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

DONALD D. DEBLIEUX[1], JAMES I. KIRKLAND[1], JOSHUA A. SMITH[2], JENNIFER MC GUIRE[3] AND VINCENT L. SANTUCCI[4]

[1]Utah Geological Survey, PO Box 146100, Salt Lake City, UT 84114-6100;
[2]University of Utah, 1390 E. Presidents Circle, Salt Lake City, UT 84112;
[3]University of California, Department of Integrative Biology, 3060 Valley Life Science Building #3140, Berkeley, CA 94720-3140;
[4]National Park Service, George Washington Memorial Parkway, Turkey Run State Park, McLean, VA 22101

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 character, is almost entirely devoid of fossils. While the eye of the visitor is drawn to the spectacular cliffs of Navajo Sandstone, the eye of the paleontologist is drawn to the strata exposed as slopes and ledges below the cliffs, including the Kayenta, Moenave, and Chinle formations, all of which are known to contain comparatively more abundant fossils.

For well over a century, Zion has attracted geologists, many of whom have investigated the park's fossils sporadically over this time.

PREVIOUS PALEONTOLOGICAL STUDIES

Santucci (2000) provided the most recent, albeit preliminary, summary of the paleontological resources of Zion National Park. The first mention of fossils from the Zion region is found in the Wheeler Geographic Report (1886) regarding petrified wood and fossils found in sandstone. This may be a reference to the Shinarump Conglomerate Member of the Chinle Formation that is well known for its petrified wood, most of which is referable to *Araucarioxylon* sp. and *Woodworthia* sp. (Santucci, 2000). However, the oldest fossils in the park are found in the marine units within the Moenkopi Formation (Lower to Middle Triassic) that contain the remains of marine bivalves, snails, and ammonites. The Virgin Limestone Member contains the fossils of asteroid starfish and the internal molds of mollusks. Fragmentary wood and bone have also been found in the Moenkopi Formation.

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 km^2 (229 mi^2.) 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

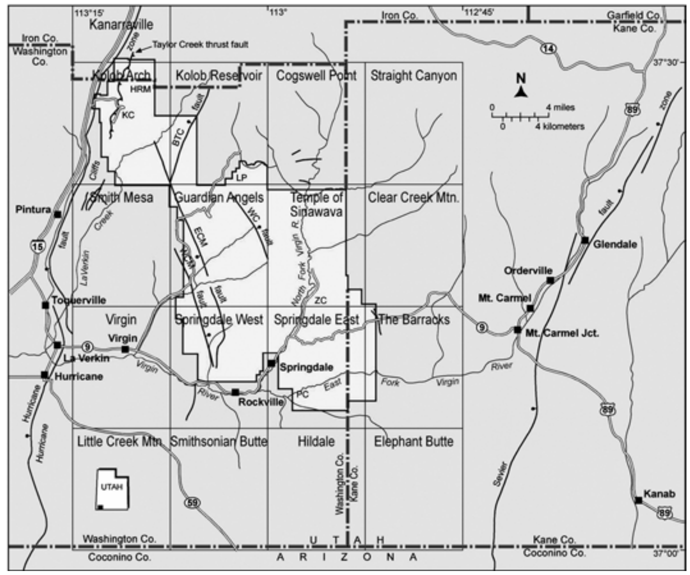

FIGURE 1. Location map of Zion National Park showing U.S. Geological Survey 7.5' quadrangles (from Biek et al., 2003). BTC, Bear Trap Canyon; ECM, East Cougar Mountain; HRM, Horse Ranch Mountain; KC, Kolob Canyons; LP, Lava Point; PC, Parunuweap Canyon; WCM, West Cougar Mountain; WC, Wildcat Canyon; ZC, Zion Canyon.

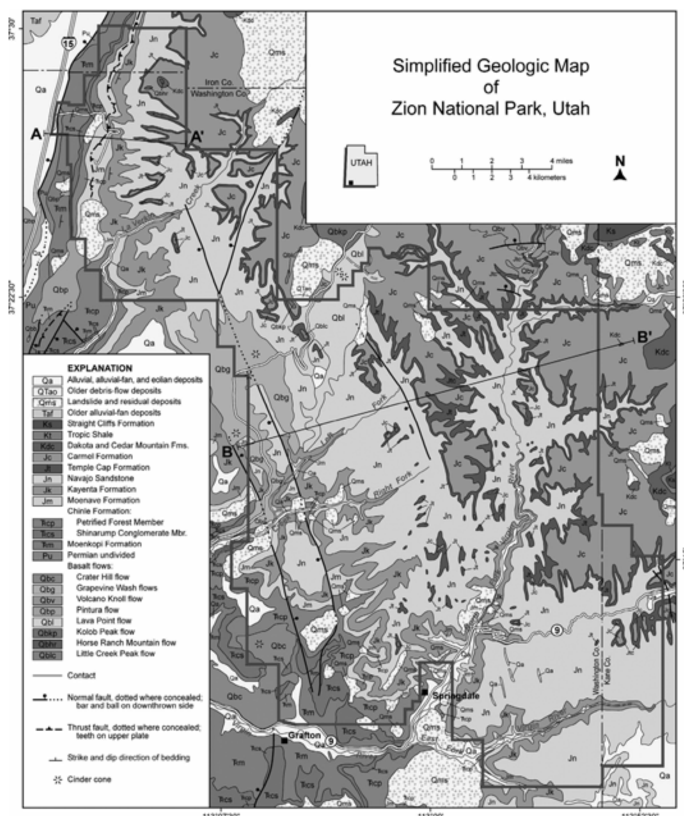

FIGURE 2. Simplified geologic map of Zion National Park (from Biek et al., 2003).

