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An Overview of National Park Service Paleontological Resources from the Parks and Monuments in Utah

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ABSTRACT

The National Park Service (NPS) administers thirteen park units within the state of Utah. Most of these parks, monuments, and other NPS units have been established and are recognized for their significant geologic features. Fossiliferous rocks of Paleozoic, Mesozoic, and Cenozoic age have been identified in all of the National Park System units in Utah. In 1998, the first comprehensive inventory of paleontological resources in the national parks and monuments of Utah was initiated. A wide diversity of fossilized plants, invertebrates, vertebrates, and trace fossils has been documented. Paleontological resources identified from within the parks and monuments have been assessed relative to their scientific significance, potential threats, and management as non-renewable resources. Considerable focus has been directed towards the *in situ* management of the abundant fossil vertebrate tracks identified throughout the Mesozoic formations within at least seven NPS areas in Utah. The baseline paleontological resource data obtained during this inventory will assist park staff with improved management of their paleontological resources and protection of fossils within their park.

HISTORY OF PALEONTOLOGY IN UTAH NATIONAL PARKS

During five expeditions into Utah led by Captain John C. Fremont between 1842 and 1854 (Rolle, 1991), rock, mineral and fossil specimens were collected and sent to geologist and paleontologist James Hall in New York. Hall contributed descriptions of the Utah fossils as an appendix in Fremont's 1845 report (Fremont, 1845). This work represents the first scientific publication to document Utah's geologic resources (Willis, 1996).

Captain Howard Stansbury explored Utah in 1850, searching for a railroad route across the Wasatch Mountains. During this survey, Stansbury collected fossils that he sent to James Hall for identification. Hall described these fossils in Stansbury's published report (Stansbury, 1852).

In 1859, the remains of the first dinosaur from the Utah Territory were discovered by John S. Newberry, a member of Captain John N. Macomb's survey party. This partial skeleton was later studied and described by paleontologist Edward D. Cope who named the specimen *Dystrophaeus viaemalae* (Cope, 1877; Barnes, 1988; Gillette, 1996). The fossil is a Late Jurassic sauropod dinosaur collected in the basal Morrison Formation.

After the American Civil War, there was renewed interest in westward expansion. Congress funded four great surveys of the western territories during the late 1860s and 1870s (Bartlett, 1962). Three scientific civilian surveys were organized under Ferdinand V. Hayden, Clarence E. King, and John Wesley Powell (figure 1). One military survey was formed and led by Lieutenant George M. Wheeler. All four of these surveys spent some time mapping and documenting geologic resources in Utah. Paleontologist F.B. Meeks participated in both the Hayden and King surveys and authored reports on fossils collected in Utah.

Yale paleontologist O.C. Marsh conducted field work in the Utah Territory during 1870. Marsh crossed the Uinta Mountains and traveled into the Uinta Basin where his field party discovered Eocene mammals, turtles, the rare Cretaceous crinoid *Uintacrinus*, and the second dinosaur specimen from Utah (Marsh, 1871). Marsh's dinosaur was the first theropod dinosaur known from Utah and was found near the current west boundary of Dinosaur National Monument (Bilbey and Hall, 1999).

A dinosaur bonebed (Carnegie Quarry) was discovered in northeastern Utah in 1909 by Carnegie Museum

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Figure 1. John Wesley Powell, circa 1870 (National Park Service photo collection).

paleontologist Earl Douglass. Many significant dinosaur skeletons have been collected from the Upper Jurassic Morrison Formation in the Carnegie Quarry. One of the most complete sauropod skeletons ever found (*Apatosaurus louisae*) and a nearly complete specimen of *Allosaurus fragilis* were collected from the quarry (Holland, 1916a). In 1915, the site was established as Dinosaur National Monument through presidential proclamation. The Carnegie Museum continued field excavations at the quarry between 1915 and 1922.

Over the past 150 years, Utah has been the focus of considerable interest by paleontologists. The 1939 Smithsonian Paleontological Expedition, the 1951 American Museum of Natural History field party led by Dr. Edwin Colbert, and other similar endeavors uncovered a great diversity of ancient plants and animals from Utah's national parks and monuments. During the 1990s, the Morrison Formation Extinct Ecosystem Project was a multi-disciplinary approach to understanding the geology and paleontology of the Upper Jurassic Morrison Formation. Many of the Utah national parks and monuments were assessed during this project. Although the Mesozoic strata and fossils have received the most attention in Utah, recent work in the late Paleozoic and early Cenozoic has led to some important paleontological discoveries. The National Park Service (NPS) has undertaken baseline paleontological resource inventories for the parks in Utah and on the Colorado Plateau during the past decade (Santucci and others, 1998, 2001; Koch and Santucci, 2002; Tweet and others, 2009). Fossil-rich deposits within the national parks and monuments of Utah yield specimens that contribute towards a better understanding of the history of life.

FOSSILIFEROUS UNITS IN THE UTAH NATIONAL PARK AREAS

Most of the NPS areas in Utah lie within the Colorado Plateau Province (figure 2). The plateau parks are dominated by a thick sequence of sedimentary rocks. The landscape is composed of colorful, eroded geologic features, punctuated by sparse vegetation in this semi-arid region. The Colorado, Green, and other rivers dissect the plateau rocks, forming canyons and mesas exposing the colorful layers of sedimentary strata that lend so much to the beauty of Utah. The scenic landforms that have formed naturally in Utah have gained the attention of the public and scientific communities. Many of these outstanding geologic features of Utah are preserved within the National Park System.

The stratigraphic units vary between the eastern and western parts of the state and facies changes frequently reflect transgressive and regressive marine events. Between the Paleozoic and the Early Triassic, a sea on the western portion of Utah repeatedly advanced and retreated. During the Cretaceous, a broad seaway that stretched northward from the Gulf of Mexico across the Great Plains and up to the Arctic Ocean, expanded and contracted intermittently, flooding eastern Utah from time to time. Tertiary and Quaternary fluvial and lacustrine deposits represent more recent geologic events. Stokes (1986), Hintze and Kowallis (2009), and the contributions included within this volume provide comprehensive overviews of the geologic history of Utah and the NPS areas within the state.

ARCHES NATIONAL PARK

Arches National Park was originally established as a national monument by presidential proclamation on April 12, 1929. The monument was redesignated as a national park on November 12, 1971, to preserve the extraordinary products of erosion including arches, windows, pinnacles, pedestals, and other landforms. For more detailed information on the geology and a stratigraphic section of Arches National Park see Doelling (1985) and Arches National Park article in the volume. A baseline paleontological resource inventory of Arches National Park was undertaken by the NPS between 2002 and 2004 (Swanson and others, 2005).

The oldest fossils known from the Arches National Park area occur in the Middle Pennsylvanian Paradox Formation. The Paradox is a marine unit composed largely of limestone that contains the remains of algae, corals, bryozoans, brachiopods, crinoids, and other marine fossils. During the Late Pennsylvanian, cyclic sediments of the Honaker Trail Formation were deposited and are now exposed on the western boundary of the park. Melton (1972) reports the following fossils from the Honaker Trail For-

Figure 2. Map showing the locations of the National Park System units in Utah (copyright National Geographic Maps, Trails Illustrated).

mation in the Moab area: fusilinids, corals, bryozoans, brachiopods, gastropods, bivalves, crinoids, echinoids, and a variety of marine trace fossils (figure 3). In addition, Tidwell and others (1972) reported on a *Calamites*-like stem that was collected from the Honaker Trail Formation.

Fragmentary vertebrate remains occur in the Triassic Moenkopi and Chinle Formations in the Moab area. Just west of Arches National Park, vertebrate bone, phytosaur teeth, and numerous theropod tracks have been reported from within the Upper Triassic Chinle Formation (S. Duffy, NPS, verbal communication, 1999). Crayfish burrows are abundant below a syndepositional, angular unconformity caused by salt tectonics within the Upper Triassic Chinle Formation along the Colorado River on the southwest side of Arches National Park. As the normally vertical trace fossils are tilted with the rock layers establishes that the rock layers were initially horizontal and then were tilted and then truncated during the Late Triassic (figure 4).

Dinosaur tracks have been reported from in and around Arches since the 1940s. Paleontologist Roland Bird is reported to have visited some tracksites in the Arches National Park area. Tracks of *Brachichirotherium* and *Grallator* are common in the Upper Triassic Church Rock Member of the Chinle Formation and the Triassic-Jurassic Wingate Sandstone. Two theropod tracks have been identified in the Lower Jurassic Kayenta Formation in the "Petrified Dunes" area of Arches National Park (S. Duffy, NPS, verbal communication, 1999) and there are dozens if not hundreds of known tracksites throughout the Glen Canyon Group south of Arches National Park (Lockley and Hunt, 1995; Barnes, 1998). Tiny theropod tracks and a single quadrupedal trackway are reported from the Jurassic Entrada Sandstone on the perimeter of the park (Fran Barnes, written communication, 1999). A dinosaur megatracksite, consisting of thousands of theropod tracks,

Figure 3. Marine invertebrates from the Pennsylvanian Honaker Trail Formation at Arches National Park.

Figure 4. View across Colorado River to exposures of the middle portion of the Chinle Formation exhibiting angular unconformity between the Owl Rock and Church Rock Members in Arches National Park. Arrow indicates the orientation of the abundant crayfish burrows within the stacked paleosols below the unconformity.

weaves in and out of the Arches National Park boundary and may be one of the largest tracksites in the world (Lockley and Hunt, 1995; Barnes, 1998). The track-producing layer was originally identified as the Entrada Sandstone but is currently mapped as the upper surface of the Moab Tongue of the Jurassic Curtis Formation (Lockley, 1990, 1991; Duffy, 1993; Doelling, 2001). Additional dinosaur track localities occur in the Morrison and Cedar Mountain Formations just outside of Arches (Kirkland and others, 1997, 1998; Engelmann and Hasiotis, 1999; Lockley and others, 1999).

The Upper Jurassic Morrison Formation is well exposed in and around Arches National Park. Petrified wood is reported from the Morrison within the park and large petrified logs occur just west of the park at the contact between the base of the Morrison and the underlying Summerville Formation. In 2000, inventory work resulted in the discovery of a new sauropod dinosaur site at the very top of the Morrison Formation that may represent the youngest known dinosaur from the Morrison on the Colorado Plateau. Salvage collecting in 2003 of part of the specimen enabled the dinosaur to be identified as *Apatosaurus* (Foster, 2005).

The Yellow Cat Flat area northeast of the park was administered as part of Arches National Park until 1971. The Lower Cretaceous Cedar Mountain Formation is capped by the Dakota Sandstone in the Yellow Cat Flat area. The Cedar Mountain is divided into three members in the Arches National Park area. The oldest, the Yellow Cat Member, preserves the earliest Cretaceous fauna in North America. Several active research quarries occur in the Cedar Mountain around Arches. The Gaston Quarry, situated just northeast of the park, is the site from which the first specimen of *Utahraptor* and the armored polacanthine ankylosaur *Gastonia* were collected along with other vertebrate remains referred to as the "Yellow Cat Fauna" (Kirkland and others, 1993, 1997, 1999; Kirkland, 1998).

The Dalton Wells Quarry, situated on the east side of Arches National Park (Britt and Stadtman, 1997), was discovered in the 1970s and represents the largest dinosaur site of this age known in North America. It has been excavated by Brigham Young University (BYU) for many years (Eberth and others, 2006; Britt and others, 2009). Other important new dinosaurs from these rocks include the small theropod *Nedcolbertia* (Kirkland and others, 1998) and the brachiosaurid sauropod *Cedarosaurus* (Tidwell and others, 1999). Additionally, BYU and Utah Geological Survey (UGS) are excavating a number of other new dinosaur sites on both the east and north sides of Arches that are yielding additional new dinosaur, crocodilian, and mammal genera. Several iguanodontid tracks in the collections at the College of Eastern Utah have been collected from the Yellow Cat Member just north of Arches (Kirkland and others, 1997). Most recently, the oldest bird tracks in North America were discovered in the transition between the Yellow Cat and overlying Poison Strip Sandstone Member of the Cedar Mountain Formation about one 1 mile north of Arches National Park (Wright and others, 2007).

Bodily (1969) reported on a specimen of the ankylosaur *cf. Hoplitosaurus* from the Poison Strip Sandstone Member just west of Arches National Park (Kirkland and others, 1997; Kirkland and Madsen, 2007). Another specimen, reported as *Sauropelta,* was discovered west of the park at the same stratigraphic level (K. Carpenter and others, 1999). Currently these specimens are thought to represent a giant species related to the polacanthine ankylosaur *Gastonia* (K. Carpenter, Denver Museum of Nature and Science, verbal communication, 2009). The Denver Museum of Nature and Science (DMNS) discovered a series of dinosaur sites in these rocks near the Gaston Quarry northeast of Arches National Park that have yielded the titansauromorph sauropod *Veneneosaurus*, an ornithopod

Figure 5. Dromaeosaur ("raptor") track from the Lower Cretaceous Ruby Ranch Member of the Cedar Mountain Formation at Arches National Park. Note only two weight supporting digits (Lockley and others, 2004).

