GEOLOGY OF THE INTERMOUNTAIN WEST

an open-access journal of the Utah Geological Association

ISSN 2380-7601

Volume 7 ***2020***

PALEONTOLOGY OF BEARS EARS NATIONAL MONUMENT (UTAH, USA)— HISTORY OF EXPLORATION, STUDY, AND DESIGNATION

Robert J. Gay, Adam K. Huttenlocker, Randall B. Irmis, M. Allison Stegner, and Jessica Uglesich

GEOLOGY OF THE INTERMOUNTAIN WEST

an open-access journal of the Utah Geological Association

ISSN 2380-7601

Volume 7 ***2020***

Cover

Jessica Uglesich prospects the Triassic Chinle Formation in Bears Ears National Monument, with the Bears Ears themselves visible on the far horizon. The Triassic Moenkopi Formation and Pennsylvanian-Permian Cutler Group are exposed in the canyon in the middle ground.

Utah Geological Association formed in 1970 from a merger of the Utah Geological Society, founded in 1946, and the Intermountain Association of Geologists, founded in 1949. Affiliated with the American Association of Petroleum Geologists.

GEOLOGY OF THE INTERMOUNTAIN WEST
an open-access journal of the Utah Geological Association
Volume 7 *2020*

Paleontology of Bears Ears National Monument (Utah, USA)—History of Exploration, Study, and Designation

Robert J. Gay[1], Adam K. Huttenlocker[2], Randall B. Irmis[3], M. Allison Stegner[4], and Jessica Uglesich[5]

[1]*Colorado Canyons Association, 543 Main St. #4, Grand Junction, CO 81501; rob@canyonsassociation.org; paleorob@gmail.com*
[2]*Department of Integrative Anatomical Sciences, University of Southern California, Los Angeles, CA 90007; huttenlo@usc.edu*
[3]*Natural History Museum of Utah and Department of Geology & Geophysics, University of Utah, Salt Lake City, UT 84108-1214; irmis@umnh.utah.edu*
[4]*Department of Biology and Jasper Ridge Biological Preserve, Stanford University, Stanford, CA 94305-5020; astegner@standford.edu*
[5]*Friends of Cedar Mesa+, Bluff, UT 84512 and University of Texas at San Antonio, Department of Geosciences+, San Antonio, TX 78249; jessica.ugelsich@gmail.com; +Former affiliation*

ABSTRACT

Bears Ears National Monument (BENM) is a new landscape-scale national monument in southeastern Utah, jointly administered by the Bureau of Land Management and the U.S. Forest Service as part of the National Conservation Lands system. As initially designated in 2016, BENM encompassed 1.3 million acres of land with exceptionally fossiliferous rock units. Subsequently, in December 2017, presidential action reduced BENM to two smaller management units (Indian Creek and Shash Jáá). Although the paleontological resources of BENM are extensive and abundant, they have historically been under-studied. Herein we summarize prior paleontological work within the original BENM boundaries to provide a more comprehensive picture of the known paleontological resources, which are used to support paleontological resource protection. The fossil-bearing units in BENM comprise a nearly continuous depositional record from aproximately the Middle Pennsylvanian Period (about 310 Ma) through the middle of the Cretaceous Period (about 115 Ma). Pleistocene and Holocene deposits are known from unconsolidated fluvial terraces and cave deposits. The fossil record from BENM provides unique insights into several important paleontological intervals of time including the Carboniferous-Permian icehouse-greenhouse transition and evolution of fully terrestrial tetrapods, the rise of the dinosaurs following the end-Triassic mass extinction, and the response of ecosystems in dry climates to sudden temperature increases at the end of the last glacial maximum.

INTRODUCTION

Southeastern Utah has a diverse and significant paleontological record of the late Paleozoic through mid-Mesozoic eras. The first published paleontological work in the region dates to the 1870s, based on fieldwork by the 1859 Macomb Expedition (Newberry, 1876), but interest and exploration among local native communities predates the late 19th century and extends to Ancestral Puebloan communities (Mayor 2005; Smith and others, 2016; W. Greyeyes, Navajo Nation, verbal communication, 2017). In a remarkable union of archaeol-

Citation for this article.
Gay, R.J., Huttenlocker, A.K., Irmis, R.B., Stegner, M.A., and Uglesich, J., 2020, Paleontology of Bears Ears National Monument (Utah, USA)—history of exploration, study, and designation: Geology of the Intermountain West, v. 7, p. 205–241, https://doi.org/10.31711/giw.v7.pp205-241.

ogy and paleontology, there is evidence in Bears Ears National Monument that Ancestral Puebloans intentionally utilizing fossils in pueblo construction (Smith and others, 2016). Today, paleontological research in the region is advancing our understanding of critical evolutionary events, major extinctions, biogeography and ecology of extinct and extant organisms, and the morphologic and taxonomic diversity of life on Earth through time. Specific high-priority research objectives in BENM include deepening our understanding of the evolution of fully terrestrial ecosystems during the icehouse-hothouse transition preserved in the Upper Pennsylvanian-Lower Permian Cutler Group, generating a comprehensive unified stratigraphy and inventory across the Triassic Chinle Formation, and inventory and study of the Quaternary fossil resources of the monument to elucidate post-glacial diversity change.

Illegal excavations and collections in this region have been problematic for at least the past several decades, and likely longer (R. Gay, J. Uglesich, R.B. Irmis, and M.A., Stegner., personal observations; R. Hunt-Foster, National Park Service (formerly BLM), verbal communication, 2017). Despite stronger enforcement and education of paleontological laws over the past several decades (United States v. Peter Larson, 1997; Public Law 111-11, Title VI, Subtitle D; 16 U.S.C. §§ 470aaa – 470aaa-11), looting and vandalization of paleontological resources remains a prevalent problem in southeastern Utah. Looting hinders resource preservation and past, present, and future geoscience research. In December 2016, President Barack Obama, in an executive order, proclaimed 1.35 million acres of southeastern Utah as BENM (Obama, 2016), under authority delegated by the Antiquities Act of 1906 (figure 1). The monument is named for two resistant sandstone-capped buttes, which are sacred to the Navajo, Hopi, Ute, and New Mexico Pueblo peoples. BENM's natural beauty provides the backdrop to lands incredibly rich in paleontological and cultural resources, both of which are explicitly protected in the monument proclamation (Obama, 2016). As noted in the proclamation: "The paleontological resources in the Bears Ears area are among the richest and most significant in the United States, and protection of this area will provide important opportunities for further archaeological and paleontological study (Obama, 2016)."

INSTITUTIONAL ABBREVIATIONS

BENM, Bears Ears National Monument; BLM, Bureau of Land Management; GSENM, Grand Staircase-Escalante National Monument; SGDDS, St. George Dinosaur Discovery Site at Johnson Farm; UCMP, University of California Museum of Paleontology; UMNH, Natural History Museum of Utah; USGS, United States Geological Survey; USC, University of Southern California.

HISTORY OF MONUMENT DESIGNATION

The idea of federal protection for the region now known as BENM was conceived as early as 1936. At that time, a proposed "Escalante National Monument" included what is now Grand Staircase-Escalante National Monument, Glen Canyon National Recreation Area, Natural Bridges National Monument, and the majority of Canyonlands National Park (Davidson, 1991). As awareness of the conservation value of the region increased, so too did scientific data on the fossils of the region, further supporting preservation. Heightened federal protection of this overall region has been piecemeal, with BENM the last major unit to receive special designation. By 2016, public support for the idea of a national monument or national conservation area in southeastern Utah was gaining momentum. This was due in large part to the immense numbers of archaeological sites documented across the region. At the time, most of support regarding monument designation and conservation was centered on these archaeological resources. However, two alternative proposals both recognized the significance of paleontology within the area. One plan put forward by Utah's congressional delegation, known as "Utah's Public Lands Initiative" (or PLI) included a broad-reaching rearrangement of public lands in the state of Utah, including the creation of a 1.4-million-acre Bears Ears National Conservation Area (Bishop, 2016). The second proposal, put forward by a coalition of five Native American tribes with historic and prehistoric connections to the region, called for the creation of a 1.9-million-acre Bears Ears National Monument (Bears Ears Intertribal Coalition, 2016). In late December of 2016, BENM was established by a

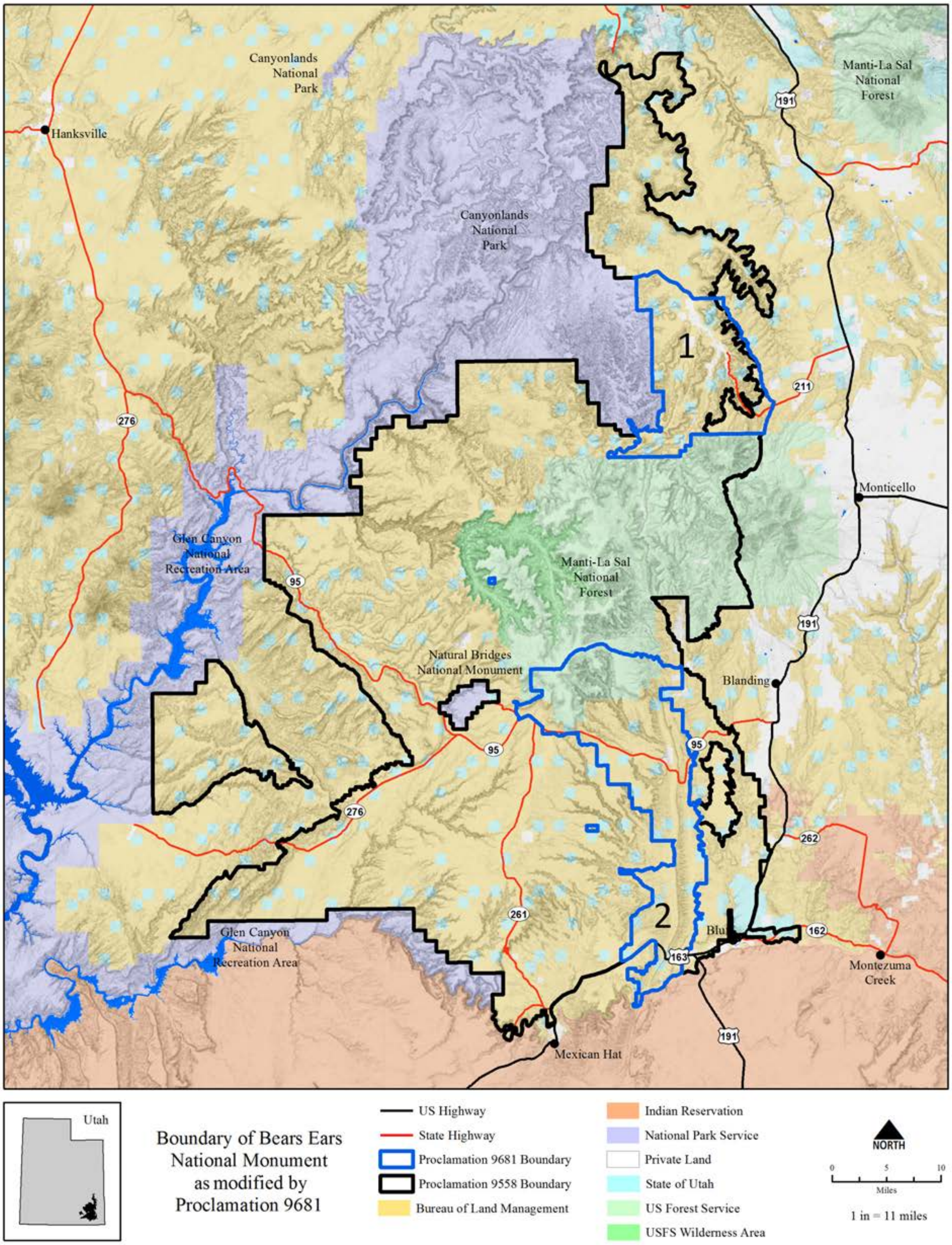

Figure 1. The boundaries of Bears Ears National Monument (BENM) as established by Proclamation 9558 (Obama, 2016), as modified by Proclamation 9681 (Trump, 2017), and its location within the state of Utah. The Indian Creek unit is labeled 1 and the Shash Jáá unit is labeled 2.

presidential proclamation which incorporated language that explicitly protected known paleontological resources and the localities in which those resources have potential to be found (Obama, 2016).

At the recommendation of Secretary of the Interior Zinke, following lengthy public discourse and a formal public comment period, President Trump issued a new proclamation in December 2017, greatly reducing BENM to two management units—Indian Creek and Shash Jáá (Trump, 2017) (figure 1). This reduced the size of the national monument by 85%, and thus excluded lands containing paleontology resources from the Valley of the Gods, Cedar Mesa, White and Fry Canyons, the northern portion of Indian Creek, and Black Mesa. Also excluded were Beef and Lockhart basins (Trump, 2017), which remain largely un-prospected despite notable fossil-bearing potential (see discussion below). This executive order is currently the subject of ongoing litigation. The Monument Management Plan (MMP) for the Indian Creek and Shash Jáá units was released in July 2019 but has not yet been implemented. For the purposes of the following discussion, BENM refers to the original boundaries of the monument.