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

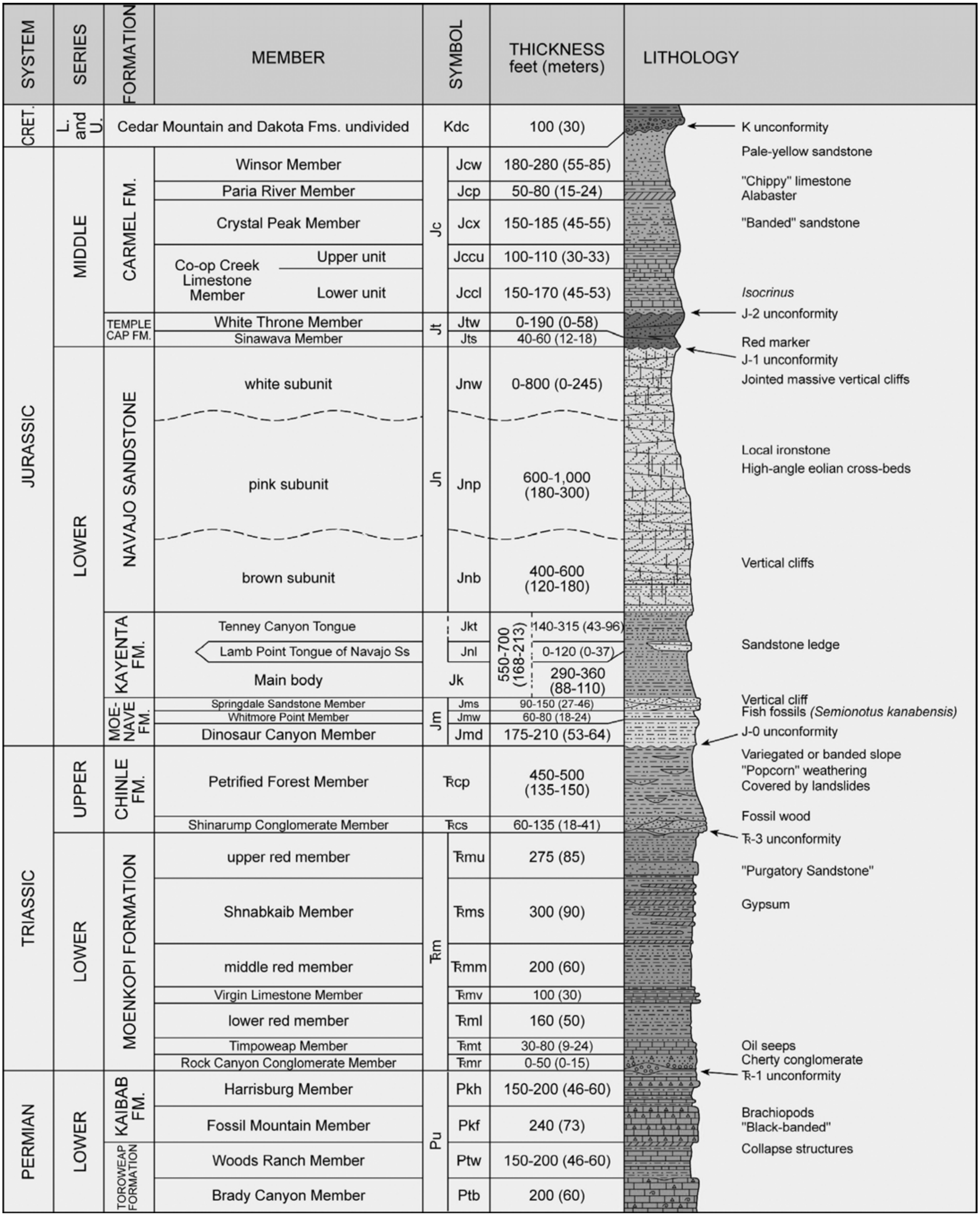

FIGURE 3. Stratigraphic column showing rock units present in Zion National Park (from Biek et al., 2003). Note that herein we include the Springdale Sandstone Member as the basal member of the Kayenta Formation.

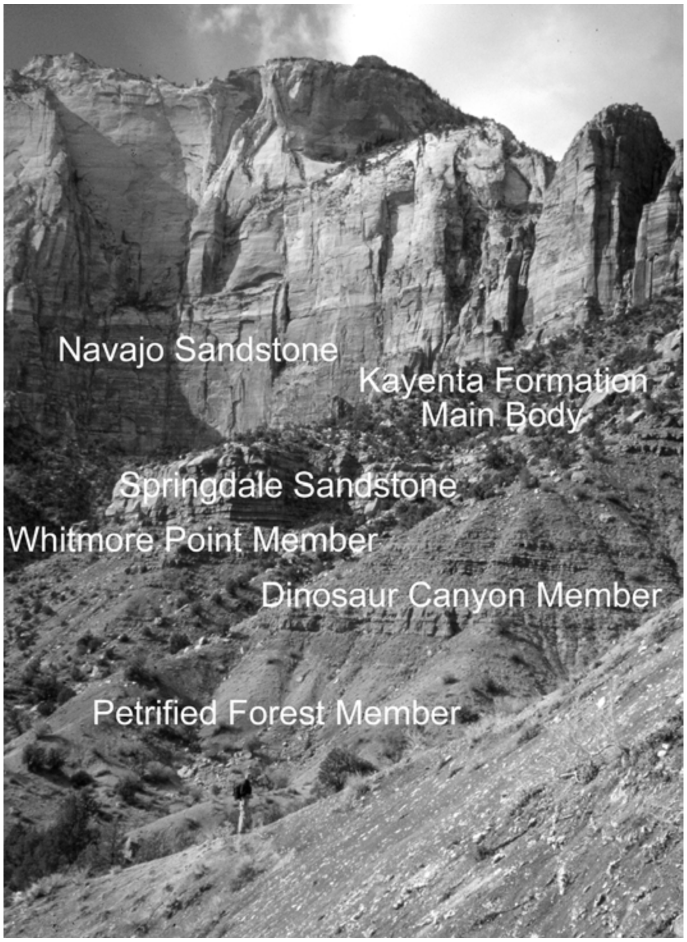

FIGURE 4. Overview of some of the strata (labeled) that were the focus of our studies as seen in Black's Canyon, Zion National Park.