Planacoxa and numerous skeletons of another polacanthid ankylosaur similar to *Gastonia* (DiCroce and Carpenter, 2001; Tidwell and others, 2001; K. Carpenter, Denver Museum of Nature and Science, verbal communication, 2008).

The Ruby Ranch Member of the Cedar Mountain Formation has not yielded much dinosaur material in the area around Arches, but preserves one of the largest lake deposits known in the Lower Cretaceous of Utah along the west side of the park. The deposits preserve fish debris and well-preserved plants and have the potential to yield significant climatic data concerning the Cedar Mountain. Within Arches National Park, a variety of dinosaur tracks, and possible pterosaur feeding traces, have been identified in the Cedar Mountain. These tracks represent invertebrates, crocodilians, ankylosaurs, sauropods, and iguanodonts. Also found are the tracks of small generalized theropods like those that would have been made by *Nedcolbertia*, and the first recognized dromaeosaur tracks (figure 5) in North America (Lockley and others, 2004).

Specimens of the cycadeoidales *Monanthesia* have been collected from the Cedar Mountain Formation near Arches National Park (Furniss and Tidwell, 1972). The Poison Strip Sandstone preserves an extensive petrified forest of conifers and cycads to the east of the Gaston Quarry northeast of Arches.

The Dakota Formation spans the Lower/Upper Cretaceous boundary and the DMNS and UGS have found scattered dinosaur remains at a number of sites in the con-

Figure 6. A mammoth mandible collected from a rock shelter in Arches National Park.

glomeratic sandstones near its base (Kirkland and Madsen, 2007). Most notable is the occurrence of a poorly preserved brachiosaur sauropod forelimb (K. Carpenter, Denver Museum of Nature and Science, verbal communication, 2005). The youngest Mesozoic unit in Arches National Park is the Upper Cretaceous Mancos Shale, which is exposed in the southern portion of Salt Valley. These marine shales preserve a rich and often well preserved invertebrate fauna. Shells of the small free floating oyster *Pycnodonte newberryi* are abundant and can be found weathering out of the basal portion of the Mancos within Arches. Plesiosaur and mosasaur remains have been discovered in the Mancos Shale about 35 miles outside of the park.

During the 1950s, Arches National Park Chief Ranger, Lloyd Pierson, discovered the remains of a Columbian mammoth in the park. A partial mandible was collected from the site and was determined to be from a juvenile (figure 6). The specimen, nicknamed "Woody," may represent one of the youngest juvenile mammoths from the Colorado Plateau. The remains of a bighorn sheep (*Ovis canadensis*) and a bison (*Bison bison*) were found in rock shelters within Arches (Mead and others, 1991). Packrat middens are common in the dry rock shelters and contain needles from Douglas fir (*Pseudotsuga menziesii*) and Limber Pine (*Pinus flexilis*). Radiocarbon dating of organic remains from the middens have yielded dates between 12,400 to 20,000 yr B.P.

BRYCE CANYON NATIONAL PARK

Bryce Canyon National Park was originally established as a national monument on June 8, 1923. The area was designated and renamed Utah National Park on June 7, 1924. Finally, on February 25, 1928, the park was renamed Bryce Canyon National Park. Bryce Canyon National Park lies along the eastern margin of the Paunsaugunt Plateau in south-central Utah. The pink and white spires and cliffs have developed along an eroding fault escarpment within the early Tertiary Claron Formation. Underlying Upper Cretaceous rocks have produced a variety of paleontological resources from within and near Bryce Canyon National Park. For more information on the geology and a stratigraphic section of Bryce Canyon National Park, see Gregory (1951), Bowers (1990), and the Bryce Canyon article in this volume.

The Dakota Formation is the oldest exposed unit within Bryce Canyon National Park. A large collection of vertebrate fossils, including the remains of fish, sharks, rays, lizards, crocodiles, turtles, dinosaurs, and early marsupial mammals occur in the fluvial facies of the Dakota near the park (Jeff Eaton, Weber State University, written communication, 1999). This fauna represents the most complete upper Cenomanian terrestrial vertebrate record in the world (Eaton, 1993a, 1995; Eaton and others, 1997, 1999a, 2001; Eaton and Kirkland, 2001, 2003). Many freshwater vertebrate lineages typical of the Jurassic and Early Cretaceous are last recorded in these sites. The last North American fossil lungfish is known from the Dakota just east of the park, which documents the last gasp of a largely Jurassic freshwater fish fauna that dies out at the end of the Cenomanian (Kirkland, 1987; Kirkland and Eaton, 2002). Locally, *in situ* petrified tree stumps, large fragments of silicified and coalified wood, and palynomorphs (spores and pollen) have been found in the carbonaceous beds of the Dakota (May and Traverse, 1973). Overlying the carbonaceous beds, the remains of the bivalves (oysters) *Exogyra* and *Pycnodonte* commonly occur at the top of the Dakota (Gayle Pollock, NPS, written communication, 1999; Cobban and others, 2000).

The Tropic Shale and its equivalents are some of the most fossiliferous Upper Cretaceous (upper Cenomanian to middle Turonian) marine units in North America. The Tropic contains an abundance of marine invertebrates and the remains of a few marine vertebrates. The lower portion of the Tropic contains concretions preserving a diverse invertebrate fauna associated with the upper Cenomanian index fossil *Sciponoceras gracile* and the upper portion contains the middle Turonian index fossil *Collignoniceras woollgari* (Peterson and Waldrop, 1965). A small collection of invertebrate fossils has been recovered from within the park (Cobban and others, 1996, 2000). Gayle Pollock of Bryce Canyon National Park has collected fossil pearls from the Tropic Shale outside of the park near the town of Tropic, Utah (W. Cobban, U.S. Geological Survey, written communication, 2000). A few localized concentrations of fossil shark and ray teeth have been recovered from the upper portions of the Tropic Shale at nearby localities outside of the park.

A significant upper Middle Turonian brackish water molluscan locality occurs in the Smoky Hollow Member of the Straight Cliffs Formation on the northeastern side of Bryce Canyon National Park at Glory Cove (Hoffman, 2005). The Straight Cliffs and Wahweap Formations contain significant terrestrial vertebrates (theropods and hadrosaurs) (Eaton, 2005). Eaton and his colleagues continue to research the Straight Cliffs and Wahweap sediments in an effort to refine the biostratigraphy of the up-

Figure 7. Rostral teeth (left) and oral teeth (right) of a new species of freshwater sawfish recovered by screen-washing a microvertebrate site in the Upper Cretaceous Wahweap Formation at Bryce Canyon National Park.

permost Cretaceous from the Paunsaugunt Plateau (Eaton and others, 2009). The vertebrate fauna from Bryce Canyon includes fish (figure 7), dinosaurs (figure 8), crocodiles, lizards, turtles, and mammals, including a partial upper molar from a marsupial (Eaton and Morrow, 1990; Eaton and others, 1993a, 1998, 1999c; Eaton, 1994, 1995, 1999a; Munk, 1998). Chris Shierup of Northern Illinois University surveyed the Wahweap Formation in the western part of the Paunsaugunt Plateau, including one locality in the park, during 1999. Shierup recovered vertebrae, ribs, shoulder bones, and one theropod tooth that are currently under study. East of Bryce Canyon hadrosauromorph dinosaur skeletons were discovered in both the upper Turonian Smoky Hollow and upper Coniacian basal John Henry Members of the Straight Cliffs Formation and are being researched by UGS paleontologists. These discoveries represent the only dinosaur skeletal sites of these ages in North America.

Eaton (1993b; Eaton and others, 1999c) initially suggested that the fauna from the stratigraphically highest Cretaceous rocks of the plateau shows affinities to the Kaiparowits Formation. Recent research indicates that the Wahweap Formation comprises the youngest preserved strata and approximately a mile of strata is missing at the top of the Cretaceous section at Bryce Canyon National Park. This suggests significant uplift and erosion along the Paunsaugunt fault on the eastern boundary of Bryce Canyon during Laramide time (J.G. Eaton, Weber State University, verbal communication, 2010).

The Claron Formation (late Paleocene to early Eocene) is composed of limestone, mudstone, sandstone, and conglomerate beds that form the scenic landforms of Bryce Canyon National Park. The strata were deposited in lacustrine, fluvial, and overbank floodplain environments, but have been altered considerably by massive calcretization within many of the beds. A few invertebrate fossils and palynomorphs have been documented from this for-

Figure 8. Hadrosaur jaw fragment from John Henry Member of Straight Cliffs Formation at Bryce Canyon National Park.

mation (Eaton and others, 1999b). A large number of invertebrate trace fossils were recently reported from the Claron (Bown and others, 1997). The ichnofossils include hymenoptera nests, beetle burrows, and scorpion trails.

The Boat Mesa Conglomerate, inferred to be Oligocene in age, overlies the Claron Formation. Permian invertebrates are preserved within chert pebbles from this conglomerate, indicating that Permian-age rocks were at least a partial source of the clasts. A single mammoth tooth (*Mammuthus*) is cataloged in the park collections and was allegedly collected from Pleistocene alluvium within Bryce Canyon National Park (Gayle Pollock, Bryce Canyon Natural History Association, written communication, 1999).

CANYONLANDS NATIONAL PARK

Canyonlands National Park was established on September 12, 1964. The park consists of scenic geologic features including spires, mesas, and canyons formed by the down-cutting of the Colorado and Green Rivers into the heart of the Colorado Plateau. For more information on the geology and a stratigraphic section of Canyonlands National Park, see Lohman (1974), and Huntoon and others (1982), and the Canyonlands article in this volume.

The Honaker Trail Formation is a very fossiliferous Pennsylvanian limestone exposed in Canyonlands National Park. This unit contains rugose corals, bryozoans, brachiopods, gastropods, a few trilobites, and crinoids (Baars, 1993, Canyonlands article in this volume). The nomenclature of the overlying fossiliferous Upper Pennsylvanian-Lower Permian rocks are confusing, with different authors using the Elephant Canyon Formation, Halgaito Shale, upper Hermosa Formation, and lower Cutler Formation for the intergrading lithologies. Marine invertebrates are common in these rocks and are known from many localities at Canyonlands National Park. Fossils include foraminifera, corals, bryozoans, brachiopods, bivalves, cephalopods, gastropods, scaphopods, ostracodes, trilobites, crinoids, shark teeth, and bony fish (McKnight, 1940; Rigby and others, 1971; Baars, 1993; Sumida and others, 1999). Rigby and Stokes (1971) described sponges from limestone ledges of the Hermosa Formation.

The Lower Permian Cedar Mesa Sandstone of Canyonlands National Park has yielded foraminifera and (rare) crinoids (Canyonlands article in this volume). Langford and others (2007) found bryozoans, brachiopods, and crinoids from marine transgressive surfaces in sandstones of The Needles District. Loope (1984) plotted the location of two Cedar Mesa tracksites (both rockfall specimens from dune sandstones in the lower part of the unit) within the park. There may also be some tracks in the Cedar Mesa in the park that are accessible by river (A. Hunt, New Mexico Museum of Natural History, verbal communication, 1998). A fossil-rich locality within the Cedar Mesa is reported from the Indian Creek drainage just east of Canyonlands National Park (Stanesco and Campbell, 1989; Sumida and others, 1999). Cranial and vertebral remains of the pelycosaur reptile *Sphenacodon* and fragments identified as the temnospondyl amphibian *Eryops* were collected from within a petrified log jam. The logs at this locality have been identified as conifers and reach nearly 6 feet in diameter. This site was completely destroyed by vandalism in 1995 (Sumida and others, 1999). Examples of these logs are on exhibit at the Dinosaur Museum in Blanding, Utah. Continued research on the vertebrate fossils is being conducted with some success by the Utah Museum of Natural History (Randy Irmis, University of Utah, verbal communication, 2009).

A few fossils have also been reported from overlying Cutler Group units within the park. Root traces are known from several horizons (Stanesco and Dubiel, 1992), and burrows are also present (Chan, 1989). The White Rim Sandstone above has even fewer fossils, but park outcrops have yielded algal laminations, root traces, tree trunk traces, possible burrows (Chan, 1989), and a crinoid fragment (Steele-Mallory, 1982). Finally, Stokes (1986) published a photograph of possible amphibian tracks from unspecified Cutler Group rocks in lower Labyrinth Canyon.