GEOGRAPHICAL AND GEOLOGICAL SETTING

Bears Ears National Monument lies in the heart of what is known as Utah's Canyon Country (figure 1). It is bounded by Canyonlands National Park to the north and west, Glen Canyon National Recreation Area to the west, the San Juan River to the south, and Highway 191 to the east. It is part of the large Colorado Plateau uplift deformed internally by anticlines related to salt tectonics (e.g., Doelling and others, 1988) and mid-Cenozoic laccolith intrusions (e.g., Abajo Mountains; Witkind, 1964). A prominent structural feature is the Monument upwarp, a broad north-south-trending anticline, 177 km long and 64 to 97 km wide, containing secondary anticlines and synclines, expressed most prominently at Comb and Elk Ridges (Sears, 1956). Uplift events, millions of years of river incision, and erosion have carved the landscape into the visually stunning, desolate terrain we see today (e.g., Barnes, 1993; Baars, 2000). Within the last two millennia this land was the home of the Ancestral Puebloan people, whose remaining stone structures and artifacts were driving forces behind the creation of BENM (Obama, 2016).

Erosion across the BENM exposed flat-lying to low-dipping, virtually continuous sedimentary strata spanning over 150 million years of geologic time, from the Pennsylvanian Paradox Formation to the Lower Cretaceous Burro Canyon Formation (Lewis and others, 2011) (figure 2). Vertebrate, invertebrate, plant, and trace fossils are found throughout most of the geologic formations within BENM.

LATE PALEOZOIC

Geology and Paleontology

The oldest rocks exposed in BENM are the middle to upper Pennsylvanian Hermosa Group, known for extensive potash and oil deposits in the Four Corners region (Stokes, 1986; Hintze and Kowallis, 2009). Locally, the group includes the Paradox and Honaker Trail Formations (Baker and others, 1933; Wengerd, 1958). During most of Pennsylvanian time, present-day Utah was close to the paleoequator and covered by a shallow tropical ocean. Sediments deposited during that time are primarily marine and highly fossiliferous. During the Pennsylvanian and early Permian, the uplift of the Ancestral Rocky Mountains was marked in Utah by the rising Uncompahgre highlands along the northeastern margin of the actively subsiding Paradox Basin (Stokes, 1986; Hintze and Kowallis, 2009), near what is today the Colorado-Utah border. This north-northwest- to south-southeast-trending uplift was relatively rapid, with high erosion rates of sediment that were subsequently deposited in the Paradox Basin to the west. In the BENM region, the oldest exposed strata of these synorogenic sediments are the Paradox Formation (mid-Pennsylvanian), which comprises cycles of limestone, dolomite, sandstone, shale, and anhydtrite beds capped by halite (Stokes, 1986; Condon, 1997). Though poorly fossiliferous, a borehole in the Indian Creek area of BENM produced important palynomorphs (Rueger, 1996). The overlying Honaker Trail Formation (cyclically bedded limestone, sandstone, and shale) is known for its diversity of invertebrate marine fossils (Melton,

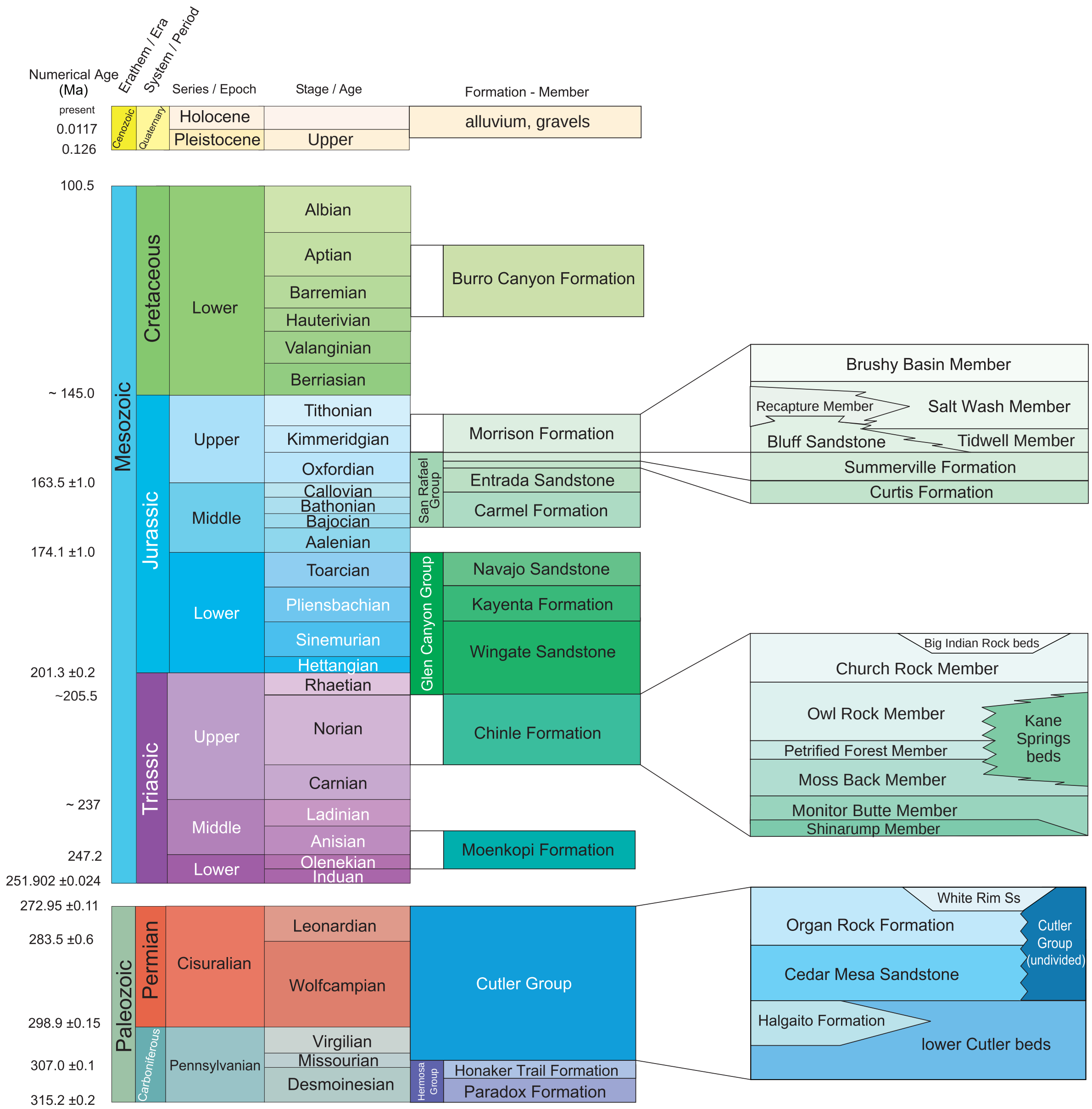

Figure 2. Stratigraphic column of rocks exposed within Bears Ears National Monument.

1972; Condon, 1997; Lewis and others, 2011). These include multiple species of fusulinaceans, brachiopods, rugose corals, bryozoans, and conodonts, among other marine invertebrates (Williams, 1949; Melton, 1972; Condon, 1997; Ritter and others, 2002). Using conodont faunas in the Hermosa Group outcropping along the San Juan River, Ritter and others (2002) pioneered conodont biostratigraphy for regional correlation of cycles in the Paradox Basin with the better-studied cycles in the Midcontinent. Based on conodonts, the top of the Honaker Trail Formation near the Valley of the Gods and the Glen Canyon Recreation Area correlates to the South Bend cycle (Lansing Group) at the top of the Missourian Midcontinental cyclothem sequence (Ritter and others, 2002).

Overlying the Hermosa Group is the Cutler Group (figure 3), which was originally named by Cross and Howe (1905) and assigned formation status by Sears (1956). These strata preserve a near continuous record of nearshore to nonmarine rocks that provide a window into early terrestrial life in western Pangea and the late Paleozoic icehouse-greenhouse transition (e.g., Montañez and others, 2007; Montañez and Poulsen, 2013). Most early authors subdivided the Cutler into four major subunits (bottom to top)—Halgaito tongue, Cedar Mesa Sandstone, Organ Rock tongue, and De Chelly Sandstone (Baker and Reeside, 1929; Baker, 1936; Orkild, 1955; Sears, 1956; Baars, 1962; O'Sullivan, 1965). Orkild (1955) and Sears (1956) redefined these units in the vicinity of Mexican Hat and Valley of the Gods where the De Chelly Sandstone is absent. Wengerd (1958) further revised the nomenclature, elevating the Cutler to group status and subsuming the transitional beds of the Pennsylvanian Rico Formation into the Cutler Group. Farther north, along the eastern and northern margins of Canyonlands National Park, these lower strata were initially assigned to both the Rico (Loope, 1984) and Elephant Canyon Formations (Baars, 1962, 1975, 1987; Terrell, 1972; Campbell, 1987), but we follow the recommendation of Loope and others (1990) and Condon (1997) in using the informal name 'lower Cutler beds.'

In addition to a diverse invertebrate assemblage, rocks of the lower Cutler beds (including the Halgaito Formation) record the rise of amniotes, egg-laying limbed vertebrates with internal fertilization. This clade includes the common ancestor of modern reptiles and mammals, and all of their descendants. Also present are some of the first terrestrial vertebrate herbivores. The geology of the Cutler Group and its fossil assemblages reveal a complex ecosystem of coastal wetlands and estuaries, seasonal and perennial lakes, alluvial fans, and shifting dune fields (e.g., Mountney and Jagger, 2004; Cain and Mountney, 2009, 2011; Jordan and Mountney, 2010, 2012; Wakefield and Mountney, 2013). During this time, repeated brief marine incursions from the west covered large portions of present-day Utah depositing thin marine carbonates, beach sands, and coastal dune strata in BENM (Jordan and Mountney, 2010). Though paleosols and fossil plants in the lower Cutler beds suggest a cool, dry climate with some seasonal precipitation, the early Permian environment became increasingly warm and arid through time (Soreghan and others, 2002a, 2002b; DiMichele and others, 2014). The

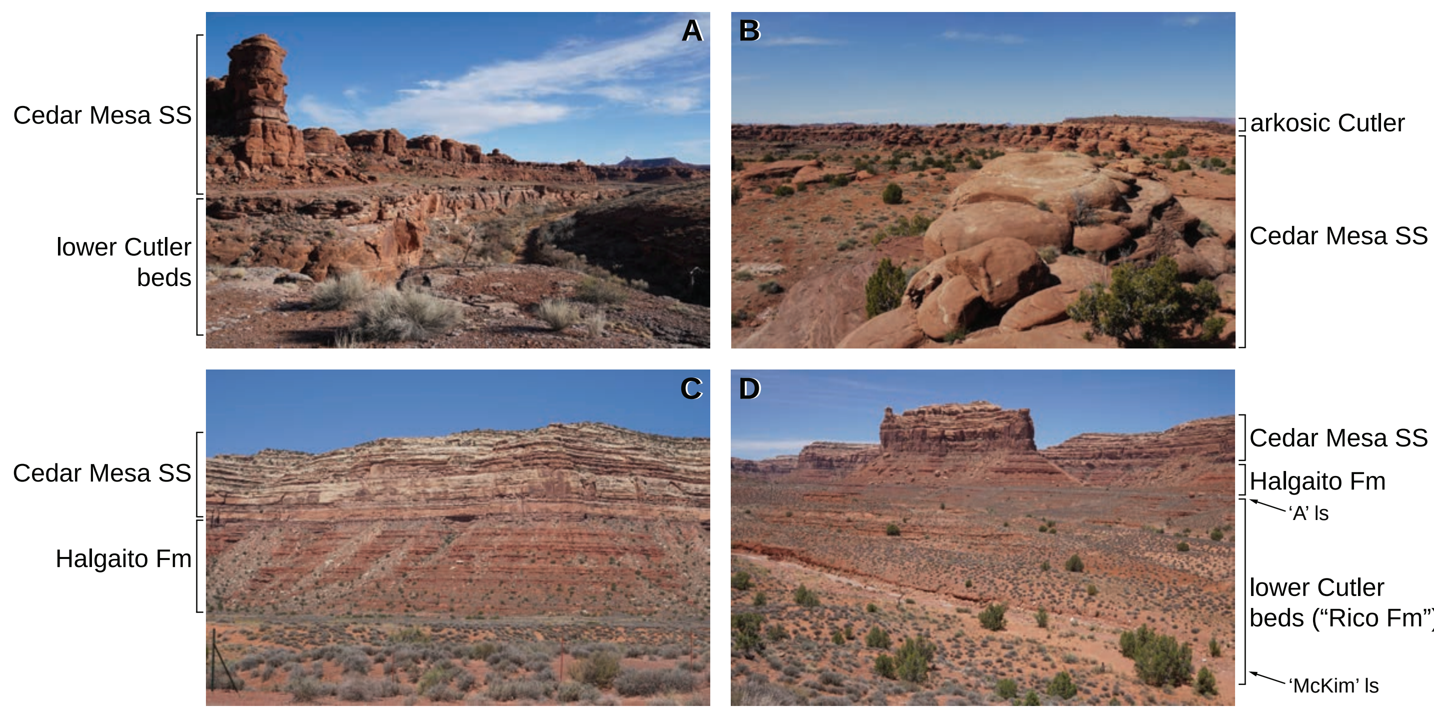

Figure 3. Upper Carboniferous-Lower Permian Cutler Group lithostratigraphy in Bears Ears National Monument and vicinity. (A and B) Indian Creek. (C) Moqui Dugway. (D) Valley of the Gods. Abbreviations: Fm, formation; Ls, limestone; SS, sandstone."

principal Cutler dune fields are preserved as the Cedar Mesa Sandstone in BENM (figure 3) (e.g., Condon, 1997; Mountney and Jagger, 2004; Mountney, 2006). Though additional erg deposits exist higher in the Cutler Group in the northwestern portions of BENM and Canyonlands National Park, such as the White Rim Sandstone, very little of these units are present within the monument boundaries.