it as formations, but others rejected this proposal (Dubiel, 1994; Lehman, 1994). 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

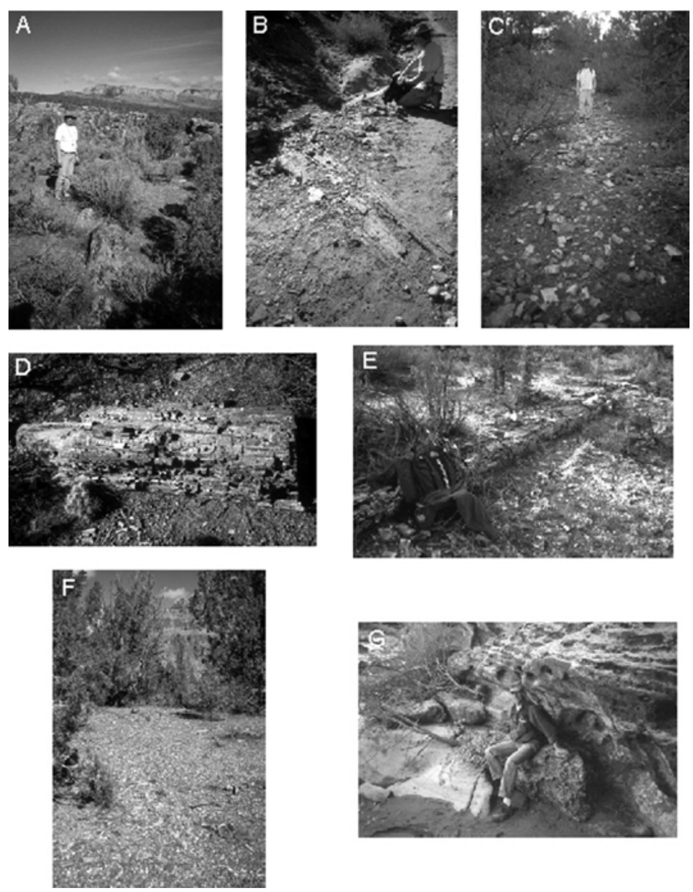

FIGURE 5. Photos of some representative Chinle Formation petrified wood localities. **A**, Large log on Rockville Bench. **B**, Log eroding out of the Chinle Trail near Huber Wash. **C**, Large chunks of wood eroding down the Shinarump dip-slope north of Taylor Creek in the Kolob Canyons District. **D-E**, Close-up views of petrified logs near the Chinle Trail. **F**, Large scatter of wood pieces near the Chinle Trail, hammer for scale. **G**, Large log (under man) eroding out of a stream channel in the Shinarump Conglomerate in Huber Wash.

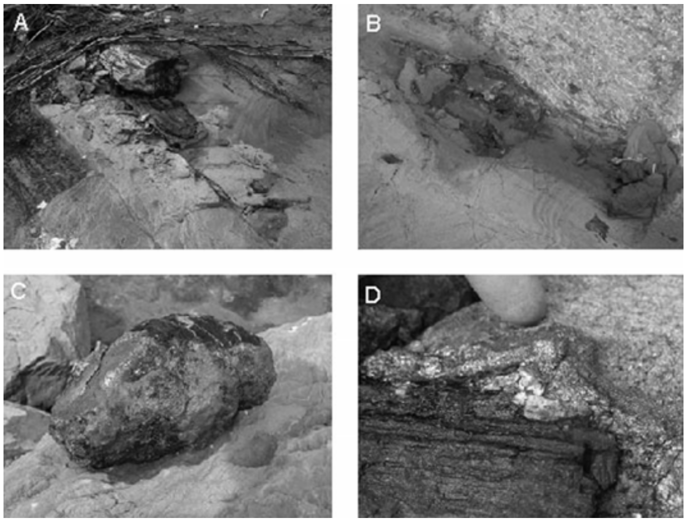

FIGURE 6. A fossil log preserved as pyrite in the Shinarump Conglomerate in the South Fork of North Creek. This is a unique occurrence of a pyritized log because pyrite normally breaks down in the presence of oxygen. Being submerged under water has preserved this specimen. **A-B**, Log *in situ* in creek. **C**, Close-up of collected specimen. **D**, Close-up of pyrite and carbonaceous material on the log.

FIGURE 7. Reptile vertebra in Shinarump Conglomerate.

and Coalpits washes, around Cougar Mountain, and in the Kolob Canyons District.

Petrified logs at the boundary between the Shinarump Conglomerate and the Petrified Forest Member of the Chinle are one of the most abundant and vulnerable paleontological resources in the park. Although petrified logs can be found throughout this member, it appears that in Zion National Park the greatest concentration of logs, locally abundant enough to form "petrified forests," is in the lower Petrified Forest Member near its contact with the Shinarump Conglomerate.