A few poorly preserved steinkerns (internal molds) and gastropod impressions were reported from the Lower Triassic Sinbad Limestone Member of the Moenkopi Formation in Canyonlands National Park (Lucas, 1995). These specimens were first reported by McKnight (1940) and are dominated by the following taxa: the brachiopod *Lingula* sp., *Monotis thaynesiana*, unidentified viviparoid gastropods, and the ammonite *Meekoceras* sp.

The Upper Triassic Chinle Formation is well exposed in Canyonlands National Park and contains diverse faunal, floral, and ichnofossil assemblages. Vertebrate body fossils reported from the park include the remains of semionotid and turseodid fish, metoposaurs, phytosaurs, and the aetosaur *Stagonolepis* (Hasiotis, 1993; Lucas and others, 1997; Heckert and others, 1999). Freshwater gastropods, bivalves, conchostrachans, and the earliest known crayfish also occur within this unit (figure 9). An abundance of fossil plants occur in the Owl Rock Member of the Chinle, including *Neocalamites* sp. and *Pagiophyllum* sp.

Burrows produced by lungfish, crayfish, worms, and

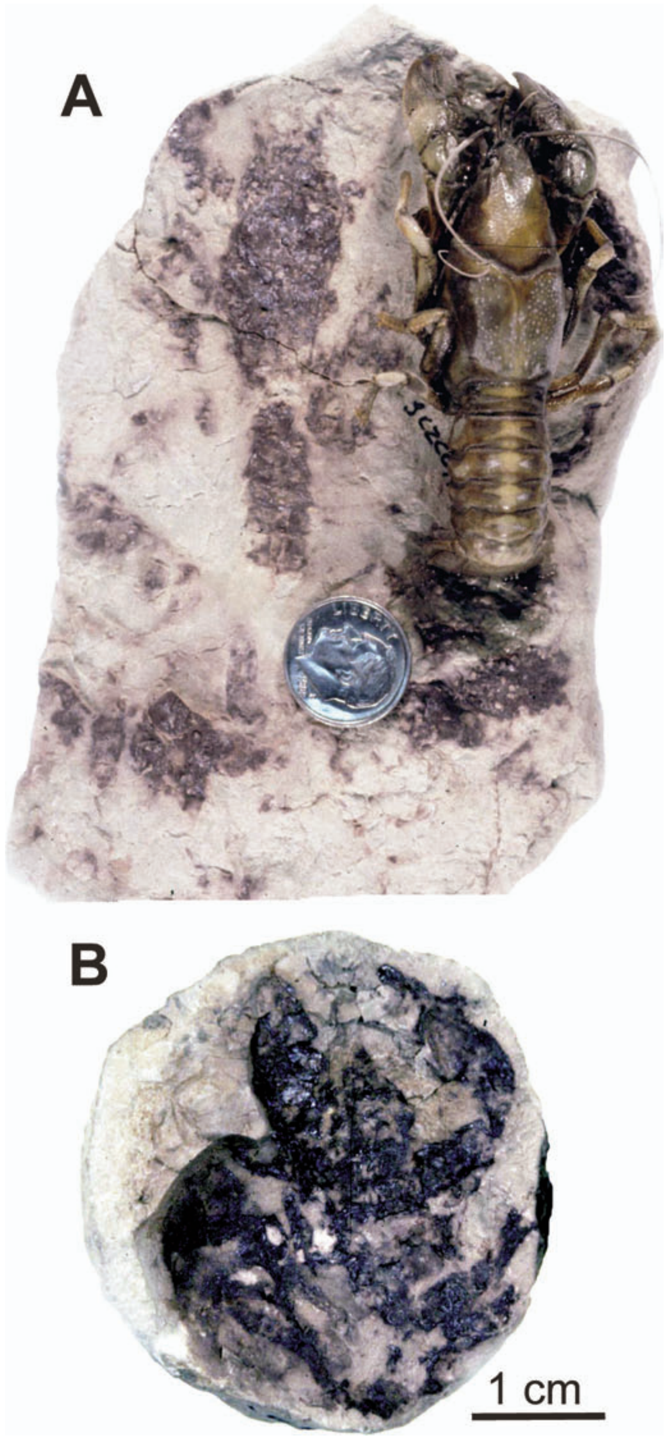

Figure 9. Fossil crayfish from the Owl Rock Member of the Chinle Formation at Canyonlands National Park. A) fossil crayfish on bedding plane compared to modern crayfish, Dime for scale. B) Crayfish preserved within its burrow.

insects are common in the Chinle Formation in Canyonlands National Park (Hasiotis and Mitchell, 1989; Hasiotis, 1993, 1995). Hasiotis (1993) also reported a horseshoe crab resting trace from the park. A single well-preserved impression of a tridactyl dinosaur footprint (*Grallator* sp.) was found in the Church Rock (= Rock Point) Member of the Chinle Formation near Upheaval Dome (Hunt and others, 1993b; Lucas and others, 1995). Another Chinle tracksite contains impressions of a tetrapod with a four-toed manus and a five-toed pes. These tracks have blunt toes, lack claw impressions, and have been identified as *Brachychirotherium* sp. There are also two types of large five-toed tracks. One set is associated with an aetosaur-like reptile and the other is attributed to a dicynodont reptile (Santucci and others, 1998).

Fossil vertebrate tracks are also known from the upper part of the Lower Jurassic Kayenta Formation just below the overlying Navajo Sandstone in Canyonlands National Park (Lockley and Hunt, 1993; Santucci and others, 1998). Additionally, complexes of vertebrate burrows are known from interdune deposits of the Navajo within and near the park (Hasiotis and others, 2007).

Quaternary fossils from Canyonlands National Park include samples used to date sediments at the park (Biggar and Adams, 1987), packrat middens and associated arthropod fossils (Elias and others, 1992; Anderson and others, 2000; Coats and others, 2008), and pollen from the Virginia Park-Needles area (Reheis and others, 2005). Cowboy Cave, a notable Quaternary site, is just south of Canyonlands National Park's Horseshoe Canyon Unit. The contents of the cave were extensively described by Jennings (1980). It is of particular interest for having both extensive Pleistocene material and four distinct Holocene cultural layers above, spanning at least the last 13,000 years (humans present only since ~9,000 years ago). In the Pleistocene layer, various types of mammal dung and hair were found with packrat middens and a handful of bones, mostly bison, but also two juvenile mammoth tusks and a possible elk bone (Barnett and Coulam, 1980; Hansen, 1980; Jennings, 1980; Spaulding and Peterson 1980). Prehistoric dung at the cave was mostly produced by bison. Other dung producers may include rodents, rabbits, Shasta ground sloths (*Nothrotheriops shastensis*), elephants, horses, elk, or camel (Hansen, 1980; Mead and Agenbroad, 1992), and humans (Hogan, 1980).

CAPITOL REEF NATIONAL PARK

Capitol Reef was established as a national monument on August 2, 1937. The site was redesignated as a national park on December 18, 1971. The park preserves narrow, high-walled gorges cut through the 100-mile-long Waterpocket Fold. For more information on the geology and a stratigraphic section of Capitol Reef National Park, see Gregory and Anderson (1939), Smith and others (1963), Davidson (1967), Billingsley and others (1987), Collier (1987), and the Capitol Reef article in this volume.

John C. Fremont traveled through the northern portion of the Capitol Reef area in 1853, during his fifth and final expedition through Utah prior to the Civil War. Fremont's party may have been the first Europeans to enter the area. G.K. Gilbert was probably the first geologist to visit the area which is now within Capitol Reef National Park. Fossil vertebrate tracks in the park received considerable attention by researchers after their discovery in

1945. A paleontological survey was conducted in 1994 along the GarKane Power Company's right of way through Capitol Reef National Park (Burres, 1994).

The Permian White Rim Sandstone (Cutler Group), which crops out locally within the park, is interpreted as a shoreface and coastal dune deposit (Kamola and Chan, 1988). The marine trace fossils *Thalassinoides* and *Chondrites* are abundant in some parts of the cross-stratified sandstone facies. The Kaibab Limestone is a fossiliferous marine carbonate unit that interfingers with the White Rim. The Kaibab contains fragmentary marine invertebrates including bryozoans, brachiopods, gastropods, bivalves, and crinoids.

The Triassic Sinbad Limestone Member of the Moenkopi Formation contains brachiopods, gastropods, bivalves, and ammonites. *Lingula* sp. is the only invertebrate fossil to be found outside of the Sinbad Limestone in the Moenkopi (Smith and others, 1963). Fossil vertebrate tracks were first reported from the Moenkopi in the Capitol Reef area by Charles Kelly in 1945. Paleontologist Charles Camp and Zion National Park naturalist Myrl Walker independently visited Capitol Reef in 1950 to survey for additional Moenkopi tracks after learning about Kelly's discovery. Peabody (1948, 1956) and Lammers (1964) published on the fossil vertebrate tracks, including *Chirotherium, Rotodactylus, Palaeophycus*, and *Diplidnites* from the Torrey Member of the Moenkopi Formation within Capitol Reef. McAllister and Kirby (1998) reported on a variety of subaqueous reptile traces, including kick-off scours, z-traces, and buoyancy-size-mitigated, variably preserved traces.

In 1921, R.C. Moore, who was working with H.E. Gregory, collected some leaf impressions from the Upper Triassic Shinarump Conglomerate Member of the Chinle Formation in the Circle Cliffs area that is now within Capitol Reef National Park (Ash, 1975). These fossil plants were described by Berry (1927) and named *Zamites powelli*. Fossil plants were also collected in the Capitol Reef area by Roland Brown of the U.S. Geological Survey. Brown identified the fossil plants as *Palissya* sp., *Sphenozamites* sp., and an undetermined cycad leaf. The best preserved and most abundant stems of the fossil horsetail *Equisetites* occur in the Shinarump in the northern part of the park. *Phlebopteris, Cyneopteris, Cladophlebis, Pagiophyllum,* and *Araucarioxylon* are also known from this locality (Ash, 1975, 1993a). Leaves of a palm-like plant called *Sanmiguelia* cf. *S. lewisi* were reported from the Owl Rock Member of the Chinle Formation at Capitol Reef National Park (Ash, 1982). Petrified wood (figure 10), leaf impressions, bivalves, vertebrate bones, coprolites and trace fossils, including a few tridactyl tracks, have also been found within the Chinle at the park.

Large algal mounds are reported from interdunal playa deposits within the Jurassic Navajo Sandstone in Capitol Reef (Len Eisenberg, verbal communication, 1999). The algal mounds occur within carbonate lenses that have been tentatively interpreted as "oasis deposits."

Figure 10. Petrified wood from the Upper Triassic Chinle Formation at Capitol Reef National Park.

The Middle Jurassic Carmel Formation in central and southern Utah, including several localities in Capitol Reef National Park, contains a small but notable marine assemblage including *Ostrea* sp., *Trigonia* sp., *Camptonectes* sp., and the star-shaped columnals of the crinoid *Isocrinus asteriscus* (Imlay, 1964; Sohl, 1965). Jurassic dinosaur bones and petrified logs occur in the upper portion of the Salt Wash Member of the Morrison Formation in and near Capitol Reef National Park. A skeleton of a possible *Tenontosaurus* is being excavated by the Utah Geological Survey in the Lower Cretaceous Ruby Ranch Member of the Cedar Mountain Formation from within 1 mile of the eastern boundary of the park near Cathedral Valley. A highly diverse terrestrial fauna (80+ taxa) has been documented from the basal Upper Cretaceous in the overlying Mussentuchit Member of the Cedar Mountain just north of the park on the west side of the San Rafael Swell (Cifelli and others, 1997, 1999; Kirkland and others, 1997; Kirkland and Madsen, 2007).

The Cretaceous Dakota Sandstone is locally fossiliferous at Capitol Reef and contains a dense oyster shell coquina known within the park as the "Oyster Reef." Study of the "Oyster Reef" reveal that the distribution of oysters provide important clues to the specific environments responsible for each layer of rock in the transition from the Dakota into the lower Mancos Shale, as oysters have shells made out of calcite, which preserves well, and each species has distinct environmental preferences (Kirkland, 1996). Thus, the fossil oysters record a detailed environmental history of changing environments as the Cretaceous Western Interior Seaway spread westward across Capital Reef National Park (figure 11). Many additional marine fossils, including bivalves, gastropods, ammonites, and shark teeth, have been recovered from the Tununk Shale and Blue Gate Members of the Mancos Shale in and around Capitol Reef (W. Cobban, U.S. Geological Survey, written communication, 2000).