Resulting from early geological surveys of the Monument Valley area, collections of Cutler vertebrates in the vicinity of BENM were known to paleontologists for decades before their first descriptions (Baker, 1936). In 1954, the Museum of Comparative Zoology and the USGS made brief collecting trips in the red beds near the Utah-Arizona border. The University of California, Los Angeles, added to these collections in the 1960s and 1970s. Vaughn (1962, 1973) described many fossils from nonmarine strata of the Halgaito Formation in the Mexican Hat and Valley of the Gods areas, including the first Utah records of Paleozoic xenacanth sharks, actinopterygians, osteolepiforms, temnospondyl amphibians (such as *Eryops* and the sail-backed dissorophoid *Platyhystrix*), a possible nectridean lepospondyl, stem amniote diadectomorphs, and the non-mammalian synapsids *Ophiacodon* and *Sphenacodon*. Additionally, this unit contains plant macrofossils (leaves and stems) of walchian conifers, calamitaleans, cordaitaleans, marattialean ferns, and lycopsids (Vaughn, 1962; Berman and others, 1981; Lockley and Madsen, 1993; Sumida and others, 1999a, 1999b, 1999c; Hasiotis and Rasmussen, 2010; DiMichele and others, 2014).

During the 1990s and 2000s, work was conducted in the vicinity of Valley of the Gods by California State University at San Bernardino and the Carnegie Museum of Natural History. These studies focused on the latest Pennsylvanian vertebrates of the Halgaito Formation, prompting taxonomic revisions and producing additional new records that included dipnoans, the osteolepiform *Lohsania*, limnoscelid diadectomorphs, *Edaphosaurus*, and an araeoscelid reptile (Frede and others, 1993; Sumida and others, 1999a, 1999b, 1999c, 2005; Scott and Sumida, 2004; Scott, 2005, 2013; Huttenlocker and others, 2018). Chondrichthyans, actinopterygians, osteolepiforms (*Lohsania*?), and possible aïstopod (*Phlegethontia*?) fossils have also been reported from lateral equivalents of the upper Halgaito in the lower Cutler beds of the Arch Canyon area, approximately 27 km northeast of Valley of the Gods (Vaughn, 1967; Sumida and others, 1999a, 1999b, 2005). Nearshore and marine strata here also preserve abundant marine invertebrates and conodont elements (A.K. Huttenlocker, in preparation), making these time-transgressive facies of the lower Cutler beds in Arch Canyon an ideal location to precisely identify the Carboniferous-Permian (C-P) boundary in Utah. In nearby Monument Valley, vertebrate records from the Organ Rock Formation include numerous large-bodied *Diadectes*, *Tseajaia*, *Seymouria*, and the sphenacodontid *Ctenospondylus*. Their presence suggests that multiple assemblages may be distributed stratigraphically throughout the Cutler Group of Utah, some likely correlative to parts of the Permian Wichita Group in north-central Texas (Vaughn, 1964, 1966a, 1966b, 1967, 1973; Sumida and others, 1999a, 1999b, 1999c). Vaughn (1962, p. 530) remarked, "It may be possible to build up in the Four Corners region a broad paleozoogeographic picture of faunas, at the same horizons, spread across several wide belts of different environmental conditions … San Juan County would occupy a central part of such a picture." However, unlike in Monument Valley, the truncated Organ Rock Formation sequence in Comb Wash (BENM) appears to preserve only some well-developed paleosols and rhizoliths; it is apparently largely devoid of body fossils.

Farther to the north, in the northeastern part of BENM, rare fossil localities have been reported from the Cutler Group. Vaughn (1967, p. 153) first reported, but did not describe, "shark teeth, marine invertebrates, and small vertebrae" from the lower Cutler beds of Indian Creek. Subsequently, Stanesco and Campbell (1989, p. F8–F9) reported the first fossils from the Cedar Mesa Sandstone at Indian Creek, including plant leaf and stem impressions in fluvial facies, and permineralized logs and associated tetrapod bones in a fluvio-lacustrine interdunal setting. In the early 1990s, the Dinosaur Museum (Blanding, Utah) collected vertebrate material and a large permineralized log from the same site. Although the log is currently on display in the museum's exhibits, these specimens were never published. Teams from the Smithsonian Institution's National Museum of Natural History collected leaf and stem fossils from a dozen different sites in the lower Cedar Mesa Sandstone in Indian Creek, describing marattialean pteridophytes (*Pecopteris* and *Asterotheca*), sphenophyllaleans, and conifers (*Walchia*) from these assemblages (DiMichele and others, 2014).

Carboniferous-Permian strata west-southwest of Moab and adjacent to the northern boundary of Canyonlands National Park are continuous with those in the northernmost tip of the Monument. Here, where these units are bisected by the Colorado River, abundant and diverse marine invertebrates have been reported from the Honaker Trail Formation (Melton, 1972). In the overlying transitional lower Cutler beds, marine invertebrates, chondrichthyan teeth, and osteichthyan vertebrae have been described or reported (Vaughn, 1967; Terrell, 1972; Carpenter and Ottinger, 2018). Close to the boundary of the Honaker Trail Formation and lower Cutler beds, Tidwell (1988) described a diverse latest Pennsylvanian floral assemblage containing nearly 20 taxa, including leaf and stem impressions of lycopodiopsids, sphenophyllaleans, equisetaleans, marattialean pteridophytes, medullosalean pteridosperms, and cordaitaleans. Although these localities are outside BENM, they nevertheless indicate potential paleontological resources that are likely present in Lockhart Basin at the northernmost portion of the monument.

Ongoing Work

Relatively few continuous stratigraphic records of this time interval and paleoenvironment exist in other parts of North America, so BENM rocks continue to provide a rare and relatively complete picture of ecosystems that developed during the late Paleozoic prior to the devastating end-Permian mass extinction. The oldest rocks of the Paradox Formation, though poorly fossiliferous, contain biohermal dolomitic limestone and a diverse assemblage of microfossils important for biostratigraphy (Wengerd, 1955). Most recently, Ritter and others (2016) reported conodont assemblages just north of BENM that promise to provide new age controls on the Desmoinesian (mid-Pennsylvanian) marine assemblages of the Paradox Formation in southeastern Utah.

The Carboniferous-Permian transition and the location of the C-P boundary in Utah continues to be of considerable interest in documenting the key evolutionary innovations evident in animals and plants during this time. Ongoing field investigations by the University of Southern California, California State University at San Bernardino, and Carnegie Museum of Natural History are focusing on correlating old and new vertebrate sites in San Juan County, including those in the Halgaito Formation at the Valley of the Gods, to the lower Cutler beds in the north (Arch Canyon, Dark Canyon, and Canyonlands areas). This work has resulted in discovery of several new localities and specimens that are currently under study by two of us (A.K. Huttenlocker and R.B. Irmis). Along with USC-UMNH collaborative fieldwork at latest Carboniferous-Permian localities exposed in northern San Juan County just north of BENM, the ongoing studies fill substantial spatial and temporal gaps between the Carboniferous and Permian vertebrate assemblages of Utah. For example, new work at the "birthday bonebed" in the upper Halgaito Formation in Valley of the Gods has revealed a diverse vertebrate assemblage preserved in a slackwater deposit of a nonmarine channel tributary, providing critical new data for the latest Carboniferous on the Colorado Plateau (Huttenlocker and others, 2018).

Investigations into the sedimentary environment, flora, and invertebrate fauna by teams from the National Museum of Natural History and Illinois State Geological Survey reveal the seasonally fluctuating riparian environments. Discoveries include lycopsids, walchian conifer branches, calamitalean and cordaitalean foliage, and myriapod invertebrate trackways in the Valley of the Gods, Lime Ridge, and Indian Creek areas, where work is still ongoing (DiMichele and others, 2011, 2014; Chaney and others, 2013). Additional work on trace fossils led by University of Kansas has discovered large-diameter burrows of possible vertebrate origin in the Cedar Mesa Sandstone (Hasiotis and Rasmussen, 2010), research that is ongoing. This and other studies of trace fossils are contributing to a more complete understanding of the record of early terrestrial life and environments in the Cutler Group (Dzenowski and others, 2013), and by extension early tetrapod life globally.

In 2009, UMNH began long-term excavation of the Indian Creek bonebed in the Cedar Mesa Sandstone that was first mentioned by Stanesco and Campbell (1989). This interdunal site has revealed in situ permineralized logs and hundreds of tetrapod bones from the interface between pond and fluvial deposits, as well as permineralized logs, conifer foliage, and osteichthyan and small tetrapod bones from the immediately overlying lacustrine limestone. The specimens are currently being studied by A.K. Huttenlocker, R.B. Irmis, and colleagues. Preliminary results show that tetrapod assemblage is dominated by the early synapsid *Sphenacodon*, including a new species of the temnospondyl amphibian *Eryops* (Rasmussen and others, 2016). Elsewhere in the area, the USC-UMNH team has discovered plant and vertebrate material from both marine and nonmarine horizons in the lower Cutler beds. This research group is collaborating on several other important sites in northern San Juan County relevant to BENM, and though this work is in its earliest stages, a faunal assemblage broadly consistent with other late Paleozoic localities in North America is emerging, although with some significant taxonomic differences.

EARLY-MIDDLE TRIASSIC

Geology and Paleontology

During the Triassic Period, southwestern North America was located between the equator and approximately 15°N (Kent and Irving, 2010; Torsvik and others, 2012). At this time, western Utah was situated on the coast and shallow marine shelf along the eastern margin of the Panthalassic Ocean. During the Early and Middle Triassic, central and eastern Utah comprised the coastal and nonmarine fluvial siliciclastic deposits of the Moenkopi Formation (McKee, 1954; Stewart and others, 1972b; Blakey, 1974). Outcrops of the Moenkopi Formation are widespread in BENM (figure 4A), including the Indian Creek area, Dark Canyon Wilderness and farther west, and Comb Ridge. None of the carbonate-bearing units (e.g., Black Dragon and Sinbad Limestone Members) of the Moenkopi extend far enough east to reach BENM (Blakey, 1974). Consequently, exact correlation of BENM Moenkopi strata to the marine stages of the geologic time scale is poorly constrained. Within BENM, the Moenkopi Formation contains the Hoskininni, Torrey, and Moody Canyon Members, in ascending order. The base of the Hoskininni Member is coarse grained, but the rest of the Moenkopi in BENM comprises reddish deltaic and fluvial mudstone, siltstone, and fine-grained sandstone that are slope and ledge-forming units (McKee, 1954; Stewart and others, 1972b; Blakey, 1974). To the west and north of BENM, the Torrey Member overlies the marine Sinbad Member, which preserves an ammonoid assemblage characterized by *Anasibirites kingianus* (Stewart and others, 1972b; Blakey, 1974; Lucas and others, 2007; Brayard and others, 2013), suggesting a latest Spathian (middle Olenekian) age (e.g., Balini and others, 2010; Ogg, 2012). This implies that the greater part of the Moen-

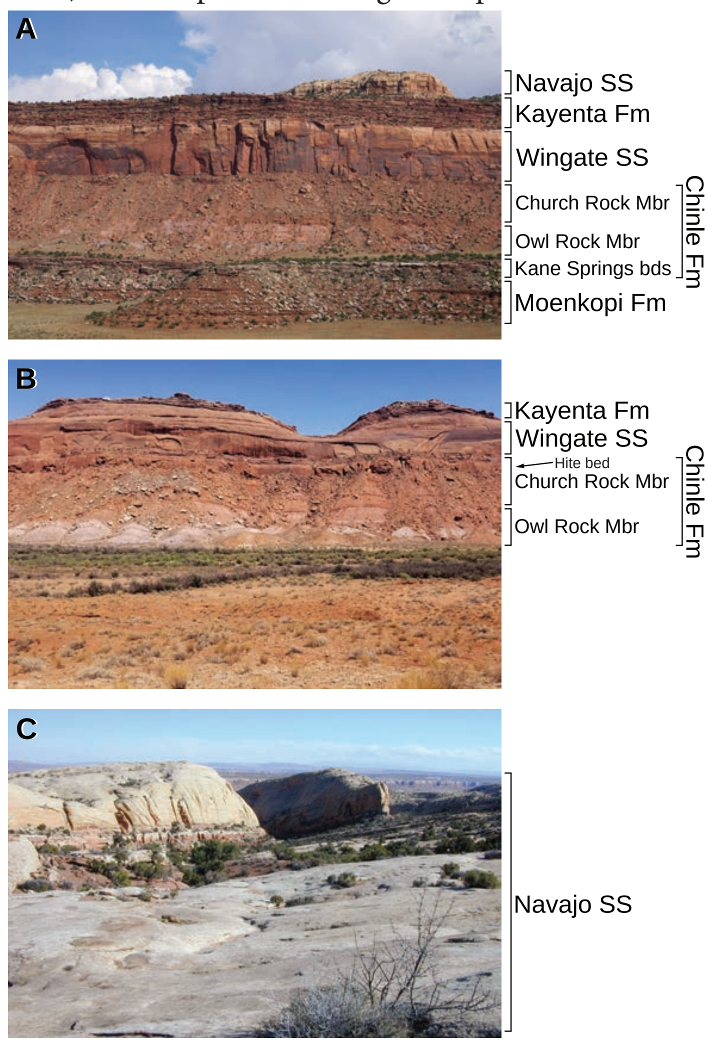

Figure 4. Triassic-Lower Jurassic lithostratigraphy in Bears Ears National Monument and vicinity. (A) Indian Creek. (B and C) Comb Ridge. Abbreviations: Fm, formation; Mbr, member; SS, sandstone; bds, beds.

kopi Formation, the Torrey and Moody Canyon Members, are Spathian (middle-upper Olenekian) in age or younger (i.e., Anisian).