In addition to the plant fossils, this unit also has the highest potential for containing the bones and teeth of vertebrate animals. An important phytosaur site, located adjacent to the park, was excavated during the mid-1990s by the College of Eastern Utah. During our work, as expected, we found many sites containing fossilized remains of vertebrate animals. We found large quantities of bone fragments and teeth (commonly within nodules) belonging to fishes, metoposaurs, phytosaurs (Fig. 8), and aetosaurs, in addition to coprolites (Fig. 9), petrified wood, plant material, and invertebrate burrows.

Moenave Formation (Late Triassic-Early Jurassic, ~200-196 Ma)

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)

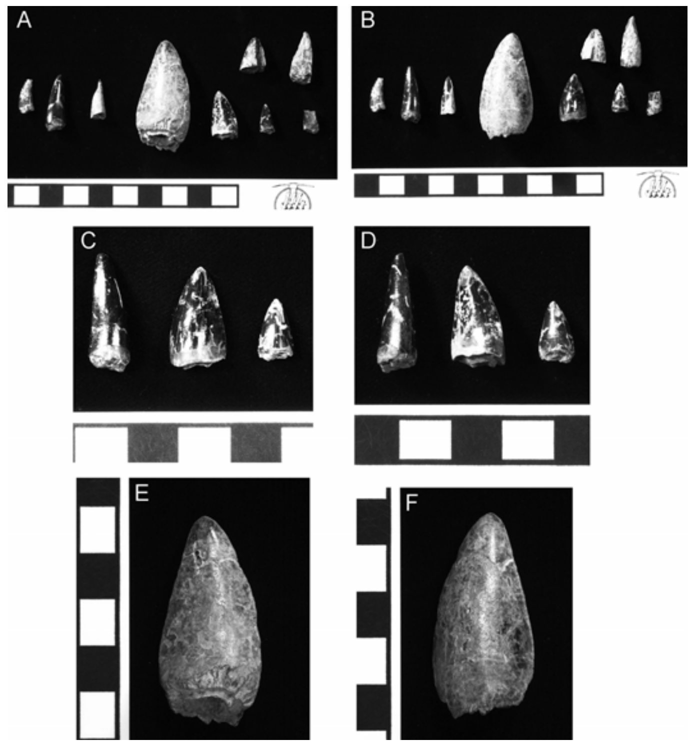

FIGURE 8. Phytosaur teeth (ZION 15681) from Al's Tooth Site, located north of Mt. Kinesava.

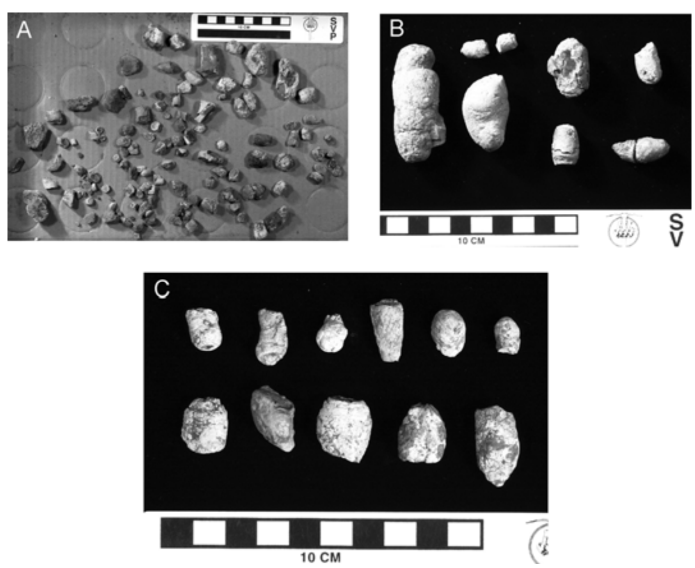

FIGURE 9. Coprolites (ZION 15680) from the Petrified Forest Member of the Chinle Formation in Zion National Park.

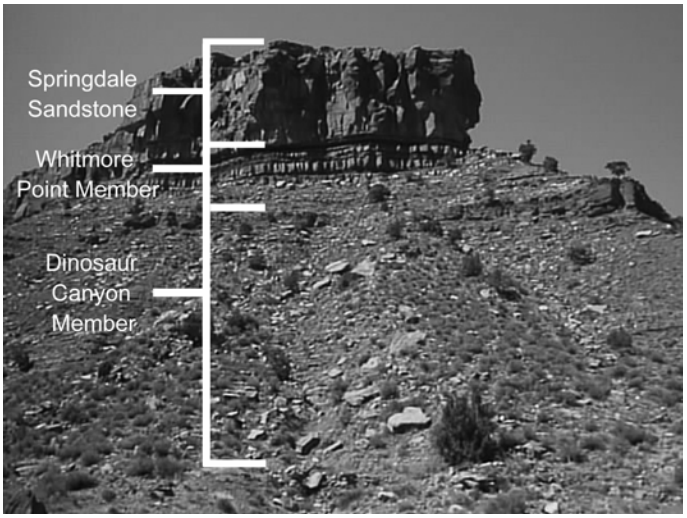

FIGURE 10. Moenave Formation and basal Kayenta Formation strata exposed near park headquarters. Many of the fallen blocks on the slope in the center of the photo are from the Whitmore Point Member and preserve tracks.