The Flagstaff Limestone is a fossiliferous unit of late Paleocene or early Eocene age in the park. Charophytes,

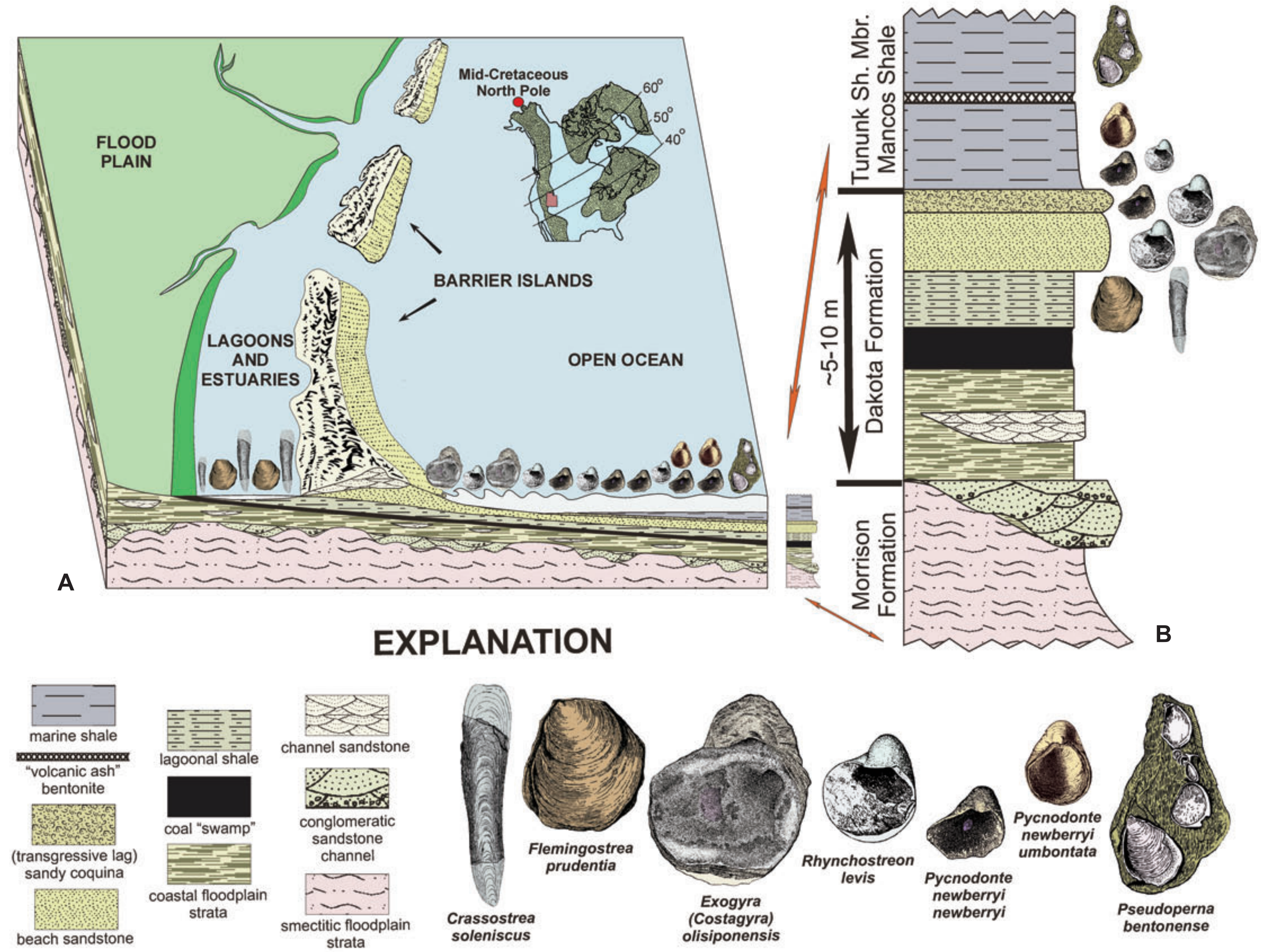

Figure 11. Environmental interpretation of the distribution of mid-Cretaceous oysters during the deposition of the Dakota Formation and lower Tununk Shale Member of the Mancos Shale at Capital Reef. A) Generalized block diagram illustrating the general distribution with mid-Cretaceous sea level rise in the Capital Reef National Park area. Inset of North America during mid-Cretaceous showing extent of Cretaceous Western Interior Seaway. B) A generalized stratigraphic section of the Dakota Sandstone and basal Tununk Shale at Capital Reef National Park. Oyster illustrations modified after Stanton (1893) and oyster paleoecology after Kirkland (1996).

ostracods, bivalves, and gastropods indicate a freshwater origin for the carbonate unit (Smith and others, 1963).

Over two dozen packrat middens from Capitol Reef National Park have been studied in order to assess local vegetational changes from the Pleistocene through the Holocene (Cole, 1992; Cole and Henderson, 1993). The oldest midden is dated to somewhat older than 39,000 yr B.P. The remains of a Pleistocene mammoth were found on Boulder Mountain, west of the park.

CEDAR BREAKS NATIONAL MONUMENT

Cedar Breaks National Monument was established through Presidential proclamation on August 22, 1933. The monument preserves a huge and colorful natural amphitheater eroded from a 2,000-foot-thick escarpment in Upper Cretaceous and Paleogene rocks. For more information on the geology and a stratigraphic section of Cedar Breaks National Monument see the Cedar Breaks article in this volume.

The only reports of paleontological resources from within or near Cedar Breaks National Monument include some marine invertebrates from the Jurassic Carmel Formation just west of the monument (Imlay, 1964) and freshwater gastropods and fish scrap are known from the early Tertiary Claron Formation (J.G. Eaton, Weber State University, personal communication, 2010). Eaton (Eaton and others, 1999a, 2001; Eaton, 2003a, 2003b, 2006) reported on vertebrate fossils, including fish, turtles, dinosaurs, and mammals from within the Dakota, Straight Cliffs, and possibly Wahweap Formations in Cedar Canyon extending to the west of the monument. During the 1990s a partial theropod dinosaur skeleton was collected from the Straight Cliffs Formation below Cedar Breaks by David Archibald of San Diego State University.

David Madsen (Utah Geological Survey [currently

Desert Research Institute], verbal communication, 1999) has examined Quaternary pond deposits from two localities that are adjacent to Cedar Breaks National Monument. The remains of insects, plant macrofossils, and palynomorphs (spores and pollen) have been recovered. Radiocarbon dates from these deposits range from 17,000 yr B.P. through the Holocene.

DINOSAUR NATIONAL MONUMENT

Dinosaur National Monument was established by presidential proclamation on October 4, 1915. The site was originally established to protect the famous dinosaur quarry discovered in the Upper Jurassic Morrison Formation by Carnegie Museum paleontologist Earl Douglass (figure 12). The monument was enlarged in 1938 to include the spectacular canyons cut by the Green and Yampa Rivers. For more information on the geology and a stratigraphic section of Dinosaur National Monument, see Untermann and Untermann (1954, 1969), Hansen and others (1983), Hansen (1996), and Dinosaur National Monument article in this volume.

The oldest sedimentary unit known from Dinosaur National Monument is the Precambrian Uinta Mountain Group. Hansen (1996) reported on fossilized algal globules of *Chuaria* sp. from the Uinta Mountain Group near Manila, Utah, about 70 miles north of the monument.

The Upper Cambrian Lodore Formation consists of variegated, glauconitic shales, and sandstones that contain marine invertebrates and trace fossils. Brachiopods, gastropods, and trilobites have been identified from the Lodore Formation in Dinosaur National Monument (Herr, 1979; Herr and others, 1982; Hansen, 1996).

Corals, brachiopods, gastropods, and echinoderms are preserved, but rare, in the Lower Mississippian Madison Limestone (Hansen and others, 1983). Upper Mississippian brachiopods, fish, and coal beds are present in the Doughnut Formation (Hansen and others, 1983). The Lower Pennsylvanian Round Valley Limestone contains bryozoans, brachiopods, mollusks, and echinoderms (Hansen and others, 1983). Sponge spicules, corals, brachiopods, echinoid spines, crinoids, foraminifera, and conodonts are common in the marine facies of the Middle Pennsylvanian Morgan Formation (Driese, 1982).

The Permian Park City Formation (equivalent to the Phosphoria Formation farther north) consists of limestone, dolostone, sandstone, and some chert layers. Marine invertebrates including brachiopods, bivalves, cephalopods, gastropods, and other invertebrates have been found in this unit (Hansen and others, 1983).

Peabody (1948) studied some unusual reptile tracks in the Lower Triassic Moenkopi Formation in the vicinity of Dinosaur National Monument. These include some swimming traces now in the collections of the Utah Field House of Natural History in Vernal, Utah. *Scoyenia* traces have been reported from the Moenkopi at Dinosaur National Monument (Lockley and others, 1990).

Figure 12. Paleontologist Earl Douglass during the excavation of a Diplodocus skeleton in the Douglass Quarry at Dinosaur National Monument, circa 1923 (National Park Service photo collection).

In the 1960s an important vertebrate tracksite was discovered just northeast of Dinosaur National Monument. Today over two dozen tracksites have been identified within the monument. Numerous tracksites have been discovered in the Upper Triassic Popo Agie and Chinle Formations. Fossil tracks are diverse and include those identified from dinosaurs, mammal-like reptiles, phytosaurs, aetosaurs, lepidosaurs, trilophosaurs(?), and tanystropheids (Lockley and others, 1990, 1992a, 1992b, 1992c; Hunt and others, 1993a). Among these is a swimming trackway of *Gwyneddichnium* that shows webbing between the toes. In addition, there are examples of both walking and swimming types of these tracks. Horseshoe crab-like tracks are documented from the Chinle Formation at Dinosaur National Monument. There is also some petrified wood in the Chinle in the monument.

Tridactyl theropod tracks and a rich *Otozoum* tracksite are known from the Triassic-Jurassic Nugget Sandstone (Lockley and others, 1992a; Santucci and others, 1998). In 2009, paleontologists Dan Chure and George Engelmann discovered a locality with hundreds of small mammal tracks in an eolian sandstone in the Nugget Sandstone within the monument. The Middle Jurassic Carmel Formation is a shallow marine deposit that locally contains gypsiferous beds. Bivalves, gastropods, echinoderms, and a few rare tridactyl vertebrate tracks have been reported from the Carmel in nearby areas adjacent to Dinosaur National Monument.

Chure (1993) reported on three plesiosaur specimens that may have been collected from the Redwater Member of the Stump Formation (Upper Jurassic) near the western boundary of Dinosaur National Monument. Belemnites, ammonites, gastropods, and bivalves occur in the Middle Jurassic Curtis Member of the Stump Formation in the Dinosaur National Monument area.

The Upper Jurassic Morrison Formation is widely recognized as one of the most prolific dinosaur-bearing units

Figure 13, Skull of Allosaurus fragilis (Utah's State fossil) collected by the University of Utah in the Brushy Basin Member of the Morrison Formation at the Carnegie Quarry, Dinosaur National Monument.

in the world. In addition to the dinosaurs, the Morrison has produced important collections of Jurassic mammals and other vertebrates (Chure and Engelmann, 1989). The Morrison at Dinosaur National Monument contains four members including, from oldest to youngest, the Windy Hill, Tidwell, Salt Wash, and Brushy Basin Members (Turner and Peterson, 1999, 2004).

Utah's first theropod dinosaur (also recognized as the second dinosaur discovered in Utah) was found in 1870 near what is today Dinosaur National Monument (Marsh, 1871; Bilbey and Hall, 1999). Earl Douglass made his famous discovery of the dinosaur bonebed in 1909. Under Douglass' direction the Carnegie Museum worked the site until 1922. During 1923, the U.S. National Museum collected a specimen of *Diplodocus*, which was mounted for display in that museum (figure 12). In 1924, the University of Utah collected a skeleton of *Androdemus* (now *Allosaurus*) from the quarry (figure 13). Holland (1912, 1915, 1916b, and 1924) and Gilmore (1924, 1925a, 1925b, 1926, 1932, 1936a, and 1936b) published extensively on the dinosaur discoveries from Dinosaur National Monument.

Theodore White was hired as the monument's first paleontologist in 1953. White focused his attention on the preparation of the *in situ* bone-bearing layer and talking with the public about the world of dinosaurs. He hired and trained two maintenance men, Tobe Wilkins and Jim Adams, to relief the bones on the Carnegie Quarry cliff face (figure 14). White published both scientific and popular articles about the fossils at Dinosaur National Monument (White, 1958, 1964, 1967). White liked to call himself the "Chief Ramrod of the Hammers and Chisels" until his retirement in 1973 (Ann Elder, NPS, written communication, 1999). Russ King, Dan Chure, Ann Elder, and Scott Madsen have recently worked as staff paleontologists at Dinosaur National Monument (Chure, 1987, 1992; Chure and McIntosh, 1990). Elder (1999) provides an historical overview of the Carnegie Quarry at Dinosaur National Monument.