Published reports of fossils from the Moenkopi Formation within the BENM are rare. McKee (1954) noted "plant fragments" and "good fish remains" from the upper Moenkopi Formation (about 40 m below the top of the unit) near Bears Ears proper; but did not illustrate or describe any specimens. Stewart and others (1972b, p. 68) briefly described actinopterygian scales, vertebrae, and teeth from the upper Moenkopi Formation (8 m below the top of the unit) in Fry Canyon, but failed to illustrate the specimens or mention repository/specimen numbers. Nearby in White Canyon, just outside of the western boundary of BENM, McKee (1954, figure 9) noted a bone-bearing conglomerate just above the base of the formation, but again no details were provided. McKee (1954, p. 69) also mentioned "amphibian bones" from Bears Ears (about 15 m below fish-bearing unit mentioned above) and "vertebrate remains" from the Indian Creek area. McKee (1954, p. 71) noted reptile tracks in the measured sections from Bears Ears and the Indian Creek area, but did not provide any further details. More recently, Thomson and Lovelace (2014) described archosauriform reptile swim tracks from the Torrey Member just inside the western boundary of BENM along Highway 95, as well as a number of similar sites just outside the western boundary of the monument.

Perhaps the most important fossil locality in the Moenkopi Formation within BENM is a site discovered in 1945 by University of California-Berkeley paleontologist Samuel P. Welles and colleagues in the Indian Creek area. Here, the Berkeley team discovered and excavated the complete skull and lower jaws of a capitosaurian temnospondyl amphibian in the upper Moenkopi Formation. Although Welles (1967, 1969) failed to describe the specimen, it was twice mentioned and once illustrated (Welles, 1967, p. 14), noting its striking similarity to *Parotosuchus helgolandicus* (Welles, 1967, p. 13) from the lower Middle Buntsandstein of northern Germany, which is Smithian/lower Olenekian in age (see Szurlies, 2007; Hounslow and Muttoni, 2010). Morales (1987, p. 6) also mentioned the specimen and stated, without further explanation, that it was from the Torrey Member. Despite a lack of detailed description, formal taxonomic assignment, or stratigraphic data, Lucas and Schoch (2002, p 101) asserted that the specimen was assignable to *Parotosuchus helgolandicus* and repeated Morales' statement that it was from the Torrey Member. Lucas and Schoch (2002) also incorrectly described the specimen as being found near Hite. These authors then used the specimen to correlate the Moenkopi Formation with the Buntsandstein in Germany.

Ongoing Work

Work on new Moenkopi Formation track sites from the White Canyon region is in its nascent stages but the assemblage of invertebrate burrows and surface tracks indicates a diverse fauna that requires full description. These track sites were discovered in the 2016 and 2017 field seasons by one of us (R.J. Gay). Additionally, R.B. Irmis has recently relocated the site of Welles' *Parotosuchus*-like temnospondyl in the Indian Creek area, as part of work to describe the specimen and place it in a precise geologic context. Although the Moenkopi Formation in BENM has historically been poorly surveyed, these discoveries suggest that systematic prospecting of the unit may reveal significant fossil localities.

LATE TRIASSIC

Stratigraphy and Depositional Environments

During the Late Triassic, Pangaea began to drift northward (Kent and Tauxe, 2005; Kent and Irving, 2010). What is now the southwestern United States changed from having a semi-humid to a semi-arid climate (Kent and Tauxe, 2005; Whiteside and others, 2011, 2015). No strata are preserved in this region that record the late Middle Triassic and early Late Triassic environment. Base-level change near the end of the Carnian (about 228 Ma) (Atchley and others, 2013) initiated deposition of the fluvially dominated sediments of the Chinle Formation (e.g., Blakey and Gubitosa, 1983; Dubiel, 1994; Riggs and others, 1996). As the climate of the region became progressively more arid toward the end of the Triassic Period, the northwest-flowing rivers and floodplains depositing the Chinle Formation were increasingly better drained (e.g., Dubiel and Hasiotis, 2011; Martz and others, 2014). Ultimately, during the latest Triassic, fluvial deposition became ephemeral and sand dunes gradually encroached upon the eastern half of the state (Martz and others, 2014; Irmis and others, 2015; Britt and others, 2016). By the beginning of the Jurassic, dune fields extended across large portions of the Colorado Plateau. The dunes are preserved as the Wingate Sandstone (Stokes, 1986; Peterson, 1988, 1994; Blakey, 1994), which directly overlies the Chinle Formation.

No other geologic formation in BENM has attracted more paleontological research than the Upper Triassic Chinle Formation (e.g., Parrish and Good, 1987; Parrish, 1999; Fraser and others, 2005; Gay and St. Aude, 2015, Martz and others, 2014, 2017; figures 4A and 4B). The lithostratigraphy of the Chinle is complex with a high degree of lateral facies variability. Within the southern BENM, the Chinle Formation can be divided into six members, from oldest to youngest—Shinarump, Monitor Butte, Moss Back, Petrified Forest, Owl Rock, and Church Rock (Stewart, 1957; Stewart and others, 1972a; Blakey and Gubitosa, 1983; Dubiel, 1994; Lewis and others, 2011) (figure 4B). In the south-central and southeastern parts of BENM, near Bears Ears proper and Comb Ridge, the Monitor Butte and Moss Back Members interfinger (Stewart and others, 1972a; Blakey and Gubitosa, 1983; Dubiel, 1994), making them difficult to differentiate (Lewis and others, 2011). For stratigraphic convenience the interfingered parts of the formation is referred to simply as the Monitor Butte Member (Gay and St. Aude, 2015). In the Abajo Mountains and Indian Creek areas to the north, the lower part of the Chinle Formation is absent. The base of the formation is equivalent to the Petrified Forest Member (Blakey and Gubitosa, 1983; Martz and others, 2014, 2017). Here the Chinle subdivisions are, from oldest to youngest—Kane Springs beds, Owl Rock Member, and Church Rock Member (Witkind, 1964; Blakey and Gubitosa, 1983, 1984; Martz and others, 2014, 2017) (figure 4A).

The Shinarump Member fills paleovalleys incised into the underlying Moenkopi Formation. This member is dominated by coarse-grained braided stream deposits laid down by large river systems flowing to the northwest (Blakey and Gubitosa, 1983, 1984; Dubiel, 1983, 1987, 1994). The coarse-grained sediments pass upward with an interfingering relationship into finer-grained floodplain sediments of the Monitor Butte Member that preserve marsh, pond, and small stream environments having a fluctuating water table (Blakey and Gubitosa, 1983; Dubiel, 1983, 1987, 1994; Dubiel and Hasiotis, 2011). Laterally the Monitor Butte strata grade into and are overlain by braided stream deposits of the Moss Back Member, which represent the larger trunk streams of the same fluvial system (Blakey and Gubitosa, 1983, 1984; Dubiel, 1983, 1987, 1994). In the southern BENM, the Moss Back is overlain by the well-drained paleosols and meandering stream deposits of the Petrified Forest Member, which record increasingly arid and seasonal conditions during the Norian (Blakey and Gubitosa, 1983; Dubiel, 1987, 1994; Dubiel and Hasiotis, 2011; Martz and others, 2017).

In the northern BENM and vicinity, the Kane Springs beds are in part correlative to the Petrified Forest Member. These beds are the lowest Chinle strata in this area (Blakey and Gubitosa, 1983, 1984; Martz and others, 2014, 2017). This unit represents an assemblage of fine-grained floodplain and meandering stream deposits that locally fill paleovalleys in the underlying Moenkopi Formation (Blakey, 1978; Blakey and Gubitosa, 1983, 1984; Martz and others, 2014; Hartley and Evenstar, 2018). The Owl Rock Member rests on both the Petrified Forest Member and Kane Springs strata throughout BENM (figure 4A). This member is characterized by fine-grained overbank and minor channel deposits (Blakey and Gubitosa, 1983; Dubiel, 1994; Dubiel and Hasiotis, 2011). Crayfish burrows extending from channel and levee facies down into underlying fine-grained paleosols are common (Hasiotis and Mitchell, 1989, 1993; Hasiotis and others, 1993; Hasiotis, 1995). Descriptions of widespread lacustine environments in the Owl Rock Member are a consequence of misinterpretation of the carbonate-rich pedogenic horizons and the coarse-grained layers with both diagenetic carbonate cement and intraformational carbonate nodule clasts (Tanner, 2000, 2003). The uppermost unit of the Chinle Formation across all the BENM is the Church Rock Member having coarse-grained overbank and ephemeral channel deposits indicating a distinctly seasonal paleoclimate (Blakey and Gubitosa, 1983; Dubiel, 1987, 1994; Martz and others, 2014). Locally at the boundary between the top of the Church Rock Member and the overlying Wingate Sandstone, there are fluvial sandstone and conglomerate beds named Big Indian Rock beds by Martz and others (2014). These beds indicate that the Chinle-Wingate transition was variable and not correlative strictly with the onset of eolian deposition. As in northeastern Utah (cf. Irmis and others, 2015), the fossils in these beds indicate that the base of the Wingate Sandstone is still Triassic in age (Martz and others, 2014).

History of Geological and Paleontological Exploration

The earliest publication of vertebrate fossils from the BENM region described the first occurrence of a phytosaur from Utah. This specimen was collected from the Clay Hills area, south of Fry Canyon and east of what is now Lake Powell (Lucas, 1898). Phytosaurs are perhaps the most common vertebrate fossil from the Chinle Formation in BENM (Martz and others, 2014; McCormack and Parker, 2017; authors personal observations). These semi-aquatic, archosauriform reptiles superficially resemble modern crocodylians. They were globally distributed and abundant during the Late Triassic (Stocker and Butler, 2013). During the early part of the 20th century geologic exploration in BENM focused principally on mineral and oil exploration along the San Juan River (e.g., Baker, 1933, 1936; Wengerd, 1951). As part of this work, a 1926 USGS geological field party collected fragmentary phytosaur bones from Moab (Camp, 1930, p. 12; Baker, 1933, p. 41). Charles Camp of the University of California, Berkeley, conducted additional fieldwork in the Chinle Formation of southeastern Utah in 1927, discovering localities near Moab (UCMP A280), Indian Creek (UCMP A281), and Bears Ears (UCMP A277). Camp (1930, p. 13) briefly mentioned fragmentary phytosaur material, as well as other bone fragments, from these sites.

In the 1950s, exploration in the Chinle Formation shifted away from fossils and toward another resource. The post-World War II uranium boom resulted in mining claims throughout southeastern Utah. The Chinle Formation became one of the country's most productive formations for uranium (Isachsen and Evensen, 1956; Ringholz, 1989). This explosion of mineral exploration and extraction also promoted renewed interested in Triassic stratigraphy on the Colorado Plateau. During the 1950s and 1960s, the Atomic Energy Commission funded a large-scale study of nonmarine Triassic lithostratigraphy by a USGS team resulting in two comprehensive monographs (Stewart and others, 1972a, 1972b). Not only did this work provide fundamental insights into the stratigraphy and sedimentology of the Chinle Formation (Stewart, 1956, 1957; Stewart and others, 1959, 1972a; Stewart and Wilson, 1960), but additional paleontological sites were discovered. These include sites from BENM and surrounding areas, such as molluscs from Fry Canyon, White Canyon, the Clay Hills, and Lisbon Valley (Stewart and others, 1972a, p. 78–79); crustaceans from White Canyon and Lisbon Valley (Stewart and others, 1972a, p. 79); temnospondyl amphibians from Fry Canyon (Stewart and others, 1972a, p. 80); and phytosaurs from White Canyon and Deer Flat (Stewart and others, 1972a, p. 82). A diversity of fossil leaf localities were reported, including sites preserving ferns, bennettitaleans, and conifers in the Shinarump and Monitor Butte Members at Elk Ridge, Deer Flat, White Canyon, and Monitor Butte (Stewart and others, 1972a, p. 85–86). Many of these specimens subsequently were described in more detail by Ash (1975a, 1975b, 1977, 2001; Ash and others, 1982; Ash and Litwin, 1996). Mullens (1960, p. 287–288) mentioned gastropods, teeth, and bone fragments from the Clay Hills area and O'Sullivan (1965, p. 62) reported fragmentary phytosaur remains from Comb Ridge. Just east of BENM, in the Lisbon Valley area, geologists conducting uranium exploration (Isachsen, 1954; Isachsen and others, 1955; Isachsen and Evensen, 1956; Weir and Puffett, 1960) discovered several sites in the Church Rock Member (see Martz and others, 2014) that preserve articulated skeletons of multiple species of actinopterygian fish and the coelacanth *Chinlea*. These specimens were described by Schaeffer (1967).