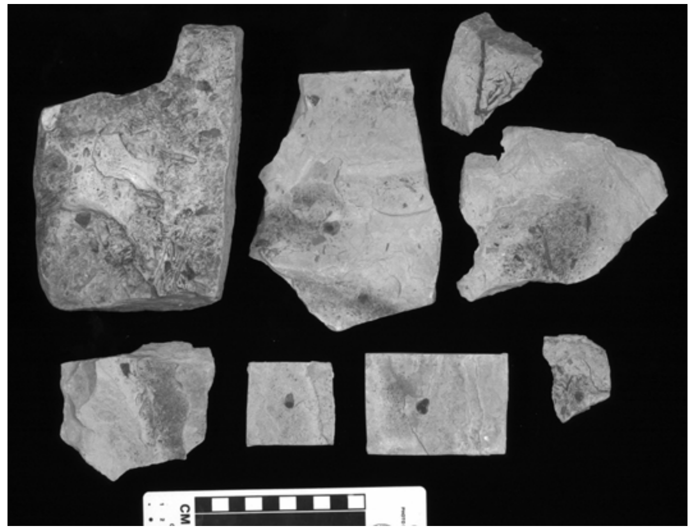

FIGURE 11. Plant fossils in yellow sandstone (ZION 15802) from the Dinosaur Canyon Member of the Moenave Formation along Kolob Scenic Road. Scale in centimeters.

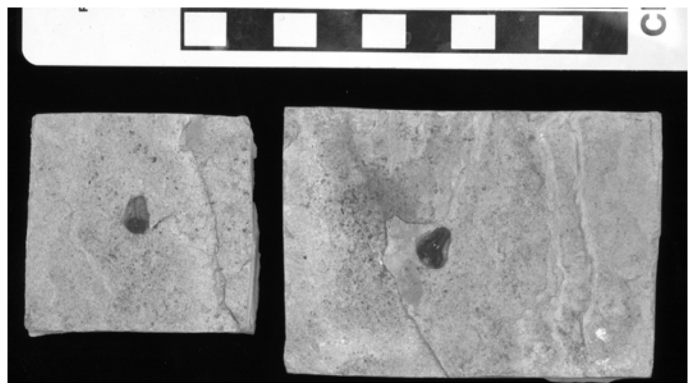

FIGURE 12. Close-up of two of the specimens shown in Figure 11 showing fossil leaf scales, possibly from a conifer. Scale in centimeters.

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-know 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.

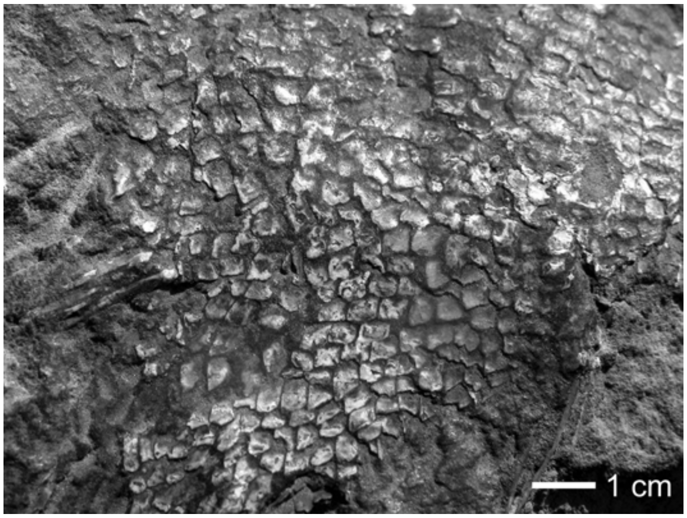

FIGURE 13. Fish scales of *Semionotus kanabensis* (ZION 667) typical of those found in the Moenave Formation of the Zion region.

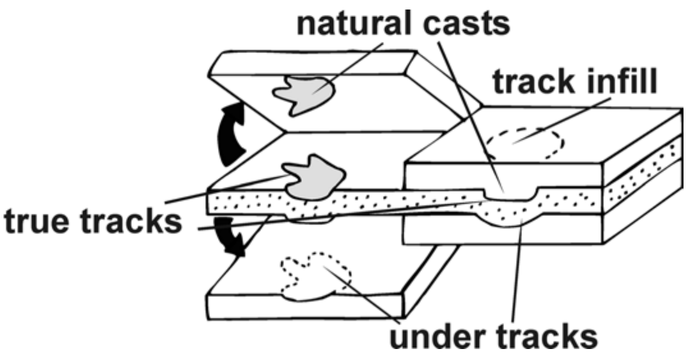

FIGURE 14. Schematic diagram demonstrating preservational modes of fossil tracks, which can be preserved as true tracks, under tracks, natural casts, and track infills. After Lockley and Hunt (1995).

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

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 concentrated 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.

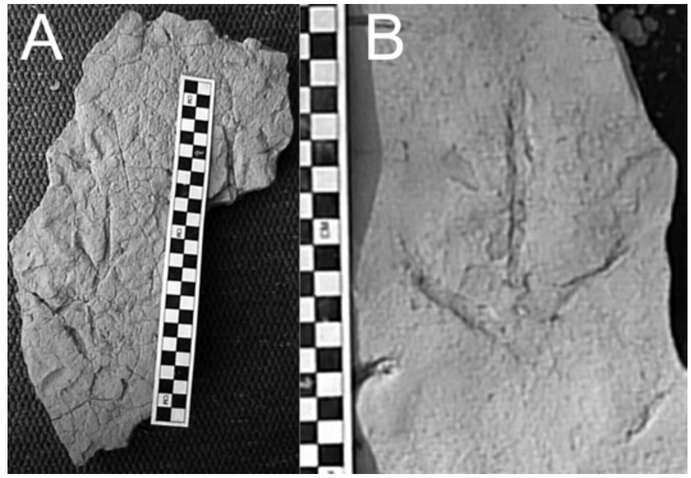

FIGURE 16. Bird-like tracks from the Whitmore Point Member of the Moenave Formation, Zion National Park. Scale bar in centimeters.