Between 1989 and 1992, George Engelmann conducted a comprehensive paleontological survey of the Morrison Formation at Dinosaur National Monument (Engelmann, 1992). More than 270 fossil sites were recorded during the survey. Most of the sites were dinosaur bone localities, but sites containing plant remains, invertebrates, and small vertebrates were also reported. In 1990, Engleman discovered the first large carnivorous theropod dinosaur in the Salt Wash Member of the Morrison (Chure and Madsen, 1993; Chure and others, 1993). Scott Madsen and Ann Elder collected the post-cranial skeleton over several years, but the skull was only discovered (figure 15) when University of Utah radiologist Ramal Jones conducted a radiological survey of the quarry (Jones, 2000; Jones and Chure, 2000). This is one of the most important paleontological specimens ever discovered through the use of technology. Chure (2000a) determined that the now virtually complete skeleton was a new, undescribed species of Utah's state fossil, *Allosaurus*.

Figure 14. In situ *dinosaur skeletal remains in the Brushy Basin Member of the Morrison Formation at the Carnegie Quarry in the visitor center at Dinosaur National Monument. Note the neck and skull of the common Upper Jurassic sauropod Camarasaurus at the top of the cliff.*

Other important dinosaur specimens have been collected in recent years from the Morrison Formation at Dinosaur National Monument. Chure (1994) reported on the oldest troodontid dinosaur which was recovered as a distinctive isolated tooth. A partial skeleton of a hatchling dinosaur, identified as *Camptosaurus*, was discovered at the monument in 1991 (Chure and others, 1992). This is the only hatchling of *Camptosaurus* sp. known from the fossil record.

Chure and others (1989) reported on non-mammalian vertebrates collected from the Brushy Basin Member of the Morrison in Dinosaur National Monument. Evans and Chure (1999) reported on lizards from the Morrison that were collected in the monument. The remains of the tur-

Figure 15. Ramal Jones with skull of new species of Allosaurus he located using high-resolution radiological mapping of the quarry in the Salt Wash Member of Morrison Formation at Dinosaur National Monument.

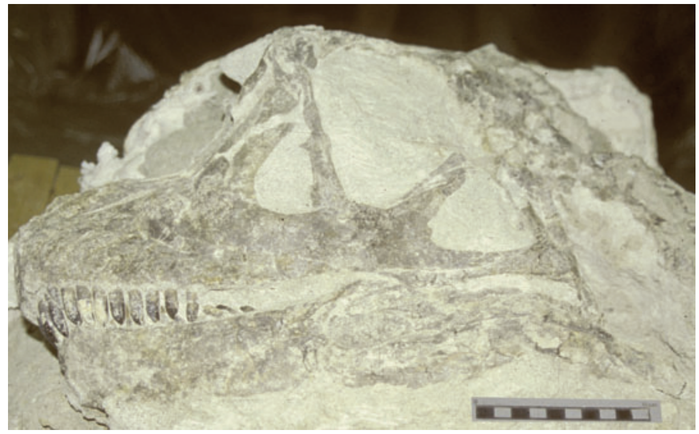

Figure 16. First known North American Cretaceous sauropod skull from the Cedar Mountain Formation at Dinosaur National Monument; holotype of Abydosaurus mcintoshi.

tle *Glyptops* sp. and the crocodile *Hoplosuchus kayi* (Gilmore, 1926) and *Goniopholis* sp. have been collected from the monument. Several tiny frog skeletons and many isolated frog bones have been collected from a Brushy Basin microvertebrate locality in the park. Some of the frog remains have recently been described and represent a new pipoid anuran named *Rhadinosteus* (Henrici, 1992, 1993, 1998).

Engelmann and others (1989) reported on microvertebrates, including mammals, that have been collected from quarries in Dinosaur National Monument. The quarries are in the Brushy Basin Member of the Morrison and have yielded hundreds of isolated teeth and a few partial jaws. The skull of a new multituberculate *Glirodon grandis* was also found at the monument (Engelmann and Callison, 1999). Other mammals identified include a triconodont, a symmetrodont, at least two species of dryolestids, and a paurodontid.

Yen and Reeside (1950) described freshwater mollusks from the Morrison Formation. Sohn and Peck (1963) identified the ostracod *Theriosynoecum wyomingense* as a guide fossil for the Salt Wash Member of the Morrison.

Ash (1993b, 1994) reported on an unusual leaf *Czechanowskia* sp. from the Brushy Basin Member of the Morrison Formation in the monument. This plant is considered by some as an indicator of humid paleoclimates. The discovery of this plant in deposits of an alkaline-saline lake farther south brings this interpretation into question (Turner and Fishman, 1991). A ginkgo leaf locality occurs in the middle of the Brushy Basin. Tidwell (1990) reported on a plant locality in Orchid Draw in the western part of Dinosaur National Monument. A palynological (fossil pollen) assessment of the Morrison, including several sites within the monument, was conducted by Litwin and others (1998).

Recent evidence shows that dermestid beetle larvae (Coleoptera: Dermestidae) borings are preserved in dinosaur bones collected from the Carnegie Quarry (Hastiotis and others, 1999). These trace fossils suggest subaerial exposure of the dinosaur carcasses prior to burial and represent the earliest evidence of dermestids in the paleontological record.

Recent work in the Lower Cretaceous Cedar Mountain Formation has produced some spectacular fossil specimens. One site in particular, a river-deposited bonebed, has yielded a nearly complete articulated sauropod skull (figure 16), elements of a second disarticulated sauropod skull, two additional skulls, numerous sauropod post-cranial elements, and a few isolated theropod bones (Chure, 2000b; Chure and others, 2006; Kirkland and Madsen, 2007). These are the first Cretaceous sauropod skulls ever found in North America and have been described as the new brachiosaurid genus *Abydosaurus mcintoshi* (Chure and others, 2010).

The Dakota Formation of late Early Cretaceous age in this region consists of shoreface and terrestrial strata deposited along the western margin of the Western Interior Seaway. Petrified wood and fragmentary invertebrate remains have been found in this formation and the Utah Field House of Natural History has a collection of dinosaur bones from the basal Dakota Formation west of Dinosaur National Monument. Additionally, bird tracks were recovered from the Dakota from a site just west of the park boundary (Anfinson and others, 2004). Fish scales and bones are locally abundant in the overlying Mowry of earliest Late Cretaceous age. Bivalves, ammonites, and shark teeth are also known from the Mowry in the Dinosaur National Monument area. The Upper Cretaceous Frontier Formation contains bivalves, gastropods, ammonites, shark teeth, petrified wood, and some thin coal beds. The Mancos is not well exposed in the monument, but locally this unit is very fossiliferous and preserves a high diversity of marine invertebrates. Ammonites are reported from the Mancos at Ashley Creek and Brush Creek near the monument (Kennedy and Cobban, 1991).

Sharpe (1991) reported on the Quaternary and Holocene flora in Dinosaur National Monument collected to assess vegetation changes.

GLEN CANYON NATIONAL RECREATION AREA

Initially administered under a cooperative agreement with the Bureau of Reclamation that was signed on April 18, 1958, Glen Canyon National Recreation Area (GCNRA) was established as a unit of the NPS on October 27, 1972. The recreation area includes the 186-mile-long Lake Powell, which was formed by one of the world's highest concrete dams. For more information on the geology and a stratigraphic section of Glen Canyon National Recreation Area see Glen Canyon article in this volume.

John Wesley Powell led expeditions down the Colorado River, passing through Glen Canyon in 1869 and 1871. Powell and his survey team traveled the Colorado River by boat and collected a few paleontological specimens. The Geographic and Geologic Survey of the Colorado Plateau was established soon thereafter and was under the direction of Powell until 1879, when all of the geographical and geological surveys of the western United States were abolished and their work was incorporated into the newly formed United States Geological Survey. Construction of the Glen Canyon Dam was initiated in 1957 and completed in 1963. Lake Powell was finally filled approximately 17 years after completion of the dam. A systematic paleontological survey was never conducted along the Colorado River in Glen Canyon prior to construction of the dam. Fossils along the lake shoreline experience periods of submergence and periods of emergence due to fluctuations in the lake's water levels. A popular publication by Crampton (1994) provides photos of the natural and cultural resources within the Glen Canyon area prior to the flooding by Lake Powell.

The oldest known fossils from GCNRA occur within the Middle-Upper Pennsylvanian Honaker Trail Formation. Ritter and others (2002) reported on one Honaker Trail locality which has produced algae, fusulinid foraminifera, other foraminifera, bryozoans, gastropods, crinoids, conodonts, and pellets. Another record of Honaker Trail fossils from just outside of the recreation area, in Dark Canyon, was reported by Loope (1994). These include rhizoliths from eolian rocks, and foraminifera, bryozoans, gastropods, pellets, and borings from marine rocks.

A species of the rare temnospondyl amphibian *Platyhystrix* was collected from the Upper Pennsylvanian Halgaito Formation at a site called the Cedar Point Locality (Sumida and others, 1999). A nearly complete dorsal "sail" from this animal was recovered from the Cedar Point Locality that overlooks the San Juan River Canyon where it winds through the upper part of the recreation area. The fossil was recovered from a conglomeratic stream channel (Vaughn, 1962; Berman and others, 1981). In a locality east of the Cedar Point Locality, just north of Mexican Hat, Utah, Vaughn (1962) documented so many specimens of this amphibian that he designated the site the "*Platyhystrix* Pocket." Isolated bones and fragments are reported from eolian sandstones, channel sandstones, and conglomerates of the Halgaito elsewhere in the recreation area by Scott and Sumida (2004).

Three Permian vertebrate tracksites are known from the Cedar Mesa Sandstone within GCNRA. One of the tracksites documented evidence of a predator attacking prey; however, only photographs and replicas of this trackway are available for study since the original site is now under the waters of Lake Powell. This tracksite was named the "Dirty Devil Tracksite" and has been interpreted as a "Permian Murder Scene" because *Anomalopus* sp. tracks converge on the smaller *Stenichus* sp. trackway (Lockley and Madsen, 1993). The two other Permian track localities are named "Steer Gulch" and "Grand Gulch" tracksites. Synapsids were the primary track makers, leaving tracks similar to *Anomalopus* and *Chelichnus*. Lizard-like tracks are also known from Oljeto Wash (Lockley and others, 1998).

At least five tracksites have been found in Lower and Middle Triassic Moenkopi Formation rocks within the recreation area (Mickelson and others, 2005, 2006). Two have been published: one at Farley Canyon, and one at Trachyte Point. The Farley Canyon site has three types of tracks, including horseshoe crab tracks, swim traces, and lizard-like tracks. The Trachyte Point tracks include horseshoe crab tracks and swim marks (Lockley and others, 1998). Three types of subaqueous traces, including both vertebrate and invertebrate swim traces, were found at two tracksites (Schultz and others, 1995). The vertebrate traces are preserved as parallel scrape marks, thought to have been formed when a buoyant animal's manus touched the substrate during a swimming stroke. The invertebrate traces are small, crescent-shaped swim traces attributed to limulids. There are also Moenkopi tracks discovered near Hite on the shores of Lake Powell.

