen blocks and on the tops of the cliffs.

**CONCLUSIONS**

Our work in Zion has helped to document the great potential for further, productive paleontological studies in Zion National Park. Rocks of Late Triassic and Early Jurassic age are especially well suited for additional research. Several projects that could be undertaken are highlighted below.

The Chinle Formation has potential for additional vertebrate body fossils. Also there should be additional study of the petrified “forests” in the Petrified Forest Member of the Chinle Formation. These fossils need

FIGURE 20. The “Subway” tracksite from the Kayenta Formation along the Left Fork of North Creek. A, Overview of the track slabs. B, Close-up view of one of the track surfaces. C, Josh A. Smith with the latex mold made during 2002.


more thorough documentation, including mapping of log orientation and distribution. This information would provide data on paleocurrent directions and depositional environments, as well as providing valuable data for resource management.

Given the importance of fossils recovered outside the park (e.g., Milner et al., this volume a, b), there should be additional prospecting and monitoring of vertebrate tracksites in the Whitmore Point Member of the Moenave Formation and the Kayenta Formation within the park. Areas that still have not been explored completely include the southern part of the Kolob Canyons District, many areas in the western part of Zion Canyon, and most of Parunuweap and Shunes canyons. Stratigraphic sections of these rocks should be measured to place tracksites into a more detailed stratigraphic context and to correlate the Whitmore Point lake environments preserved here with areas outside the park. The paleoenvironments and fossils of Early Jurassic “Lake Dixie” are becoming a focus of research in the region.

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FIGURE 22. Tracks from the Kayenta Formation in the Kolob Canyons District. **A**, Fallen block with Grallator tracks outlined. GPS unit for scale is 13 cm long. **B**, Jenny McGuire in front of a track horizon; track casts of small and large dinosaurs are preserved on the underside of the ledge behind her. Arrows point to large tracks probably belonging to Eubrontes. **C**, Close-up of ledge showing small tridactyl tracks.

FIGURE 23. Stratigraphic column of track-bearing rocks in the Zion National Park and St. George region of southwestern Utah, indicating track horizons. Coordinating this project. We thank the personnel of Zion National Park, especially Jeff Bradybaugh and the rest of the resource management staff, for their assistance during this study. We thank Rex Taylor and Aimee Painter for their work in the park. Al Bench, Ron Long, Andrew R.C. Milner, Phil Polcelli, Raivo Puusemp, and Paul Smith aided us in the field. Members of the Southwestern Chapter of the Utah Friends of Paleontology also provided field assistance. Andrew Heckert and Spencer Lucas are thanked for their research of Chine stratigraphy. Bob Biek and Grant Willis of the UGS provided maps and information. UGS staff Jennifer Cavin, Martha Hayden, Mike Hylland, Kimm Harty, Mike Lowe, Robert Ressetar, and Janae Wallace reviewed the manuscript. This research was carried out under National Park Service Permit # ZION-2003-SCI-0002.

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