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.

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-

FIGURE 18. Swim tracks on a block of rock from the Whitmore Point Member in Trail Canyon, Zion National Park. Pencil is 15 cm in length.

tain areas, Kolob Terrace, and Kolob Canyons. Talus from the overlying Navajo cliffs covers the Kayenta in many places. Strata of the Kayenta are similar to those in the underlying Moenave Formation, consisting primarily of interbedded, thin- to medium-bedded, siltstone, sandstone, and mudstone that are mainly reddish-brown in color. Additionally, the lower part of the main body of the Kayenta contains greenish-gray-weathering dolomitic beds reminiscent of those in the Whitmore Point Member of the Moenave Formation.

Springdale Member

The Springdale Member, named for the town of Springdale near the entrance to Zion Canyon, is now considered the basal member of the Kayenta Formation (Lucas and Tanner, this volume). The Springdale forms a prominent cliff in the slopes below the Navajo Sandstone in the Zion region and consists of reddish-brown sandstone and conglomerate deposited in braided-stream channels and minor floodplain environments. Fossils in the Springdale Sandstone consist primarily of poorly preserved plant fragments, petrified wood, bioturbated horizons (invertebrate burrows), and rare dinosaur tracks. Because the Springdale forms steep cliffs, it does not provide exposures conducive to finding fossils. Nevertheless, one of the most significant track horizons in Zion occurs at the top of the Springdale Sandstone (Fig. 19). Where streams and drainages expose the top of the Springdale, particularly large theropod tracks attributed to *Eubrontes*, are common, and numerous localities have been discovered at this horizon during our surveys. One of the highest concentrations of dinosaur tracks is on the top of the ledge formed from the resistant cliff of Springdale Sandstone.

"Main Body"

The "main body" of the Kayenta Formation was deposited in fluvial, distal fluvial/playa, and minor lacustrine environments (Blakey, 1994; Peterson, 1994). A tongue of eolian sandstone, called the Lamb Point Tongue, is present in the Kayenta Formation in Parunuweap and Zion Canyons (Fig. 3). The Lamb Point Tongue pinches out to the west and is not present in most of the western portions of the park.

In southwestern Utah, the fossils in the Kayenta Formation are limited mainly to tracks, though a diverse fossil assemblage exists elsewhere in the Kayenta Formation on the Colorado Plateau. Fossils include petrified wood, invertebrates such as bivalves and gastropods, vertebrates such as frogs, turtles, sphenodontians, crocodyliforms, dinosaurs, pterosaurs, and mammals (Stokes and Bruhn, 1960; Crompton and Smith, 1980; Padian, 1984; Clemens, 1986; Gaffney, 1986; Sues, 1986, 1994; Weishampel, 1990; Curtis and Padian, 1999; Tykoski et al., 2002; Lucas et al., 2005), and abundant reptile tracks, including *Eubrontes* and *Grallator* (Welles, 1971; Lockley and Hunt, 1994; Hamblin, 2006; Hamblin et al., this volume; Lockley et al., this volume). The majority of vertebrate body fossils from the Kayenta have been found in Arizona.

Of the track-bearing formations in Zion, the Kayenta Formation has the greatest concentration of dinosaur tracks (Figs. 20-24). Stokes and Bruhn (1960) first reported dinosaur tracks from a spectacular site in the Kayenta Formation from the Left Fork of North Creek (Fig. 20). We have located numerous tracksites in the Kayenta Formation of the park. Many sites contain just a few tracks, but this is because only small areas are exposed. Many of the layers with tracks probably have hundreds, thousands, and even millions of tracks, which would be visible if the entire layer were 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 kanabensis*.