The Upper Triassic Chinle Formation has yielded a variety of fossils within GCNRA including petrified wood and carbonaceous debris, gastropods, crayfish burrows, bones, coprolites, and dinosaur tracks (Anderson and others, this volume). Extensive lacustrine deposits in the lower Chinle in and near the east side of Glen Canyon in the White Canyon/Red Canyon area preserve a diversity of fossil plants, vertebrate bones, and invertebrates (Ash, 1975; Dubiel, 1983a, 1983b; Good, 1998; Parrish, 1999; Beer, 2005). Vertebrate tracks occur in the Chinle along the northern shores of Lake Powell (Lockley and others, 1992d, 1998). These tracks are identified as *Atreipus milfordensis*, which represent the first discovery of these tracks in the western United States. Tracks at Mike's Mesa may represent the same as those reported by Longwell and others (1923) (Lockley and others, 1998). Hunt (A.P. Hunt, New Mexico Museum of Natural History and Science, verbal com-

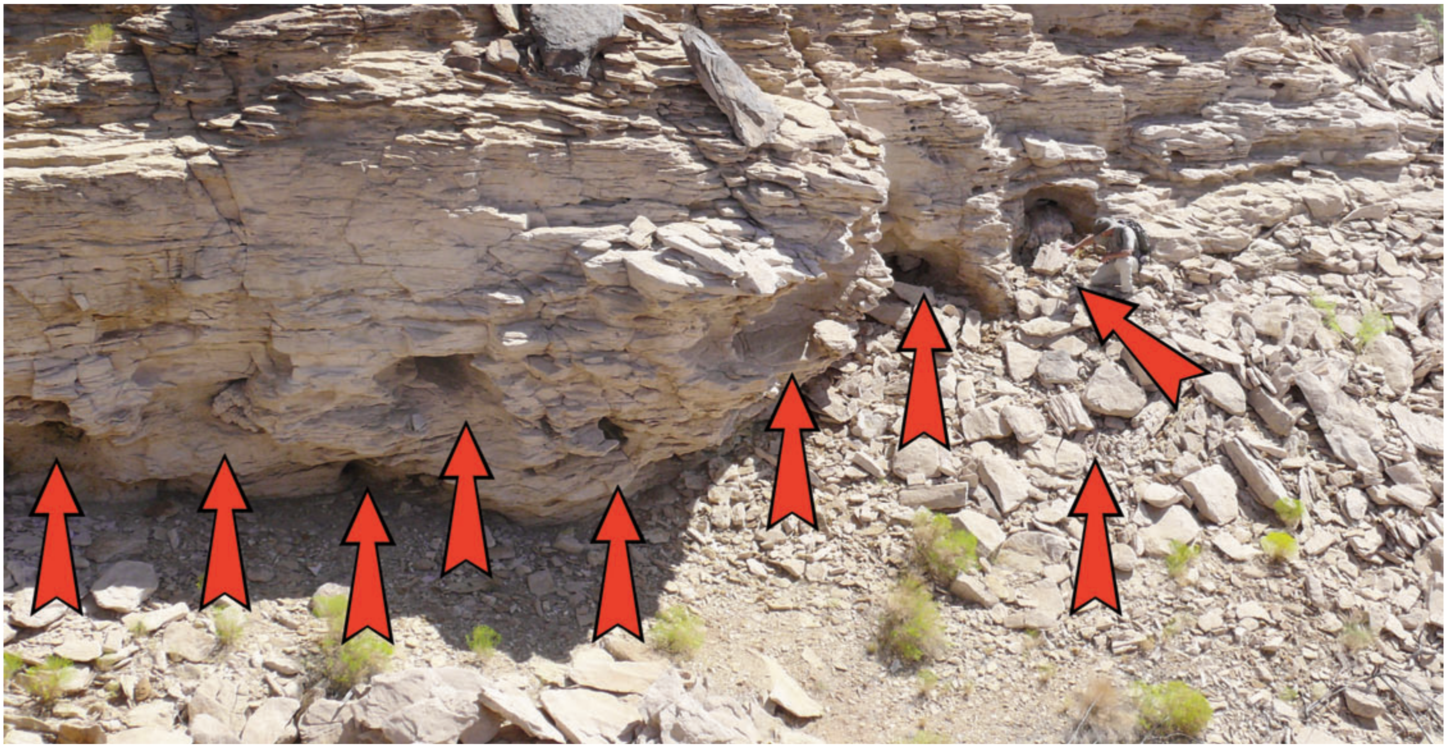

Figure 17. Numerous cross sections of petrified logs representing an Upper Triassic log jam in the Shinarump Conglomerate Member of the Chinle Formation at Glen Canyon National Recreation Area.

munication, 1998) reported that fossil vertebrate bones, including a fish, were recovered from the Rock Point Member of the Chinle in the recreation area. Gregory and Moore (1931) also reported on some Chinle vertebrate remains from the Lee's Ferry area. Vertebrate bones, including fish remains, are also reported from the Chinle in The Rincon area (T. Chidsey, UGS, written communication, 2000; S. Madsen, UGS, verbal communication, 2009). Petrified wood from the Chinle has been reported from a number of localities within Glen Canyon National Recreation Area including The Rincon, Blue Notch Canyon, along the San Juan Arm (figure 17) , and from Neskahi Wash. A petrified log 30 feet (~9 m) long was found in Trachyte Canyon in 1984 (S. Ott., verbal communication to V. Vieira, October 1984) and was removed in 1985 (D. Smith, verbal communication to L. Belli, January 1985). The Wolverine Petrified Forest is the second largest petrified forest known in the Upper Triassic (Ash, 2004) and extends from the Grand Staircase–Escalante National Monument in the Circle Cliffs, south into the northern part of Glen Canyon National Recreation Area.

At least three tracksites occur in the Triassic-Jurassic Wingate Sandstone (basal formation of the Glen Canyon Group) at Glen Canyon National Recreation Area. The three sites are at Lee's Ferry (Riggs, 1904), North Wash, and The Rincon. All of the Wingate specimens represent the ichnogenus *Grallator*. The Lee's Ferry tracks were the first fossils recovered from the area (Lockley and others, 1998).

Many tracks are also known at GCNRA and its immediate vicinity from the Lower Jurassic Kayenta Formation and the transitional zone with the overlying Navajo Sandstone. Six sites have been described from the Kayenta Formation proper, from Explorer's Canyon, Long Canyon, Mike's Mesa, Slick Rock Canyon (two sites), and at neighboring Rainbow Bridge National Monument (Lockley and others, 1998). The Explorer's Canyon tracks are best known. Large theropod tracks (*Eubrontes* sp.) were removed from the Kayenta in Explorer Canyon and are on display at the Page Visitor Center (figure 18). The Explorer Canyon tracksite was featured in a 1967 National Geographic Magazine (Edwards, 1967). *Eubrontes* sp. represents the first large theropod track type in the fossil record. At least 29 tracksites have been found in the Kayenta Formation-Navajo Sandstone transition zone. The recent low water levels in Lake Powell have revealed more sites, especially in the Kayenta-Navajo transition zone.

There are many tracksites known from the Navajo Sandstone in Glen Canyon National Recreation Area (Lockley and others, 1998). As with the Kayenta Formation, additional tracksites have been exposed by the recent water level drop of Lake Powell (Lockley and others, 2005). A number of theropod dinosaur tracks from the lower portion of the Navajo were discovered and then destroyed during the construction of Glen Canyon Dam (Stokes, 1978). One tracksite from the upper portion of the Navajo had been under water for over a decade. An *Otozoum* "giant animal" tracksite, consisting of at least 28 criss-crossing trackways, has been documented from the Navajo (Lockley and others, 1998). There are very small theropod tracks in association with the *Otozoum* tracks. Another *Otozoum* site had been improperly and illegally

Figure 18. Eubrontes dinosaur tracks from the Jurassic Kayenta Formation on display at visitor's center at Glen Canyon National Recreation Area.

Figure 19. Otozoum dinosaur tracks near top of Navajo Sandstone at Glen Canyon National Recreation Area. Note traces of calking around some of the tracks 10 years after its application.

Figure 20. Fallen block of Navajo Sandstone preserving ornithopod-like dinosaur tracks in Glen Canyon National Recreation Area.

replicated and after nearly a decade traces of the calking used to cantain the casting material is still visible (figure 19). A new *Otozoum* track locality was identified along the lakeshore at Glen Canyon in early 2010. Another impressive tracksite occurs in the Navajo on an overhang, about 150 feet above lake level at Tapestry Wall north of Bullfrog. This tracksite contains at least 14 large theropod (*Eubrontes* sp.) tracks on the underside of a long overhanging exposure. A trackway consisting of at least seven large ornithopod-like tracks, along with numerous other vertebrate tracks, was located in a large block of Navajo at Glen Canyon during 2009 (figure 20). A partial reptile skeleton was discovered from a laminated pond limestone in the Navajo in the Navajo Nation portion of the recreation area (P. Buchheim, Loma Linda University, verbal communication, 1999). A great number of tracks are known from several sites in the Slick Rock area in two distinct stratigraphic horizons, indicating the presence of small theropods, large theropods, and ornithischians (Lockley and others, 2005). In 2009, one of these sites was selected by the National Park Service as a prototype paleontological resource monitoring site to assess long-term stability and to document measureable changes to the resource over time (Santucci and others, 2009). This area is also unusual in preserving a shell bed of unioid clams. This family of freshwater clams has an obligate parasitic relationship with fish (Good, 1998), indicating at least at this Jurassic oasis significant water was present. This region around south-central Utah is proving to be pivotal in understanding the Navajo desert ecosystem (figure 21).

Fossils are rare in the Middle Jurassic Page Sandstone and overlying Entrada Sandstone, but wood is reported from the Page at GCNRA (NPS, 1999), and some theropod tracks from Lake Powell are in rocks that have been reassigned from the Navajo Sandstone to the Entrada Sandstone (Lockley and others, 2005).

There are several sauropod footprints with preserved skin impressions found near Lake Powell. These tracks occur near the contact between the Summerville Formation and the Morrison Formation. This site is near Bullfrog, on the north side of Lake Powell. There is also a site just outside of the boundaries of GCNRA that contains possible pterosaur tracks (Lockley and others, 1998). At one Morrison locality in the recreation area, termite nests are preserved by preferential cementation. Therefore, the fossilized nests appear as cylindrical concretions about 20 cm in diameter that stand 30 to 40 cm above the sandstone surface (Hasiotis and Demko, 1996; Engelmann, 1999).

The bivalve *Exogyra* occurs in the Cretaceous Dakota Sandstone in Glen Canyon National Recreation Area (Cobban and others, 2000). The Upper Cretaceous Tropic Shale on the western side Glen Canyon preserves a rich invertebrate fauna interspersed with volcanic ashes and concretion horizons that can be correlated across the Cretaceous Western Interior Seaway (Elder and others, 1994) and has formed the conceptual framework for research on a major mid-Cretaceous extinction event (Elder 1989, 1991). It was later noted that many of the Cretaceous invertebrate taxa

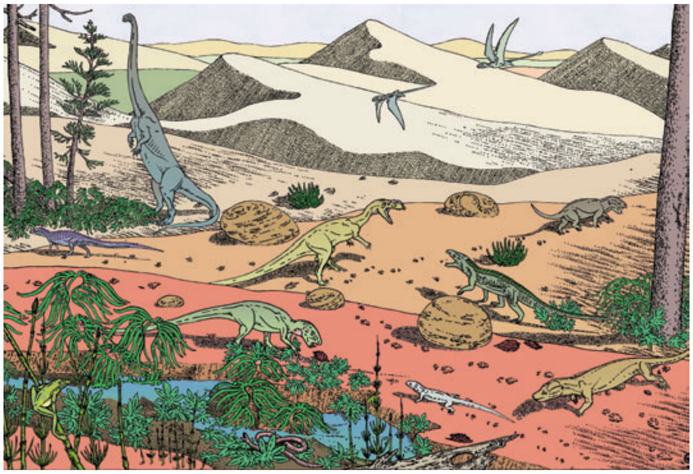

Figure 21. Reconstruction of life at the edge of the Navajo desert in southern Utah. Art by Russell Hawley, Tate Museum.

Figure 22. Excavating large pliosaur skull, Brachauchenius, in the Tropic Shale at Glen Canyon National Recreation Area.

Figure 23. Example of mammoth dung collected at Bechan Cave, Glen Canyon National Recreation Area.

described from the Mancos Shale at Black Mesa in northeastern Arizona also occurred in the correlative Tropic at GCNRA (Kirkland, 1996).

Several plesiosaur localities have been reported in the Tropic Shale from within the Glen Canyon area (Gillette and others, 1999; Albright and others, 2007a, 2007b). All sites are from the extreme southwestern part of the park near Big Water. These sites have yielded an assemblage including ammonites, bivalves, fish, possibly two genera of turtles, and at least four species of plesiosaur: *Brachauchenius lucasi* (figure 22), *Dolichorhynchops* sp., *Eopolycotylus rankini*, and *Trinacromerum ?bentonianum* (figure 22). *Eopolycotylus rankini* is based on a partial skeleton found within GCNRA. Several of the plesiosaur specimens represent juveniles. One specimen of *Dolichorhynchops* is notable for its associated gastroliths (Schmeisser and Gillette, 2009). Teeth from the duophagus shark *Ptychodus* sp., a few other unidentified shark teeth, and a variety of marine invertebrates have also been recovered from the Tropic in the recreation area. A new species of the therizinosaurid dinosaur *Nothronychus graffami* was named from a nearly complete headless skeleton found just outside of the recreation area's southwest corner (Zanno and others, 2009).

In 1982, a survey team in Glen Canyon National Recreation Area entered a large, dry sandstone cave known as Bechan Cave. The survey team found an organic layer of Pleistocene age preserved in the cave that consists of more than 10,600 cubic feet (300m^3) of plant debris, herbivore dung, and dried animal remains. Radiocarbon dates from the cave deposits range from 11,670 to 12,900 yr B.P. (Davis and others, 1984, 1985; Mead and Agenbroad, 1992). Analysis of the dung identified the sources of the fecal material as the megaherbivores *Mammuthus* sp. (figure 23), *Euceratherium collinum, Nothrotheriops shastensis, Bison* sp., and cf. *Oreamnos harringtoni* (Mead and others, 1983a; Agenbroad and Mead, 1990b). Coprolites of rabbits, rodents, and possibly mountain sheep or deer (*Ovis canadensis* or *Odocoileus* sp.) were also recovered from the dung deposits. Preliminary analysis of the hair samples indicated the sources were mammoths and two types of ground sloths. A *Euceratherium* lower molar and metapodial were also recovered from Bechan Cave with analyses of its dung indicating it was a year round resident of the area (Kropf and others, 2007). Microfaunal remains from the cave included *Scaphiopus intermontanus*, *S.* cf. *S. bombifrons, Pituophis melanoleucus, Crotalus* cf. *C. viridis*, a grouse-sized bird, *Brachylagus idahoensis, Marmota flaviventris, Spermophilus* sp., *Thomomys* sp., *Lagurus curtatus, Microtus* sp., and *Neotoma cinerea* (Mead and Agenbroad, 1992; Mead and others, 1993b). Pollen analysis of the dung blanket indicated that, away from the riparian area, the predominant plant community may have been sagebrush steppe rather than blackbrush (*Coleogyne* sp.), which is the dominant shrub today (Mead, and others, 1984; Withers and Mead, 1993).