Though the uranium boom ended in the late 1960s with falling commodity prices, its effects can still be felt in unexpected ways by modern paleontologists who work in BENM. For example, old uranium roads provide access to sites that would otherwise be inaccessible, because the Chinle Formation forms impenetrable badlands within BENM. Uranium readily replaces calcium in bone (Neuman and others, 1949) and often precipitates in association with organic material (Spirakis, 1996). In areas with high concentrations of uranium minerals, radioactive fossilized bone and wood are common (Steen and others, 1953; Gross, 1956; Isachsen and Evensen, 1956; Trites and others, 1956; Weir and Puffett, 1960; Johnson and Thordarson, 1966; R. Gay, personal observation). Historical archaeological artifacts of the uranium boom, including mine shafts and assorted machinery, core holes and discarded core, and mining haul roads are common across the region. Abandoned camps can be found across BENM wherever Triassic strata are well exposed.

Following the seminal work on Chinle stratigraphy by Stewart and others (1972a), paleontological reconnaissance of the Chinle Formation across southeastern Utah was performed during the mid-1980s by Michael Parrish, Steven Good, and Russell Dubiel. Prior to field campaigns by Parrish, Good, and Dubiel, fossil occurrences in the Chinle Formation within BENM had been limited due to the rough terrain and lack of systematic prospecting, and were largely restricted to finds made by the geologic studies cited above. Parrish and Good (1987) and Parrish (1999) had discovered vertebrate fossils in the Shinarump, Monitor Butte, Moss Back, and Petrified Forest Members of the Chinle Formation, including metoposaurid temnospondyls, phytosaurs, and aetosaurs. The discovery of the phytosaur '*Rutiodon tenuis*' (= *Machaeroprosopus pristinus*—see Long and Murry, 1995) and a partial osteoderm of the aetosaur *Typothorax* lead Parrish and Good (1987) to correlate the Petrified Forest Member in the White Canyon region of BENM with the Petrified Forest Member in Arizona and New Mexico. This correlation is consistent with lithostratigraphic correlations by Stewart and others (1972a), Blakey and Gubitosa (1983), and Martz and others (2017). Parrish and Good (1987) also discovered numerous invertebrate fossils, including bivalves, gastropods, ostracods, and conchostracans. In addition, they reported the occurrence of the molluscs *Triasamnicola assiminoides*, *Diplodon gregori*, *Antediplodon* sp., and *Unio* sp.

The most significant discoveries from the 1980s surveys were two separate sites that preserve small vertebrates, both of which are adjacent to uranium mines. The first was discovered in the Monitor Butte Member of the Red Canyon area. From this site Parrish (1999) described several vertebrae, limb elements, and armor plates of at least two individual diminutive crocodylomorphs belonging to the same taxon, as well as three additional armor plates from crocodylomorphs assigned to Archosauriformes. None of the 'crocodylomorph' material is actually assignable to that clade. The osteoderms (Parrish, 1999; figure 1) and possibly some of the postcrania (figures 2 and 3 of Parrish, 1999) appear to be referable to the early suchian *Revueltosaurus* (cf. Parker and others, 2005; R.B. Irmis., personal observation). Similarly, the indeterminate archosauriform osteoderms are nearly identical to those of the suchian archosaur *Acaenasuchus* from the Blue Mesa Member of the Chinle Formation of eastern Arizona (cf. see figures 117 and 118 of Long and Murry, 1995; figure 6d of Irmis, 2005a; Marsh and others, in press). This site, including Parrish's finds, was included in the original monument proposal (Bears Ears Intertribal Coalition, 2016) but omitted in the final declaration (Obama, 2016). The second site, in the Petrified Forest Member in White Canyon, produced vertebrae and claws from a possible theropod dinosaur and a fragmentary right mandible from a possible ornithischian dinosaur (Parrish, 1999). For nearly two decades these represented the only published occurrence of dinosaur body fossils from the Triassic of Utah. Although the discovery appeared to be highly significant, recent work has cast doubt on their assignment to Dinosauria (Jenkins and others, 2017). This site is within the original boundaries of BENM (Obama, 2016), but it is excluded from the revised monument boundaries (Trump, 2017).

Another notable discovery was a skull of a procolophonid parareptile from the Owl Rock or Church Rock Members in the Abajo Mountains area (Fraser and others, 2005). This unnamed leptopleuronine is the only described associated skull of a procolophonid from the Chinle Formation. Procolophonid remains of any kind are very rare from the unit (Martz and others, 2017). This specimen appears to be taxonomically distinct from *Hypsognathus* and other leptopleuronines known from the Late Triassic of North America (Fraser and others, 2005).

Other paleontological work in the area occurred sporadically throughout the 1980s and 1990s. Litwin (1986), Litwin and Skog (1991), and Litwin and others (1991) described diverse palynological assemblages from the Shinarump Member at Kigalia Point, north of Bears Ears Buttes, and from the Petrified Forest Member at Copper Point, east of White Canyon. The palynomorphs supported regional biostratigraphic correlation of the Chinle Formation (Litwin and others, 1991). Just east of BENM, Ash (1982, 1987) described specimens of petrified wood, casts of *Neocalamites*, leaves of *Pelourdea poleoensis*, and leaves of *Sanmiguelia lewisi* from the Church Rock Member in Lisbon Valley. Dubiel and others (1987, 1988, 1989) described lungfish burrows from the Monitor Butte and Owl Rock Members in the White Canyon area. However, it was quickly noted by other researchers that these were crayfish burrows identical to those containing rare crayfish body fossils in the Owl Rock Member at Indian Creek (McAllister, 1988; Hasiotis and Mitchell, 1989, 1993; Hasiotis and others, 1993; Hasiotis, 1995). These ichnofossils provide evidence for a fluctuating water table during the Norian in this area. Also at Indian Creek is the Shay Canyon track site described in Lockley (1986) and Lockley and Hunt (1995). This important site preserves over 250 footprints on a single horizon in the Church Rock Member. It is dominated by tracks of *Brachychirotherium*, thought to be made by aetosaurs (refer to Heckert and others, 2010; Lucas and Heckert, 2011). *Atreipus*-like tridactyl prints are also preserved (Lockley and Hunt 1995; Hunt-Foster and others, 2016).

Ongoing Work

Parrish and Good (1987) and Parrish (1999) were the first researchers to demonstrate the potential for significant Chinle sites in the area designated as BENM. Three decades later the list of institutions engaged in active Chinle research in BENM has grown significantly to include Museums of Western Colorado, the Natural History Museum of Utah, the St. George Dinosaur Discovery Site, the Natural History Museum of Los Angeles County, Petrified Forest National Park, Appalachian State University, and the University of California, Berkeley. In a large collaborative effort that has become the norm for paleontological research, scientists from these institutions are working to fill gaps in our understanding of the Late Triassic Period (Martz and others, 2014; Delgado and others, 2017; Gay and others, 2017).

Recent and ongoing efforts by teams have assembled substantial collections from BENM and the surrounding region, much of which awaits preparation and research. Work in the southern area has recovered a diverse microvertebrate assemblage from the base of the Chinle Formation at Comb Ridge (Gay and others, 2016). This site has already produced hundreds of specimens from surface collection alone, with screen washing done in 2018. The taxonomic diversity is greater than any published Upper Triassic microvertebrate site in Utah. As of 2017, the recovered diversity (293 specimens comprising 14 clades) is similar to other North American sites of the same age. Gay and others (2017) report a bonebed in the Chinle Formation in Red Canyon that had previously produced a skull and partial skeleton of the phytosaur *Pravusuchus* (McCormack and Parker, 2017). Preliminary fieldwork conducted at this site in September of 2017 indicated that the bonebed is a laterally extensive assemblage unlike any previously discovered in BENM or elsewhere in the Chinle Formation of Utah. It is apparent that over the past two decades illegal collecting had been done at this site, highlighting the fragility of this extremely significant paleontologic resource and others like it (Gay and others, 2018).

In the northern part of BENM, particularly in the Indian Creek area, joint fieldwork from 2013 to the present by the SGDDS and UMNH has identified over 200 new fossil localities in the Chinle Formation that preserve a record of Late Triassic plants, molluscs, and vertebrates. These sites occur throughout formation with fossils in the Kane Springs beds, Owl Rock Member, and Church Rock Member (see figure 12 of Martz and others, 2014, p. 426–428). Discoveries include multiple taxa of leaves, a quarry containing many articulated actinopterygian fish, metoposaurid temnospondyls, phytosaur skulls and associated skeletons, aetosaurs, "rauisuchians," skeletal remains of small as-yet unidentified tetrapods, and a diversity of tetrapod footprints (e.g., *Brachychirotherium*, *Rhynchosauroides*, *Evazoum*, and *Gwyneddichnium*; see Hunt-Foster and others, 2016). To the east, just outside of BENM, the same team encountered a similar fossil assemblage in the Kane Springs beds and Church Rock Member in Lisbon Valley. Fossils found include leaves of ferns, bennettitaleans, and *Sanmiguelia;* conchostracans; ostracods; molluscs; multiple taxa of actinopterygian fish; coelacanths; metoposaurid amphibians; the phytosaur *Redondasaurus*, the aetosaur *Typothorax;* paracrocodylomorphs; and footprints from the ichnotaxa *Grallator*, *Brachychirotherium*, *Apatopus*, and *Rhynchosauroides* (Milner, 2006; Milner and others, 2006, 2011; Gibson, 2013a, 2013b, 2015; Ash and others, 2014; Martz and others, 2014; see figures 6 to 12 and table 1 of Hunt-Foster and others, 2016). The specimens in the Indian Creek area and Lisbon Valley comprise the most abundant fossil assemblages in Utah from the Chinle Formation and are among the richest assemblages from the Church Rock Member anywhere on the Colorado Plateau.

THE TRIASSIC-JURASSIC BOUNDARY

The end of the Triassic Period is marked by one of the five largest mass extinctions in Earth's history, the end-Triassic mass extinction (e.g., Raup, 1994; Bambach, 2006; Alroy and others, 2008). This biotic crisis at 201.6 Ma is thought to have been caused by eruption of the Central Atlantic Magmatic Province (CAMP) flood basalts. These were extruded on land as the Atlantic margins of North America, South America, Europe, and Africa began to rift apart (e.g., Schoene and others, 2010; Whiteside and others, 2010; Blackburn and others, 2013; Percival and others, 2017). Although the extinction event is relatively well characterized in marine ecosystems, its severity and timing in nonmarine environments remains controversial (e.g., Pálfy and others, 2000; Olsen and others, 2002; Tanner and others, 2004; Whiteside and others, 2007, 2010; Lindström and others, 2017). The difficulty with nonmarine records is that age dating is poorly constrained (e.g., Irmis and others, 2010; Mundil and others, 2010). In North America the sole exception is the tetrapod footprint record from the Newark Supergroup along the east coast (Olsen and others, 2002), which is tied to the Newark-Harford Astrochronostratigraphic Time-Scale (Kent and others, 2017) and now verified by high-precision U-Pb ages from the Chinle Formation (Kent and others, 2018).

The uppermost Chinle Formation and Glen Canyon Group on the Colorado Plateau has potential to complement the Newark Supergroup record because it preserves an abundant footprint and body fossil record (e.g., Sues and others, 1994; Irmis, 2005b; Lucas and others, 2005; Tykoski, 2005; Milner and others, 2012) and contains a much longer post-extinction record (cf. Marsh and others, 2014; Marsh, 2015). However, the principal limitation of the Colorado Plateau record is the absence of precise geochronologic age constraints. There is even debate over the stratigraphic placement of the Triassic-Jurassic boundary (Lucas and others, 2005, 2006b, 2006c, 2011; Kirkland and Milner, 2006; Lucas and Tanner, 2007; Donohoo-Hurley and others, 2010; Milner and others, 2012; Kirkland and others, 2014; Suarez and others, 2017). Nonetheless, evidence is strong that the Triassic-Jurassic transition is preserved without significant gaps in deposition across the Colorado Plateau (Lucas and others, 2006c; Sprinkel and others, 2011a; Martz and others, 2014; Irmis and others, 2015; Britt and others, 2016; Suarez and others, 2017), and specifically in BENM (Molina-Garza and others, 2003; Lewis and others, 2011). Therefore the Glen Canyon Group within and adjacent to BENM can provide important insights into the end-Triassic extinction on land, the subsequent ecological recovery of non-marine ecosystems, and the final stages of the emergence of dinosaurs (e.g., Brusatte and others, 2010; Langer and others, 2010; Irmis, 2011).