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

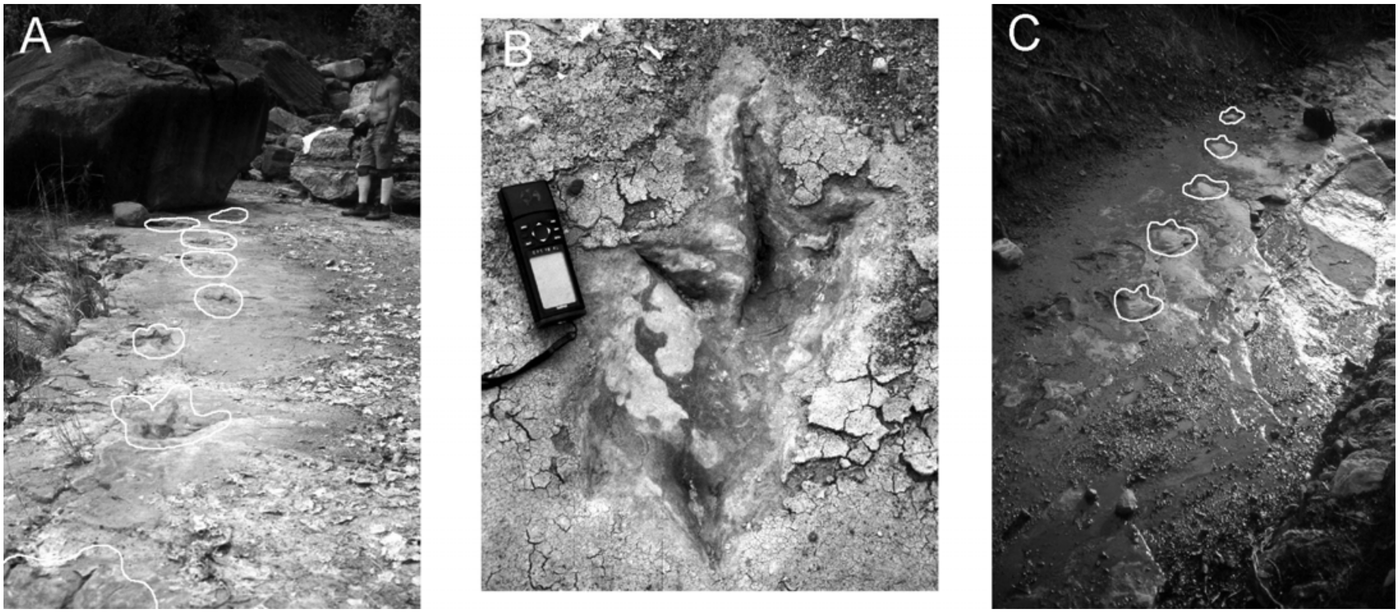

FIGURE 19. Tracksites at the Springdale Sandstone/main body Kayenta Formation interface. **A**, *Eubrontes* trackway. **B**, Close-up of superimposed *Eubrontes* tracks at same site. **C**, *Eubrontes* trackway. The GPS unit is 13 cm in length.

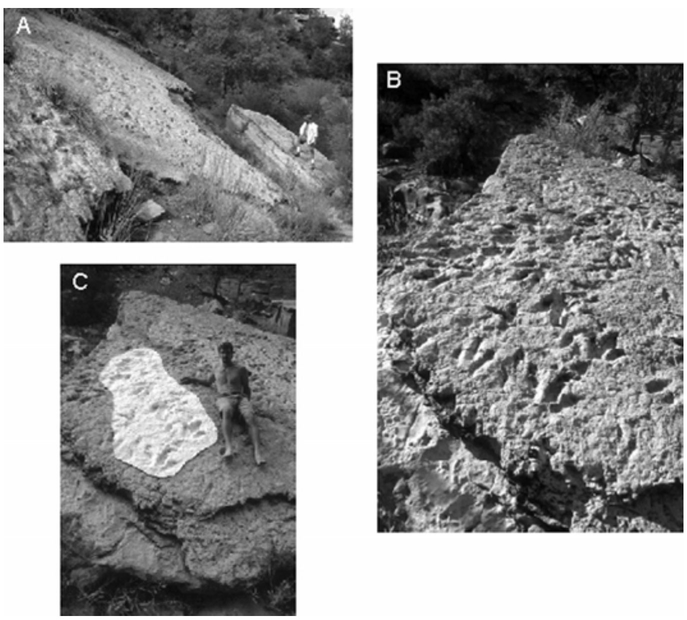

FIGURE 20. The "Subway" tracksite from the Kayenta Formation along the Left Fork of North Creek. **A**, Overview of the track slabs. **B**, Close-up view of one of the track surfaces. **C**, Josh A. Smith with the latex mold made during 2002.

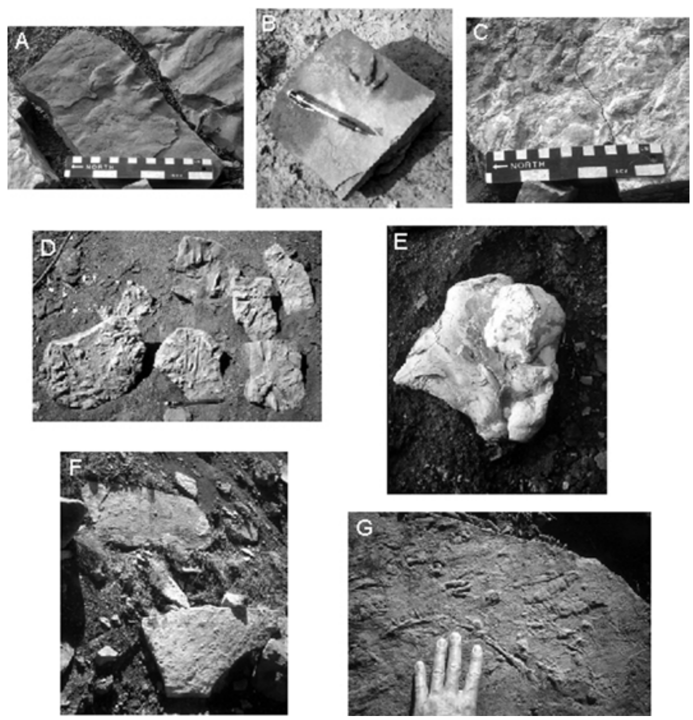

FIGURE 21. Kayenta Formation tracks from Zion. **A**, Four-toed track. **B**, Tridactyl track cast (ZION 15801). **C**, *Grallator* tracks on slab also preserving fish scales. **D**, Slabs preserving scratch-mark tracks indicative of swimming behavior. **E**, Large, "blob-like" *Eubrontes* track cast. **F**, Two fallen slabs with numerous *Grallator* tracks; many tridactyl pes prints can be seen on lower slab. **G**, Close-up of upper slab in **F**, showing possible swim tracks.