Nine other alcove sites with large mammal dung have been found at the recreation area: BF Alcove, Cottonwood Alcove, Grobot Grotto, Hooper's Hollow, Mammoth Alcove, Oak Haven, Oakleaf Alcove, Shrubox Alcove, and Withers Wallow (Mead and Agenbroad, 1992; Santucci and others, 2001). Packrat middens are also known (Elias and others, 1992), as well as mammoth bones, which have been found at Mammoth Alcove (Mead and Agenbroad, 1992), Wireglass Canyon (Agenbroad and Mead, 1989), and Clyde's Spring Canyon (J. Mead, East Tennessee State University, verbal communication to C. Wood, Providence College, March 1989). On a smaller scale, microfossils, plant material, and freshwater invertebrates can be found in Quaternary fluvial sediments, such as Pleistocene bivalves and Holocene plant debris in the canyon in the vicinity of Bechan Cave (Agenbroad and Mead, 1990a).

GOLDEN SPIKE NATIONAL HISTORIC SITE

Golden Spike National Historic Site was established on April 2, 1957, in north-central Utah, to commemorate the completion of the first transcontinental railroad in the United States. The site is located at the point where the Central Pacific and Union Pacific Railroads met in 1869.

Late Paleozoic miogeosynclinal rocks are exposed in uplifted areas in and around Golden Spike National Historic Site. The Pennsylvanian–Permian Oquirrh Formation is exposed in the nearby Promontory Mountains. The basal limestone member consists of coarse bioclastic beds that contain fusulinids, horn corals, bryozoans, brachiopods, gastropods, and crinoids that have been reported to be Early to Middle Pennsylvanian in age (Miller and others, 1991).

A fossilized mandible from an extinct marmot, *Paenemarmota* cf. *P. sawrockensis*, was collected from an early Pliocene colluvium locality near Golden Spike (Nelson and Miller, 1990).

Fine-grained lacustrine deposits associated with the upper Pleistocene Lake Bonneville Alloformation contain pockets of ostracods, bivalves, and gastropods (Don Currey, University of Utah, verbal communication, 1999).

HOVENWEEP NATIONAL MONUMENT

Hovenweep National Monument in southeastern Utah was established on March 2, 1923, to preserve a concentration of Pre-Columbian cliff dwellings, pueblos, and towers. Sedimentary rocks exposed in the monument include the Upper Jurassic Morrison Formation, the Lower Cretaceous Burro Canyon Formation, and the Upper Cretaceous Dakota Sandstone. The only report of paleontological resources from the monument is an unidentified bone found by a Utah Geological Survey geologist (Martha Hayden, UGS, written communication, 1999). Although there are no reports of fossils from within the monument, invertebrate fossils are known nearby and thus, at least invertebrate fossils are most likely present in Hovenweep National Monument.

NATURAL BRIDGES NATIONAL MONUMENT

Natural Bridges National Monument in southeastern Utah was established on April 16, 1908, to preserve three spectacular natural bridges. The monument was the first NPS unit established in Utah. The natural bridges are formed in the Permian Cedar Mesa Sandstone, which is the oldest geologic unit exposed in the monument. The rocks near the monument range from Permian to Jurassic in age. Although a paleontological survey has not been undertaken at the monument, a few isolated fossils have been reported. For more information on the geology see the Natural Bridges National Monument article in this volume.

The Permian Cutler Formation in southeastern Utah was originally divided into five members (Baker and Reeside, 1929). More recent work by Condon (1997) recognized the Cutler as a Group in southeastern Utah and identified the following subdivisions in and near Natural Bridges: lower Cutler beds, Halgaito Formation, Cedar Mesa Sandstone, and Organ Rock Formation. The Cedar Mesa Sandstone is primarily a light-colored, cross-bedded sandstone unit that locally contains pink arkosic sandstone and mudstone beds as well as scarce gray-green limestone lenses. The unit has been interpreted as largely eolian in origin because of the abundant cross-bedded sandstone. However, minute fragments of marine invertebrate fossils locally occur within the sandstone. Baars (1975) suggested that the fossils indicate a marine origin of the beds whereas Stanesco and Campbell (1989) concluded that the marine fossils were transported into the eolian sands by wind. Duffy (1998) reported on *in situ* fossilized plant roots or rhizoliths preserved in the Cedar Mesa at Natural Bridges National Monument. Poorly preserved horizontal and vertical burrows are also preserved in the fine-grained, green-gray, interdunal sandstone beds (Jackie Huntoon, Michigan Technological University, written communication, 1999).

The Upper Triassic Chinle Formation is exposed near the monument and some isolated petrified wood specimens have been reported from this formation (S. Duffy, verbal communication, 1999). Dubiel (1983, 1987) reported ostracods, conchostracans, unionid bivalves, and various trace fossils from the Chinle nearby in White Canyon.

A large, flat-floored, dry rock shelter in the Cedar Mesa Sandstone contains a wealth of indurated late Pleistocene (Rancholabrean) packrat middens and a 100-cm stratigraphic profile that contains skeletal and plant remains. Dung pellets from the shelter were radiocarbon dated and range in age between 39,000 and 9660 yr B.P. (Mead and Agenbroad, 1992; Mead and others, 1993b). Two metapodials, identified as those belonging to the extinct mountain goat *Oreamnos harringtoni*, were recovered from the shelter and represent the oldest dated remains of this species. Plant microfossils indicate that Engelmann spruce (*Picea engelmannii*), limber pine (*Pinus flexilis*), and Douglas fir (*Pseudotsuga menziesii*) grew nearby during the late Pleistocene, whereas a riparian willow (*Salix* sp.) and cottonwood (*Populus* sp.) are now present in the bottom of the canyon and a pinyon-juniper (*Pinus edulis-Juniperus osteosperma*) community now predominates higher up on the canyon walls and in the benchlands above the canyon (Mead and others, 1987).

RAINBOW BRIDGE NATIONAL MONUMENT

Rainbow Bridge in south-central Utah was proclaimed a national monument on May 30, 1910, to preserve one of the world's largest natural bridge. The bridge is 246 feet (73 m) above the floor of Bridge Canyon and spans 234 feet (85 m) (Brandt-Erichsen and Wilbur, 2010). The bridge is carved in the Lower Jurassic Navajo Sandstone which forms vertical cliffs in the area. The floor of Rainbow Bridge consists of the Lower Jurassic Kayenta Formation. The Kayenta is a reddish-orange fluvial sandstone unit. For more information on the geology see the Rainbow Bridge National Monument article in this volume.

Hall (1934) was the first to report dinosaur tracks near Rainbow Bridge. The tracks were discovered during the University of California's Rainbow Bridge Expedition of 1933. These poorly preserved tracks are named *Eubrontes* sp. and are in the Kayenta Formation. Today there is at least one *Eubrontes* track visible at Rainbow Bridge National Monument. The weathered footprint can be seen at the bridge viewing area (see Rainbow Bridge article in this volume). It is described in Lockley and others (1998).

TIMPANOGOS CAVE NATIONAL MONUMENT

Timpanogos Cave was proclaimed a national monument on October 14, 1922. However, it was administered by the U.S. Forest Service until it was transferred to the jurisdiction of the NPS on August 10, 1933. The monument was established to protect a colorful limestone cavern and associated karst features on the north side of Mount Timpanogos near the American Fork River in north-central Utah. For more information on the geology and a stratigraphic section of Timpanogos Cave National Monument see Baker and Crittenden (1961), White and Van Gundy (1974), and the Timpanogos article in this volume.

The oldest fossils in the monument are trace fossils found within the Precambrian Mutual Formation. Invertebrate fossils are preserved in the Cambrian Maxfield Limestone, Ophir Shale, and the Devonian/Mississippian Fitchville Formation. Walcott reported Early and Middle Cambrian trilobites (*Olenellus*) from the Ophir. Worm burrows and brachiopods also occur within the Ophir (Baker and Crittenden, 1961). The limestone caves in the national monument are developed in the Mississippian Deseret Formation. A variety of fossilized marine invertebrates, including syringoporoid corals and brachiopods, have been found in the formation.

Packrat middens have been found at several localities within the national monument including the Timpanogos Cave System and Hidden Cave Mine. In 1939, Tom Walker found mammal bones in a rockshelter called the Grotto, which was known to be the den for a mountain lion until 1880. Bones were collected from packrat nests found in the Organ Pipe Room of Hansen Cave. During 1998, George (1999) initiated an assessment of packrat middens from three cave areas within Timpanogos Cave National Monument. Eleven species of mammals were collected and identified from the middens. A partial bison skeleton was found in the gravels at the mouth of Swinging Bridge Canyon in the monument (Rod Horrocks, NPS, written communication, 1999).

ZION NATIONAL PARK

The area that is now Zion National Park was originally proclaimed Mukuntuweap National Monument on July 31, 1909. The area was renamed Zion National Monument on March 18, 1918. The site was redesignated as Zion National Park on November 19, 1919. For more information on the geology see Gregory (1939, 1945, 1950), Hamilton (1978, 1984), and the Zion article in this volume.

Several important expeditions by Europeans came into or near Zion Canyon during the 18th and 19th centuries. The earliest description of the area is in the diaries of the Dominguez-Escalante Expedition of 1776. The federal government initiated scientific surveys into southwestern Utah during 1853, some of which passed into and near Zion Canyon. Some of the more notable surveys were led by George Wheeler and John Wesley Powell. These two surveys mapped and interpreted the geographic and geologic features in a region that covered more than 50,000 square miles.

The Wheeler Survey, also referred to as the U.S. Geographic Surveys West of the One Hundredth Meridian, was a series of military and scientific expeditions undertaken by the U.S. Army. The survey was led by Captain George M. Wheeler. Although field surveys were conducted in 1869 and 1871, Wheeler did not receive funding to organize a regional scientific survey until 1872. The Wheeler Survey continued field work until 1879. Geologists G.K. Gilbert and Edwin E. Howell joined the Wheeler Survey and were involved in geologic field work in Zion Canyon and the surrounding area during 1872. The results of the survey, including descriptions of the geology and paleontology, were published in a series of volumes by the U.S. government.

The following quote is found within the Wheeler Geological Report (1886) in reference to southwestern Utah:

> *"Clambering along the cliff, and while securing a large haul of fossils, the crisp edge of coal crops was noticed,*

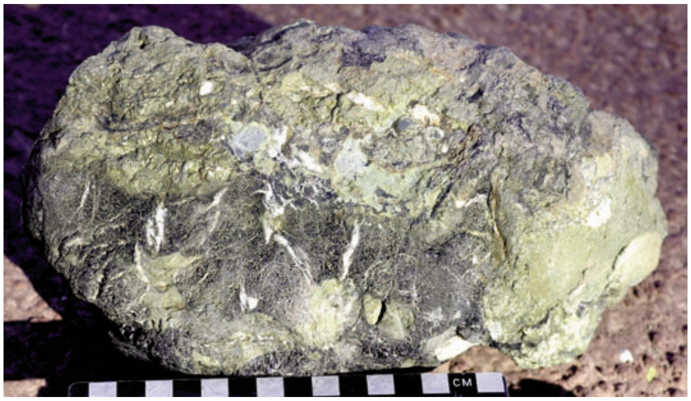

Figure 24. Pyritized petrified wood from stream bed cutting down into the Shinarump Conglomerate Member of Chinle Formation at Zion National Park.

Figure 25. Phytosaur teeth from the Chinle Formation at Zion National Park.

> *and prospecting which a 12-foot vein of dense bituminous coal, having both above and below a bed of shale 15 to 18 inches thick, was found, with petrified wood strewn in many directions. Fossils were found in sandstones..."*

John Wesley Powell followed the Virgin River Valley northward into Zion Canyon during 1871 (Powell, 1875). Powell did not focus much attention on the geology until he employed Howell in 1874 and Gilbert and Dutton in 1875. William Henry Holmes produced several outstanding line drawings of the area that are well known for their geological and topographical accuracy as well as their artistic beauty.