Geology and Paleontology

In BENM, the Chinle Formation is overlain by the Upper Triassic-Lower Jurassic Wingate Sandstone of the Glen Canyon Group, which acts as a resistant cliff-forming "cap" (Baker, 1936; Sears, 1956; Stewart, 1957; Witkind and others, 1963; Witkind, 1964; O'Sullivan and MacLachlan, 1975; Martz and others, 2014, 2017). Although predominantly an eolian sandstone, the base of this unit locally preserves fluvially deposited sands (e.g., Martz and others, 2014). The Wingate Sandstone represents the onset of the Early Jurassic continental erg (e.g., Blakey, 1994; Blakey and others, 1988; Peterson, 1988, 1994; Sprinkel and others, 2011a; Irmis and others, 2015; Britt and others, 2016), a profound and sustained desertification of western North American driven in part by the breakup of Pangea and the northward drift of the continent (Kent and Irving, 2010). Paleontologic (Lockley and others, 2004; Lucas and others, 2006c; Martz and others, 2014; Hunt-Foster and others, 2016), geochronologic (Molina-Garza and others, 2003), and lithostratigraphically correlative strata (Sprinkel and others, 2011a; Irmis and others, 2015; Britt and others, 2016; Suarez and others, 2017) all indicate that the Triassic-Jurassic boundary is preserved within the Wingate Sandstone.

Except for vertebrate body fossils found at the Chinle-Wingate contact in the aforementioned fluvial sandstones (Morales and Ash, 1993; Martz and others, 2014), the Wingate Sandstone has yet to produce diagnostic body fossils. No Wingate fossil sites within BENM have been published. However, numerous Wingate track sites have been found north and west of BENM, as well as in northeastern Arizona (Longwell and others, 1925, p. 13; Baker, 1936, p. 50; Lockley and Hunt, 1995; Schults-Pittman and others, 1996; Lockley and others, 2004; Smith and Foster, 2004; Lockley and Gierliński, 2006; Lucas and others, 2006c; Hunt-Foster and others, 2016). At these sites the presence of *Brachychirotherium* and absence of *Eubrontes* in the lower Wingate Sandstone and vice versa in the upper Wingate, along with the presence of synapsid, *Batrachopus*, and *Otozoum* tracks, is consistent with the placement of the Triassic-Jurassic boundary near the middle of the formation (Lockley and others, 2004; Lucas and others, 2006c).

Ongoing Work

A SGDDS-UMNH investigation in the Indian Creek area has discovered a number of important Wingate Sandstone footprints in slump blocks covering the slope-forming Chinle Formation. These include tracks of *Brachychirotherium*, *Eubrontes*, and a spectacular vertical block covered in dozens of tracks of *Evazoum* and *Grallator* (see figures 16f and 17 of Hunt-Foster and others, 2016, p. 88–89). Although not in original stratigraphic position, the footprint assemblages add credence to the proposition that the Wingate Sandstone in BENM contains a record of the end-Triassic extinction and the Triassic-Jurassic boundary.

JURASSIC

Geology and Paleontology

The Glen Canyon Group contains three formations—the eolian Wingate Sandstone at the base, the fluvial-dominated Kayenta Formation, and, with an interfingering relationship, the eolian Navajo Sandstone at the top (Middleton and Blakey, 1983; Herries, 1993; Blakey, 1994; Peterson, 1994). All three units outcrop prominently throughout the BENM (figures 4A and 4B). Access to the outcrops is generally difficult because they form steep ledges and cliffs.

Radioisotopic ages, magnetostratigraphy, and palynomorphs from the underlying Moenave Formation in southwestern Utah and northern Arizona provide maximum age constraints for the Kayenta Formation indicating it is no older than Sinemurian (Litwin, 1986; Cornet and Waanders, 2006; Downs, 2009; Donohoo-Hurley and others, 2010; Suarez and others, 2017). New U-Pb zircon ages from the 'silty facies' of the formation in northern Arizona suggest at least part of the Kayenta is late Pliensbachian to early Toarcian in age (Marsh and others, 2014; Marsh, 2015). This is consistent with magnetostratigraphic data from the Kayenta Formation and interfingering Tenny Canyon Tongue of the Navajo Sandstone in southwestern Utah, which Steiner and Tanner (2014) correlated with the lower-middle Pliensbachian, but would be equally consistent with an upper Pliensbachian-lower Toarcian age (cf. Moreau and others, 2002; Ogg and Hinnov, 2012).

Descriptions of fossils from the Kayenta Formation in BENM are few. Baker (1933, p. 46) reported unionid bivalves from the northern tip of the original monument. UMNH has in its collection a tetrapod rib (UMNH VP 29841) and a large bone fragment (UMNH VP 29842) from the formation in the Comb Ridge area. There are no published accounts of footprints in BENM, but diverse and abundant track assemblages are known to the north and west (Lockley and Hunt, 1995; Foster and others, 2001; Lockley and Gierliński, 2006, 2014a; Milner and others, 2012). In northeastern Arizona, the 'silty facies' of the Kayenta Formation contains a diverse body fossil assemblage, including hybodont and osteichthyan fishes, amphibians, caecilians, turtles, crocodylomorphs, dinosaurs, cynodonts, dicynodonts, and mammals (Sues and others, 1994; Lucas and others, 2005; Tykoski 2005). A new site in southwestern Utah has produced a diverse assemblage of fossil leaves, vertebrate body fossils, and vertebrate ichnotaxa (Milner and others, 2017).

The hypothesized Toarcian age of the Navajo Sandstone is constrained only by the age of the unit that conformably underlies it, as described above, and the Middle Jurassic (Aalenian) Temple Cap Formation (Kowallis and others, 2001; Sprinkel and others, 2011b; Doelling and others, 2013) that unconformably rests on it. A remarkable discovery in the Navajo Sandstone at Comb Ridge in BENM is the type specimen of the early sauropodomorph dinosaur *Seitaad ruessi* (Sertich and Loewen, 2010). This is the oldest dinosaur identified to the species level in Utah. The single specimen is an articulated postcranial skeleton missing the neck and tail. It is one of few vertebrate body fossil specimens collected from the entire formation. Elsewhere the Navajo Sandstone contains other sauropodomorphs, the theropod *Segisaurus*, crocodylomorphs, tritylodontid cynodonts, and actinopterygian fish (Irmis, 2005b; Harward and Irmis, 2014; Frederickson and Davis, 2017). Trace fossils in the Navajo Sandstone are abundant and diverse. Rainforth (1997) documented occurrences in BENM near Comb Ridge, Indian Creek, and Kane Springs Canyon, including footprints of *Grallator*, *Eubrontes*, *Anomoepus*, and *Otozoum*. In southern Utah outside of BENM, Navajo Sandstone invertebrate and vertebrate traces are numerous. They include the extensive trackway site at the Kayenta-Navajo boundary in Lisbon Valley (Stokes, 1978; Lockley and others, 1992; Lockley and Hunt, 1995; Rainforth, 1997; Loope and Rowe, 2003; Loope, 2006a; Ekdale and others, 2007). Particularly important are spring-fed interdunal pond deposits containing fossils of large conifer logs, leaves, ostracods, invertebrate and vertebrate burrows, and dinosaur tracks (Eisenberg, 2003; Loope and others, 2004; Lucas and others, 2006a; Parrish and Falcon-Lang, 2007; Riese and others, 2011; Parrish and others, 2017).

The Middle to Upper Jurassic San Rafael Group unconformably overlies the Glen Canyon Group. Middle Jurassic and younger strata are exposed only on the eastern and western margins of BENM (figure 5). Post-Lower Jurassic rocks have been eroded from the top of the Monument upwarp (e.g., Hintze and others, 2000; see figure 1 of Doelling and others, 2013). Consequently, the oldest unit in the San Rafael Group is the Carmel Formation, which is biostratigraphically and radioisotopically dated as Bajocian through lower Callovian (Sprinkel and others, 2011b; Doelling and others, 2013). No fossils have been reported from the Carmel Formation in southeastern Utah, but extensive invertebrate fossil assemblages are known from marine facies to the west and north (Imlay, 1948, 1964; Lowrey, 1976; Bagshaw, 1977). Dinosaur footprints have been reported from coastal deposits in northeastern Utah (Lockley and Hunt, 1995; Lockley and others, 1998a). The Carmel Formation is conformably overlain by the eolian Entrada Sandstone, which is thought to be late Callovian (Sprinkel and others, 2011b; Doelling and others, 2013). No fossils have been reported from the Entrada in BENM, but to the west and north invertebrate burrows (Ekdale and Picard, 1985), vertebrate burrows (Loope, 2006b, 2008), and theropod and sauropod di-

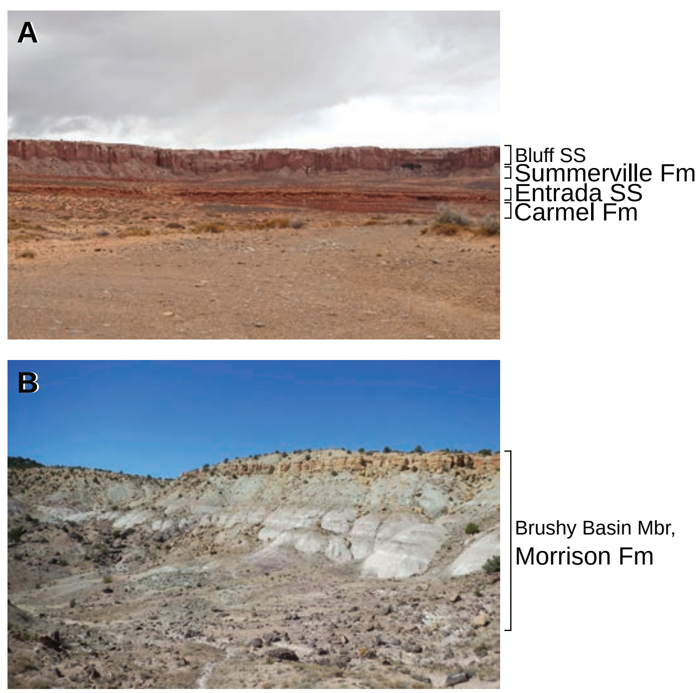

Figure 5. Middle-Upper Jurassic lithostratigraphy in Bears Ears National Monument and vicinity. (A) Butler Wash. (B) Black Mesa. Abbreviations: Fm, formation; Mbr, member; SS, sandstone.

nosaur footprints (Foster and others, 2000) occur. The San Rafael Group includes the Moab Tongue along the eastern margin of GSENM. This localized stratigraphic unit had been considered part of the Entrada Sandstone, but it is now assigned to the younger Curtis Formation (Doelling, 2001, 2004; O'Sullivan 2010a). The Curtis Formation is considered to be latest Callovian or earliest Oxfordian in age, because the base of the overlying Morrison Formation is dated as middle-late Oxfordian (cf. Pellenard and others, 2013; Trujillo and Kowallis, 2015; Muttoni and others, 2018). This age assignment is consistent with U-Pb dates from detrital zircon in the Curtis Formation (Dickinson and Gehrels, 2009). No Curtis Formation fossils have been reported in BENM; however, to the north the top of the Moab Tongue contains abundant dinosaur tracks, a "mega track site," as well as tracks of the controversial archosaur ichnotaxon *Pteraichnus* (Lockley, 1991; Lockley and Hunt, 1995; Lockley and Gierliński, 2014b). In eastern BENM the Summerville Formation (Oxfordian) directly overlies the Moab Tongue. The Summerville's assigned age is constrained only by its stratigraphic position immediately beneath the fossiliferous Morrison Formation. At Butler Wash in BENM there is an important theropod dinosaur track site in the upper Summerville Formation. Similar footprints, including *Pteraichnus,* are found in an equivalent stratigraphic position north of Ticaboo, west of BENM (Lockley and others, 1996; Lockley and Mickelson, 1997).

Towards the close of the Jurassic Period, a broad network of rivers, floodplains, and ponds developed across the Western Interior. The deposits of variegated mudstone, siltstone, and sandstone form the Morrison Formation (Upper Jurassic). This formation holds one of the richest dinosaur-bearing fossil assemblages in North America (e.g., Turner and Peterson, 1999, 2004; Foster, 2003, 2007; Chure and others, 2006). The best exposures of the Morrison Formation are along the eastern part of BENM, from Bluff to north of Monticello. At the south end of the outcrop belt the formation has four members—Bluff Sandstone, Recapture, Westwater Canyon, and Brushy Basin (in ascending order). At the north end just three members crop out—Tidwell, Salt Wash, and Brushy Basin (Peterson, 1994; Turner and Peterson, 2004, 2010; O'Sullivan, 2010b; Kirkland and others, 2020). The Tidwell Member has been radioisotopically dated to approximately 157 Ma (middle-late Oxfordian)—the top of Morrison Formation is about 150 Ma, slightly younger than the Kimmeridgian-Tithonian boundary (Kowallis and others, 1998, 2007; Pellenard and others, 2013; Trujillo and others, 2014; Trujillo and Kowallis, 2015; Muttoni and others, 2018).