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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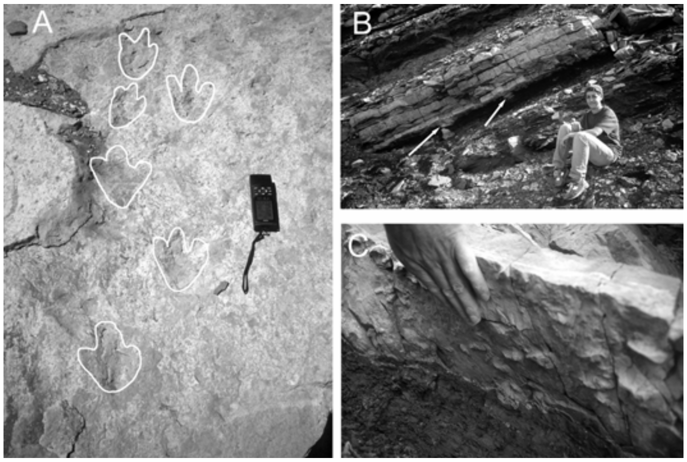

FIGURE 22. Tracks from the Kayenta Formation in the Kolob Canyons District. **A**, Fallen block with *Grallator* tracks outlined. GPS unit for scale is 13 cm long. **B**, Jenny McGuire in front of a track horizon; track casts of small and large dinosaurs are preserved on the underside of the ledge behind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

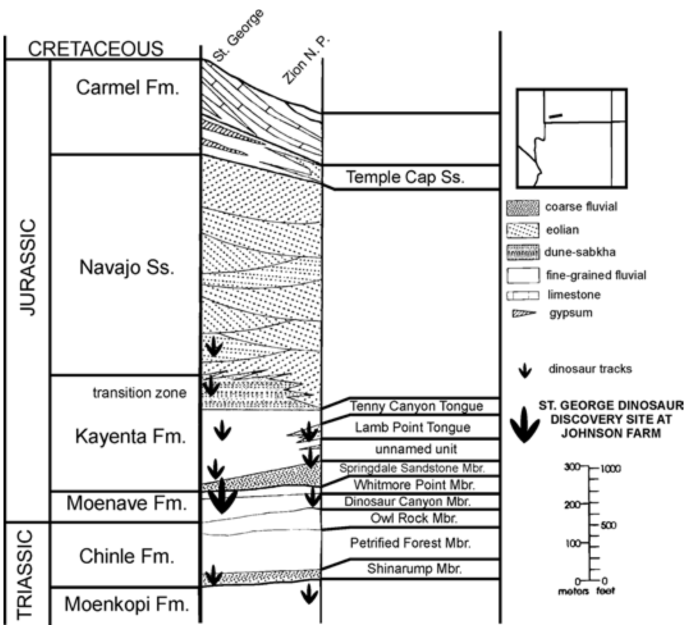

FIGURE 23. Stratigraphic column of track-bearing rocks in the Zion National Park and St. George region of southwestern Utah, indicating track horizons.

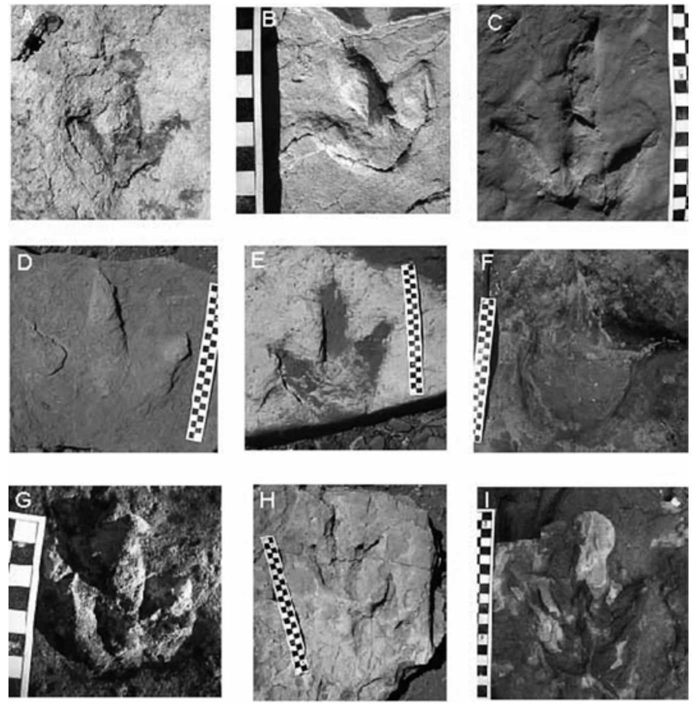

FIGURE 24. A sampling of three-toed dinosaur tracks from Zion National Park. **A**, *Grallator* from the Whitmore Point Member. **B**, ?*Anomoepus* from the main body Kayenta Formation. **C**, *Grallator* track from the Whitmore Point Member. **D**, *Eubrontes* track from the Whitmore Point Member. **E**, *Eubrontes* track from the Whitmore Point Member. **F**, *Eubrontes* from the top of the Springdale Sandstone. **G**, ?*Anomoepus* track from the main body of the Kayenta Formation. **H**, *Grallator* tracks from the Dinosaur Canyon or Whitmore Point Member. **I**, ?*Grallator* track from the Kayenta Formation. Scale bars in centimeters.

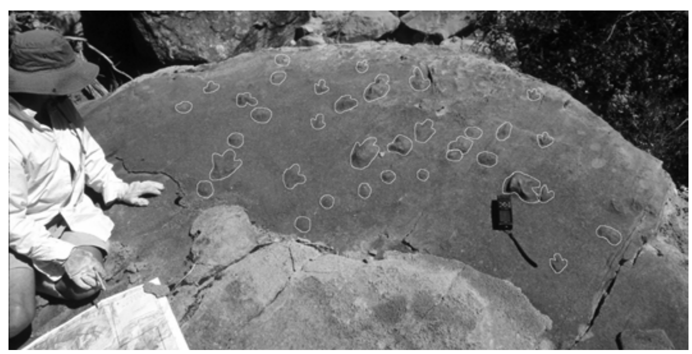

FIGURE 25. Tracks on weathered surface of a Navajo Sandstone block in a side canyon in Parunuweap Canyon. The highlighted tracks belong to at least two sizes of bipedal tridactyl track makers as well as a quadrupedal track maker.

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