Recently, a paleontological inventory of the fossil resources in Zion National Park was conducted by the UGS with the assistance of NPS paleontology interns (Santucci and others, 1998; Smith and Santucci, 1999, 2001; DeBlieux and others, 2006). This work resulted in the identification of over 120 new fossil localities in the park. The rocks exposed in and around Zion range from Permian through Cretaceous in age. During this interval, the Zion area was repeatedly covered by marine transgressions from seaways that lay largely to the west, north, or east. The oldest unit exposed in the park is the Lower Permian Toroweap Formation. The Kaibab Limestone of late Early Permian age is a marine limestone unit overlying the Toroweap, exposed in two small areas in the northwest corner of the park along the escarpment produced by the Hurricane fault. Brachiopods, bryozoans, corals, crinoids, and sea urchins have been recovered in the Zion area (McKee, 1952) although fossil preservation generally is poor.

The Moenkopi Formation (Early to Middle Triassic) represents both shallow marine and nearshore terrestrial environments in and near the Zion region.). A few pieces of fossil wood and bone have been found in this unit. Fossilized marine bivalves, snails, and ammonites (*Meekoceras* sp.) are known from the formation. Large well-preserved ammonites have been described from the Timpoweap Member north of the Kolob Canyons district near Cedar City (Lucas and others, 2007). The Virgin Limestone Member contains fossilized asteroid starfish and abundant internal molds of mollusks. This unit is well exposed in the northwest and southwest corners of the park. The terrestrial component of the Moenkopi Formation increases up section, reflecting gradual transgressions and regressions of the Early Triassic sea. Cyclic nearshore deposition in the Shnabkaib Member resulted in many thin limestone beds preserving algal stromatolites. Several significant vertebrate tracksites, including some preserving swim tracks, were found during the UGS inventory in the Moenkopi below the Virgin Limestone in the Kolob Canyons district. One of these sites lies below the Virgin Limestone Member and may be the oldest Mesozoic vertebrate tracksite in North America (Mickelson and others, 2006).

The Chinle Formation (Late Triassic) includes petrified wood that was originally transported by streams from the east and southeast. The logs are found in the basal Shinarump Conglomerate Member (figure 24) and have been identified as *Araucarioxylon* sp. and *Woodworthia* sp. Fossilized bones from the labyrinthodont *Metoposaurus* sp. have been collected from freshwater mudstone beds near Cougar Mountain. Many sites were documented by the UGS in the Petrified Forest Member at Zion. The sites in the park contained the bones and teeth of vertebrates including fishes, metoposaurs, phytosaurs (figure 25), and aetosaurs; additionally plants, wood, coprolites, and invertebrate burrows were found (DeBlieux and others, 2006; Heckert and others, 2006).

The Triassic-Jurassic Moenave Formation includes, from oldest to youngest, the Dinosaur Canyon and Whitmore Point Members. The Springdale Sandstone Member has historically been considered the uppermost member of the Moenave Formation but is now placed as the basal member of the overlying Kayenta Formation (Lucas and Tanner, 2006). The Dinosaur Canyon Member consists of red mudstone, siltstone, and some sandstone deposited in mudflat, fluvial, and overbank environments. Fossil plants were found in the Kolob Canyons area and with correlative plant horizons found to the south at St. George are the first basal Jurassic plant sites known from western

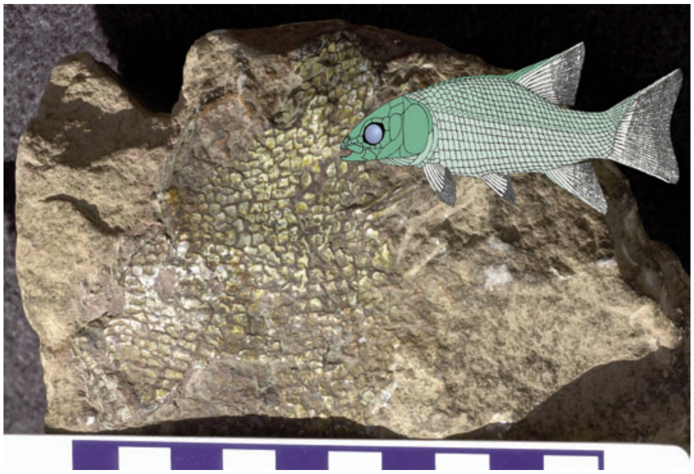

Figure 26. Partial semionotid fish from Triassic-Jurassic Moenave Formation at Zion National Park. Inset, reconstruction of Semionotus kanabensis from Milner and Kirkland (2006).

Figure 27. Typical setting for fossil tracks in Kayenta Formation at Zion National Park. Arrows indicate natural casts of Grallator on underside of sandstone.

North America (Tidwell and Ash, 2006). The Whitmore Point Member is a gray mudstone and shale unit deposited primarily in lacustrine environments. Palynomorphs recovered from this member are especially important as they provided the most reliable dating of this formation. Pond and stream deposits from the Moenave contain the remains of the fish *Semionotus kanabensis* (figure 26) (Hesse, 1935; Day, 1967) in the park, with a diversity of fish being recovered recently to the west in the St. George area, including the hybodont shark *Lissodus johnsonorum*, large coelacanth fish up to 6 feet (2 m) long, the lungfish *Ceratodus stewarti*, and paleoniscoids (Milner and Kirkland, 2006). Fossil vertebrate tracks have been found in the Dinosaur Canyon and are common in the Whitmore Point (Smith and Santucci, 1999; DeBlieux and others, 2006).

The Lower Jurassic Kayenta Formation in the Zion region is now divided into two members, the Springdale Sandstone and an "upper member." The Springdale Sandstone Member is composed largely of red sandstone deposited by high-energy streams that originated in a highland source region in the ancestral Rockies of western Colorado. Small pieces of petrified wood were found in the Springdale in Zion Canyon by UGS paleontologists. The upper member consists primarily of siltstone and sandstone deposited in fluvial, distal fluvial/playa, lacustrine, and continental sabkha environments downstream of the thick and fossiliferous fluvial deposits preserved in the Kayenta to the southwest in Arizona (Blakey, 1994; Petersen, 1994; Kirkland and Milner, 2006; Blakey and Ranney, 2008). This unit contains several thin limestone beds that preserve fossil trails of aquatic snails or worms. Ganoid scales were recovered from the lower lacustrine beds in the park with semionotid and coelacanth fish being excavated from the same interval just to the east of the park (A. Milner, St. George City, personal communication, 2009). The first vertebrate tracks reported from Zion National Park were tridactyl dinosaur prints in the upper member of the Kayenta in the Left Fork of North Creek (Stokes and Bruhn, 1960). Dozens of additional vertebrate tracksites attributable primarily to *Eubrontes* and *Grallator* were discovered in the Kayenta (figure 27) during paleontological surveys in Zion (Santucci and others, 1998; Smith and Santucci, 1999, 2001; DeBlieux and others, 2006). The contact between the Springdale Sandstone and the upper member is especially rich with tracksites and can be considered a "megatracksite" (DeBlieux and others, 2006; Kirkland and Milner, 2006).

Although the Navajo Sandstone is one of the most easily recognized units in the southwest, the unit appears to be largely devoid of body fossils in Zion, although a few tridactyl dinosaur footprints have been found along the trail to Observation Point (Fred Peterson, U.S. Geological Survey, written communication, 2000). Tracks of both bipedal and quadrupedal animals were found on a fallen block of Navajo in Parunuweap Canyon during the UGS survey (DeBlieux and others, 2006). The large-scale cross-bedding that is so pronounced in the park reflects stratification produced in windblown sand deposits. In an unpublished report found in the Zion National Park files, John Bradbury (U.S. Geological Survey) claims that during 1962 poorly preserved fossil wood was found within a shale lens of the Navajo.

The Middle Jurassic Carmel Formation includes several light tan to gray limestone beds that contain marine fossils, including crinoids, pectens, oysters, and other bivalves (Gregory and Williams, 1947). The crinoids are identified as *Isocrinus* sp. An oolitic limestone bed containing algal balls, bivalves, and gastropods is present along the Wildcat Canyon Trail.

A small exposure of the Cretaceous Dakota Sandstone is exposed in the northwest corner of the park on top of Horse Ranch Mountain. The formation contains a basal conglomerate overlain by a series of sandstone and mudstone beds, some of which contain freshwater bivalves and plant impressions. A diverse microvertebrate fauna is has been recovered from the Dakota just east of Zion National Park (J. Eaton, Weber State University, written communication, 1999), from which only the mammals have been described (Eaton, 1993a, 1995).

The remains of a plesiosaur were excavated from the Upper Cretaceous Tropic Shale near the eastern boundary of Zion National Park (Gillette and others, 1999).

A large artiodactyl track (figure 28) and a bird track resembling those of herons were collected from Quaternary lacustrine deposits in the Coalpits Wash area (Santucci and others, 1998). The remains of a bison (*Bison antiquus*) were collected in the park many years ago (Wayne Hamilton, NPS, verbal communication, 1998). Hevly (1979) analyzed pollen and spore samples taken from Quaternary lacustrine sediments in Zion National Park.

Figure 28. Large artiodactyl track from Zion National Park.

PALEONTOLOGICAL RESOURCE MANAGEMENT AND PROTECTION

The paleontological resources in the national parks and monuments of Utah provide valuable information about ancient plants and animals. The NPS manages fossils along with other natural and cultural resources for the benefit of the public. Fossils are recognized as non-renewable resources that possess both scientific and educational values. All fossils are protected under federal law and their collection is prohibited except under the terms of a research permit.

Paleontological resources are placed on exhibit in many of the national parks and monuments in Utah. The Quarry Visitor Center at Dinosaur National Monument has provided visitors with the opportunity to view the world famous dinosaur bone-bearing rock wall as an *in situ* exhibit (figure 14). It is in the process of being reconstructed and is scheduled to be reopened in 2013. Glen Canyon National Recreation Area has a sandstone slab of dinosaur tracks on display outside of the Visitor Center (figure 18) and mammoth dung and bones are on exhibit within the Visitor Center.

Comprehensive paleontological resource inventories are underway in a number of NPS units in Utah. These surveys are designed to identify the scope, significance, and distribution of the paleontological resources and to assess any natural or human-related threats to the paleontological resources. Fossils reported from areas adjacent to the parks and monuments are also considered in order to assess the potential for stratigraphically equivalent resources within park boundaries. This baseline data will better enable park staff to plan strategies that increase the management, protection, research, and interpretation of park fossils.

As the NPS undertakes paleontological resource inventories, an assessment of the condition and stability of *in situ* fossil localities is documented. Paleontological resources exposed at or near the surface are subjected to various natural and human-related threats which affect their condition and stability. Weathering, erosion, freeze-thaw cycles, shoreline processes, flooding, and geohazards, as well as theft and vandalism, contribute to the loss of *in situ* fossils (Santucci, 2002). The NPS has developed a strategy for long-term paleontological resource monitoring of *in situ* fossils (Santucci and Koch, 2003; Santucci and others, 2009).

During 2009, the NPS and the UGS developed a pilot project for paleontological resource monitoring at Glen Canyon National Recreation Area. The Slick George Dinosaur Tracksite, within the lower portion of the Jurassic Navajo Sandstone, was established as the first paleontological monitoring site at Glen Canyon. The site was selected based upon a number of measureable attributes which enable long-term assessment of the condition and stability of the *in situ* tracks exposed at the surface. The site preserves over 150 individual vertebrate tracks at an elevation along the shoreline of Lake Powell which is periodically submerged due to changes in the lake water level. The track-bearing unit overlies a more rapidly weathering mudstone which results in undercutting of the fossiliferous layer. Jointing within the track layer contributes to a "conveyor-belt" movement of blocks along the peripheral edges of the exposure. Blocks of sandstone which drop from cliffs above the site have resulted in damage to the fossil tracks. There is also evidence that one section of the track layer was removed by human activity with chisel marks and other tool marks present along the edge of the missing slab. Through a variety of techniques including establishment of photo points for long-term photographic monitoring, development of site maps, assessing changes in lake levels, and joint crack monitoring, the NPS will be able to assess the variables which threaten the stability of this locality (figure 29).

Ongoing and future paleontological research in the various NPS units within the state of Utah will not only increase our knowledge and understanding of the fossil record, but will also expand our understanding of the ancient environments in which the plants and animals lived.

Figure 29. Track Site in Navajo Sandstone at Glen Canyon National Recreation Area exhibiting features noted in monitoring in situ paleontological resources in the NPS. Red arrow points to high-water mark of ~3,700 feet (130 m); blue arrow indicates waterline in September 2009 of 3,636 feet (110 m); yellow arrow indicates sandstone blocks falling on tracksite from above; green arrow indicates under cutting and collapse of track-bearing layer; red oval indicates a couple of clear deep tracks; yellow oval indicates position of section of track layer that has been removed.

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