Most fossils are found in the Salt Wash and Brushy Basin Members (Turner and Peterson, 1999; Foster, 2003). However, in 1859, just east of the Indian Creek unit of BENM, the type and only known specimen of the enigmatic sauropod dinosaur *Dystrophaeus viaemalae* was discovered in the Tidwell Member (Gillette, 1996a, 1996b; McIntosh, 1997; Bernier and Chan, 2006). This specimen comprises the oldest known skeletal remains of a eusauropod dinosaur from North America. The site is currently under renewed excavation by the Utah Field House of Natural History and UMNH (Foster and others, 2016a). Four to five million years later, during Salt Wash and Brushy Basin time, iconic dinosaurs such as *Allosaurus*, *Camarasaurus*, *Brachiosaurus*, *Apatosaurus*, and *Stegosaurus* roamed across the 1.1 million-square-km Morrison landscape leaving behind footprints and dozens of multispecies bonebeds (Turner and Peterson, 1999, 2004; Foster and Lockley, 2006; Foster and others, 2016b). Although important Salt Wash and Brushy Basin fossil sites are common across Utah (Turner and Peterson, 1999; Foster, 2003), few have been documented in BENM. This is due to insufficient systematic prospecting, though this is beginning to change (Kirkland and others, 2020).

An unpublished fragmentary sauropod specimen (UMNH VP 29894) in the White Mesa area east of BENM (UMNH VP Loc. 2391) was collected in 1979 from the Brushy Basin Member during a survey for the White Mesa Uranium Mill. The Blanding Dinosaur Museum also has Morrison Formation sauropod material in its collection, including a fragmentary pelvis from near Blanding and a *Camarasaurus* humerus. Sites near the northern boundary of BENM preserved fish; the sphenodontian *Eilenodon;* squamates; ornithischian dinosaurs *Stegosaurus*, *Camptosaurus*, and *Fruitadens;* sauropod dinosaurs *Camarasaurus*, *Apatosaurus*, *Diplodocus;* theropod dinosaur *Allosaurus*; and several mammaliaforms, including *Fruitafossor*, *Glirodon*, *Dryolestes*, a morganucodont, a eutricodont, and a paurodontid (Foster, 2003, 2005; Davis and others, 2018). Tetrapod footprints are common in the Salt Wash and Brushy Basin Members (Lockley and others, 1998b; Foster and Lockley, 2006), but only a single site has been published within BENM. Milàn and Chiappe (2009) described the first North American occurrence of the possible stegosaur ichnotaxon *Deltapodus* from the Brushy Basin Member between Blanding and Bluff. Despite the rarity of documented finds within BENM (Kirkland and others, 2020), sites in the Salt Wash Member to the south (Lockley and others, 1998c) and east (Foster and Lockley, 2006) of the monument have footprints of crocodyliforms, ornithopod dinosaurs, sauropod dinosaurs, and theropod dinosaurs, including the type localities of *Dinehichnus socialis* (Lockley and others, 1998c) and *Hatcherichnus sanjuanensis* (Foster and Lockley, 1997).

Among Morrison Formation plant localities (Parrish and others, 2004; DeBlieux and others, 2017), perhaps the most important in BENM region is in the Brushy Basin Member near Montezuma Creek. At this site fine-grained tuffaceous deposits contain fossil wood, palynomorphs, leaves, conchostracans, fish, and invertebrate traces (Ash, 1994; Ash and Tidwell, 1998; Litwin and others, 1998; Hasiotis and others, 2004; Parrish and others, 2004). The megafloral assemblage includes at least eight different species of bryophytes, ferns, cycadophytes, ginkgophytes, conifers, and problematic taxa, such as *Hermanophyton* (Ash, 1994; Ash and Tidwell, 1998). This site is assigned an age of late Kimmeridgian-earliest Tithonian (cf. Muttoni and others, 2018) and has been $^{40}Ar/^{39}Ar$ dated to 149 to 152 Ma (Kowallis and others, 1998; Trujillo and Kowallis, 2015). Baker (1933, p. 52) refers to petrified wood from the Salt Wash Member in the northern BENM, but does not specify the location.

Ongoing Work

The Morrison Formation across Utah has suffered greatly from illegal fossil collecting over the last several decades, with several looted sites discovered only by cursory BLM surveys (J. Uglesich, R.J. Gay, personal observations). Although much of the Morrison Formation has been explored in other areas, such as near Moab (Foster, 2005, 2007; Davis and others, 2018), BENM outcrops are only now being systematically surveyed by professional paleontologists (DeBlieux and others, 2017). Since late 2016 the Utah Geological Survey (UGS) has been actively surveying BENM Morrison Formation outcrops. Given the richness of the Morrison Formation in other areas and the initial results of limited sampling, it is certain that significant paleontological resources remain to be discovered (DeBlieux and others, 2017). Future exploration within BENM will continue to expand the depth and breadth of knowledge of Jurassic biodiversity within the region, especially in the largely neglected Recapture Member and Bluff Sandstone. This assertion is supported by the presence of a significant sauropod-dominated bonebed located just outside of BENM that is currently being excavated by the Natural History Museum of Los Angeles County (Mocho and others, 2014; Mocho and Chiappe, 2018).

EARLY CRETACEOUS

Although most BENM fossils are found in mid-Mesozoic and older rocks, terrestrial Cretaceous strata also exist within the monument. The Burro Canyon Formation is a lateral equivalent of the fossil-rich Lower Cretaceous Cedar Mountain Formation (Kirkland and Madsen, 2007; Kirkland and others, 2016). It outcrops on the eastern side of BENM in the vicinity of and capping the Black Mesa. Just beyond the monument boundaries, east of Blanding, abundant vertebrate trace fossils are known from the Burro Canyon Formation (Milàn and others, 2015), including footprints of theropods, sauropods, and ornithischians. Investigation of the formation by the UGS and other groups is just commencing. Baker (1933, p. 55) describes unidentified leaf fossils from the "Dakota (?) sandstone," a unit now assigned to the Naturita Formation (Carpenter, 2014; Kirkland and others, 2016), but did not provide the location. Ash and others (1976, p. 12) described petrified wood specimens of the tree-like fern *Tempskya* from both the Burro Canyon and Naturita Formations near Moab, north of BENM.

QUATERNARY

Geology and Paleontology

Beginning in the latest Cretaceous-Paleogene, Laramide tectonics drove the uplift of the Colorado Plateau (Liu and Gurnis, 2010). During the Oligocene, larger laccolithic intrusions created the Abajo and La Sal Mountains. Establishment of the Colorado River drainage (Pederson, 2008) was the primary driver of the erosion that carved Canyon Country across the Colorado Plateau. The La Sal Mountains were glaciated repeatedly during the Quaternary. Each glacial cycle brought periods of melting, alluviation, and erosion (Richmond, 1962; Richmond and Fullerton, 1986; Stokes, 1986; Pierce, 2003).

There are no pre-Quaternary Cenozoic deposits in BENM, but Quaternary cave and alcove deposits are common across the region. Packrat middens in the southwestern United States document past insect, vertebrate, and plant diversity. These sites are critical for understanding desert paleoecology, biogeography, species-environment interactions, demographic and population changes, and diets of extinct and extant mammals (Tweet and others 2012). In BENM, alcoves large enough to accumulate packrat middens for thousands of years are normally found in eolian formations, including the Pennsylvanian-Permian Cutler Group (White Rim and Cedar Mesa Sandstones), Lower Jurassic Navajo Sandstone, and Middle Jurassic Entrada Sandstone. Fossil-bearing Quaternary gravels have been reported, but little research has been conducted to date (M.A. Stegner and R. Gay, personal observations).

During the Last Glacial Maximum (LGM) and prior to about 14 ka, the Colorado Plateau was considerably cooler and more mesic than it is today. In BENM and surrounding regions, modern plant communities were 700 to 900 m lower in elevation than at present (Cole, 1990; Anderson and others, 2000). Climatically, the early Holocene was cooler than today, but more mesic than during the LGM due to stronger summer monsoons (Weng and Jackson, 1999). The current monsoon boundary was established during the early Holocene (Betancourt, 1984). From about 8.5 to 6 ka this cool, mesic period gave way to an arid and warm mid-Holocene (Weng and Jackson, 1999; Reheis and others, 2005). During the interval about 6 to 3 ka, cool-wet conditions returned (Betancourt, 1984; Reheis and others, 2005). Fossil pollen from the Abajo Mountains reveals a maize agriculture existing in the vicinity of BENM at 3.12 ka (Betancourt and Davis, 1984). Analysis of eolian and alluvial deposition in Canyonlands National Park suggests that from 2 ka to the present, drier conditions returned, as evidenced by greater mobility of eolian sand (Reheis and others, 2005).

In the 1980s and 1990s, researchers from Northern Arizona University and the USGS documented packrat cave deposits throughout the Four Corners region, mainly in national parks. Many sites were studied in the Needles District of Canyonlands National Park northeast of BENM (Elias and others, 1992; Tweet and others, 2012). Although these southeastern Utah sites contain still unpublished small vertebrate skeletal remains, it was large mammals (e.g., Mead and others, 1987; Mead and others 1991) and plant macrofossils (e.g., Betancourt, 1984; Cole, 1990; Coats and others 2008) that were the primary research focus. Remains of *Oreamnos harringtoni*, an extinct mountain goat, were discovered with packrat middens in a rock shelter in Natural Bridges National Monument, adjacent to BENM (Mead and others, 1987). Plant macrofossils and dung revealed the diet of this extinct species, as well as that early Holocene vegetation was dominated by a "no-analog" (Williams and Jackson 2007) mixture of species. Some of the plant varieties are found locally today whereas others are "extra-local," such as hackberry (*Celtis reticulata*), common juniper (*Juniperus communis*), Englemann spruce (*Picea englemanii*), and limber pine (*Pinus flexilis*) (Mead and others, 1987). Two important plant macrofossil localities, Allen Canyon Cave in the southern Abajo Mountains and Fishmouth Cave at Comb Ridge (Betancourt, 1984; Coats and others, 2008), reveal that xeric-, as well as mesic-adapted, plants were present in the region at the end of the LGM, and modern dominant species like pinyon pine (*Pinus edulis*) and ponderosa (*Pinus ponderosa*) did not appear until the mid-Holocene (Betancourt, 1984; Coats and others, 2008). These sites are historically important for shaping our understanding of high desert plant communities. Additional dendrochronological work in Beef Basin (Pederson and others, 2011), White Canyon, Natural Bridges National Monument (Dean and Bowden, 1994; Stahle and others, 2016), and near the northernmost extent of Comb Ridge (Dean and Robinson, 1994) indicate aridification of BENM and surrounding areas during the Late Holocene. Together with extensive archaeological research, dendrochronological studies reveal a series of multi-decadal "megadroughts," beginning around 870 to 820 ybp. These data are crucial to understanding why Ancestral Puebloans who lived in southeastern Utah and western Colorado migrated out of the region, a process that concluded around 650 ybp (Benson and Berry, 2009).

Ongoing Work

In the last five years, investigations conducted by University of California Museum of Paleontology researchers have concentrated on the vertebrate faunas in mid- and late Holocene packrat middens in and near BENM (Stegner, 2015, 2016; Stegner, unpublished data). Since 2013, four small cave deposits—two less than 1 km north of BENM in Dry Valley, one in the BENM Indian Creek subunit, and one now excluded from BENM, northwest of the Abajo Mountains—have been excavated and extensively radiocarbon-dated (Stegner, 2016; Stegner, unpublished data). These sites reveal how small mammals responded to environmental change during the interval of Holocene climate warming and aridification (Stegner, 2015, 2016). The mammal fauna remained remarkably stable in abundance and composition over the last about 6 ka (Stegner, 2015, 2016), though several extant species not found in BENM today (e.g., *Notiosorex crawfordii*) are also present in these deposits. The avifauna and herpetofauna of these sites are currently under study (Stegner and Stidham, 2018). Because these deposits are young and the bones are extraordinarily well preserved (M.A. Stegner, 2016, personal observation), the specimens could be used for ancient DNA studies that would deepen our understanding of Colorado Plateau biogeography. Planned excavations of packrat middens in Beef Basin, in the northwestern corner of BENM, will shed light on floral and faunal change in this understudied and remote grassland.

RESEARCH TRAJECTORIES

Research productivity in BENM has been increasing since the 1990s and ongoing efforts in the region promise continued progress (figure 6). This is attributable to both increased attention to the region overall, as well as an increase in the number of researchers in the field. The Upper Triassic Chinle Formation is the subject of 30% of total paleontology publications from BENM. Notably, there was a spike in publications from BENM during the time of the "Uranium Boom" on the Colorado Plateau (1950s to 1960s), with the majority of papers published in those decades focusing on the Chinle Formation (figure 6).

The Upper Jurassic Morrison Formation has a high fossil yield potential (PFYC) (Bureau of Land Management and Department of Energy, 2015) based on work conducted elsewhere in the region. The Lower Triassic Moenkopi Formation and Pennsylvanian-Permian Cutler Group are considered low PFYC based on work conducted elsewhere in the region, but these designations may well increase as more research is conducted. The Cutler, Moenkopi, and Morrison are widely exposed within BENM, lending themselves to future investigation. In contrast, study of the rise of the dinosaurs in the Lower Jurassic is hampered by difficult access to Wingate and Navajo Sandstones, which typically form very steep slopes. The Kayenta Formation, which is known to be fossiliferous elsewhere in the region, is typically thin and also difficult to access in BENM.

PALEONTOLOGICAL RESOURCE PROTECTION

Fossils in southeastern Utah have been the target of looting, illegal sale, and private collecting for decades (United States v. Jared Ehlers, 2014; Gay and others, 2018; R. Hunt-Foster [National Park Service]; J. Kirkland [UGS], verbal communications; J. Uglesich, personal observations; and R.B. Irmis, personal observations). The BLM has used education and outreach as a complementary approach to law enforcement in protection of paleontological resources. In 2016, the BLM partnered with the conservation group "Tread Lightly" to launch the "Respect and Protect" campaign, a statewide initia-

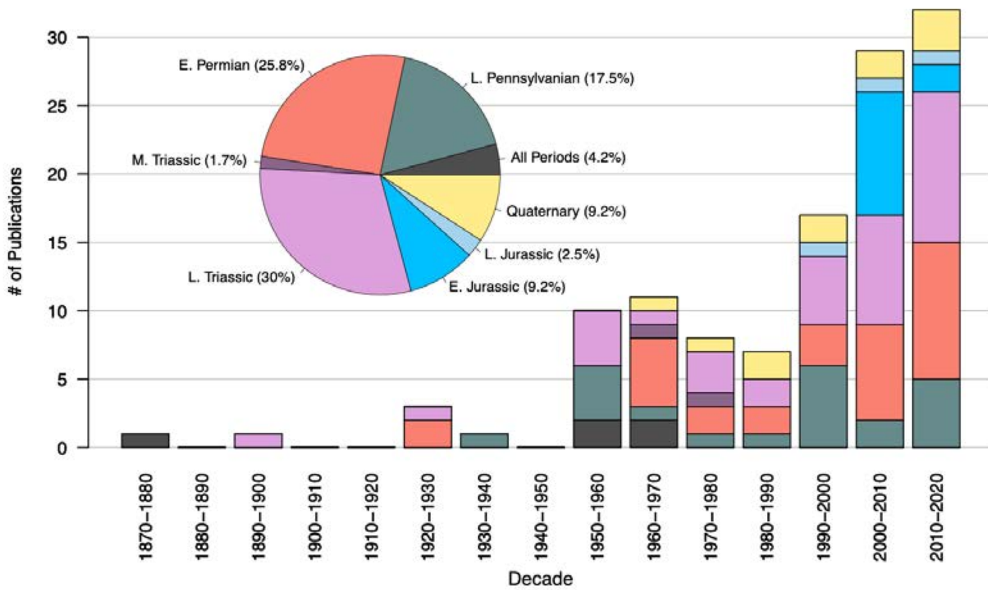

Figure 6. Graph showing both the distribution of publication topics from within BENM as well as a chronological plot showing number of papers produced per decade on data derived partially or wholly from within the initial boundaries of BENM.

tive designed to eliminate looting and destruction of fossil and cultural sites through education and outreach about the significance and fragility of these resources (Uglesich and Hunt-Foster, 2016). Respect and Protect also sought to connect local communities with public lands by bringing paleontology outreach programs into neighboring schools and community centers and to instill a sense of stewardship in these communities.

BLM's Canyon Country District, which includes BENM, is over 3.6 million acres in size. The region has abundant and diverse paleontological resources that are currently being studied by over a dozen permitted researchers. It is critical that robust staff, as well as financial and support resources continue to be allocated to manage and protect these paleontological resources. Regardless of management status, these areas preserve important world-class paleontological resources that require protection, preservation, and study. It is also essential to provide guidance and oversight for the research activities on these public lands. In many cases this means that, as far as possible, specimens must be collected and curated in a publicly accessible repository for scientific study and public enlightenment.

CONCLUSIONS

The Bears Ears National Monument region contains a geologic record of many significant events in the development of life and in the history of our planet. These include the dominance of vertebrate life on land during the Pennsylvanian-Permian transition, the Triassic-Jurassic transition and accompanying faunal turnover, the Upper Jurassic dinosaur-dominated terrestrial ecosystem of the Morrison Formation, and the response of near-modern environments to rapid climate change at the end of the last period of glaciation. The fossil resources in BENM are scientifically important and, in many instances, unique. Several taxa are known exclusively from BENM or their occurrence in BENM represents a major range extension. This includes the sauropodomorph *Seitaad ruessi*, the archosauromorph *Crosbysaurus harrisae*, and the phytosaur *Pravusuchus hortus*. Additionally, two of the five major biologic transitions, Pennsylvanian-Permian and Triassic-Jurassic, are recorded within BENM, indicating the potential for additional highly significant scientific discoveries.

At BENM, research across the geological time scale currently is being conducted by many institutions and individuals. The ongoing projects will, in many cases, take years to decades to bring to fruition. As surveying and sample excavation continue in the future, the number of fossil taxa described from BENM will increase, adding to an ever-expanding knowledge of Earth's history and the history of life itself. Long-term protection of paleontological resources is vital to advancing these efforts.

ACKNOWLEDGMENTS

We thank J.K. Haschenburger (University of Texas at San Antonio), X. Jenkins (formerly Arizona State University now Idaho State University), A.R.C. Milner (St. George Dinosaur Discovery Site), and H.G. McDonald (Bureau of Land Management) for review of early drafts. The map was generously provided by B. Mueller (Bureau of Land Management). All authors are grateful to the Bureau of Land Management (BLM) for administration of permits, and R. Hunt-Foster (National Park Service, but with BLM at the time of the study) in particular for assistance with permitting, facilitation of fieldwork, and valuable insight. Thank you to all the field crews who helped with discoveries past and present, as well as everyone who has labored over specimens from BENM and brought these discoveries to light. Fieldwork and research in BENM was conducted under permits from the BLM (R.J. Gay: UT14-001S, UT17-008E, UT17-009E; A.K. Huttenlocker: UT12-005S, UT15-019E, UT17-001S, UT18-008E; R.B. Irmis: UT07-023S-SW, UT10-005E, UT14-004E; M.A. Stegner: UT13-001S, UT13-020E), and was funded by the BLM and National Conservation Lands grants program (L17AC00064 to A.K. Huttenlocker, L17AC00057 to R.J. Gay), The Wilderness Society (R.J. Gay), National Geographic Society Committee for Research and Exploration (9071-12 to R.B. Irmis), Canyonlands Natural History Association (R.J. Gay, R.B. Irmis, and M.A. Stegner), University of Utah (R.B. Irmis), National Science Foundation (DGE-1106400 to M.A. Stegner), the Paleontological Society (M.A. Stegner and J. Uglesich), Geological Society of America (M.A. Stegner), Sigma Xi (M.A.S.), University of California Museum of Paleontology (M.A. Stegner), University of California-Berkeley Department of Integrative Biology (M.A. Stegner), and the TIDES foundation (M.A. Stegner).

REFERENCES

Alroy, J., Aberhan, M., Bottjer, D.J., Foote, M., Fürsich, F.T., Harries, P.J., Hendy, A.J.W., Holland, S.M., Ivany, L.C., Kiessling, W., Kosnik, M.A., Marshall, C.R., McGowan, A.J., Miller, A.I., Olszewski, T.D., Patzkowsky, M.E., Peters, S.E., Villier, L., Wagner, P.J., Bonuso, N., Borkow, P.S., Brenneis, B., Clapham, M.E., Fall, L.M., Ferguson, C.A., Hanson, V.L., Krug, A.Z., Layou, K.M., Leckey, E.H., Nürnberg, S., Powers, C.M., Sessa, J.A., Simpson, C., Tomašových, A., and Visaggi, C.C., 2008, Phanerozoic trends in the global diversity of marine invertebrates: Science, v. 321, no. 5885, p. 97–100.

Anderson, R.S., Betancourt, J.L., Mead, J.I., Hevly, R.H., and Adam, D.P., 2000, Middle- and late-Wisconsin paleobotanic and paleoclimatic records from the southern Colorado Plateau, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 155, no. 1–2, p. 31–57.

Ash, S.R., 1975a, The Chinle (Upper Triassic) flora of southeastern Utah, *in* Fassett, J., and Wengerd, S.A., editors, Canyonlands country: Four Corners Geological Society Eighth Field Conference Guidebook, p. 143–147.

Ash, S.R., 1975b, *Zamites poewlli* [sic] and its distribution in the Upper Triassic of North America: Palaeontographica Abteilung B, v. 149, p. 139–152.

Ash, S.R., 1977, An unusual bennettitalean leaf from the Upper Triassic of the south-western United States: Palaeontology, v. 20, no. 3, p. 641–659.

Ash, S.R., 1982, Occurrence of the controversial plant fossil *Sanmiguelia* cf. *S. lewisi* Brown in the Upper Triassic of Utah: Journal of Paleontology, v. 56, no. 3, p. 751–754.

Ash, S.R., 1987, The Upper Triassic red bed flora of the Colorado Plateau, western United States: Journal of the Arizona-Nevada Academy of Science, v. 22, no. 1, p. 95–105.

Ash, S.R., 1994, First occurrence of *Czekanowskia* (Gymnospermae, Czekanowskiales) in the United States: Review of Palaeobotany and Palynology, v. 81, no. 2-4, p. 129–140.

Ash, S.R., 2001, New cycadophytes from the Upper Triassic Chinle Formation of the southwestern United States: PaleoBios v. 21, no. 1, p. 15–28.

Ash, S.R., and Litwin, R.J., 1996, Two new species of the pinnate microsporophyll *Pramelreuthia* from the Upper Triassic of the southwestern United States: American Journal of Botany, v. 83, p. 1091–1099.

Ash, S.R., Litwin, R.J., and Traverse, A., 1982, The Upper Triassic fern *Phlebopteris smithii* (Daugherty) Arnold and its spores: Palynology, v. 6, p. 203–219.

Ash, S.R., Milner, A.R.C., Sharrow, D., and Tarailo, D., 2014, First known post-Triassic occurrence of the palm-like plant fossil *Sanmiguelia* Brown, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, p. 511–516.

Ash, S.R., Read, C.B., and Zeller, Jr., R.A., 1976, North American species of *Tempskya* and their stratigraphic significance: U.S. Geological Survey Professional Paper 874, p. 1–42.

Ash, S.R., and Tidwell, W.D., 1998, Plant megafossils from the Brushy Basin Member of the Morrison Formation near Montezuma Creek Trading Post, southeastern Utah: Modern Geology, v. 22, p. 321–339.

Atchley, S.C., Nordt, L.C., Dworkin, S.I., Ramezani, J., Parker, W.G., Ash, S.R., and Bowring, S.A., 2013, A linkage among Pangean tectonism, cyclic alluviation, climate change, and biologic turnover in the Late Triassic—the record from the Chinle Formation, southwestern United States: Journal of Sedimentary Research, v. 83, p. 1147–1161.

Baars, D.L., 1962, Permian system of Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 46, p. 149–218.

Baars, D.L., 1975, The Permian system of Canyonlands country, *in* Fassett, J., and Wengerd, S.A., editors, Canyonlands country: Four Corners Geological Society Eighth Field Conference Guidebook, p. 123–128.

Baars, D.L., 1987, The Elephant Canyon Formation revisited, *in* Campbell, J.A., editor, Geology of Cataract Canyon and vicinity: Four Corners Geological Society Tenth Field Conference Guidebook, p. 81–90.

Baars, D.L., 2000, The Colorado Plateau—a geologic history (revised and updated): Albuquerque, University of New Mexico Press, 268 p.

Bagshaw, L.H., 1977, Paleoecology of the lower Carmel Formation of the San Rafael Swell, Emery County, Utah: Brigham Young University Geology Studies, v. 24, pt. 2, p. 51–62.

Baker, A.A., 1933, Geology and oil possibilities of the Moab District, Grand and San Juan Counties, Utah: U.S. Geological Survey Bulletin 841, 95 p.

Baker, A.A., 1936, Geology of the Monument Valley-Navajo Mountain region, San Juan County, Utah: U.S. Geological Survey Bulletin, v. 865, 106 p.

Baker, A.A., Dane, C.H., and Reeside, Jr., J.B., 1933, Paradox Formation of eastern Utah and western Colorado: American Association of Petroleum Geologists Bulletin, v. 17, p. 963–980.

Baker, A.A., and Reeside, Jr., J.B., 1929, Correlation of the Permian of southern Utah, northern Arizona, northwestern New Mexico, and southwestern Colorado: American Association of Petroleum Geologists Bulletin, v. 13, p. 1413–1448.

Balini, M., Lucas, S.G., Jenks, J.F., and Spielmann, J.A., 2010, Triassic ammonoid biostratigraphy—an overview: Geological Society of London Special Publication, v. 334, p. 221–262.

Bambach, R.K., 2006, Phanerozoic biodiversity mass extinctions: Annual Review of Earth and Planetary Sciences, v. 34, p. 127–155.

Barnes, F.A., 1993, Geology of the Moab area: Moab, Utah, Canyon Country Publications, 150 p.

Bears Ears Intertribal Coalition, 2016, Proposal overview: Online, https://bearsearscoalition.org/proposal-overview/, accessed November 24, 2017.

Benson, L., and Berry, M.S., 2009, Climate change and cultural response in the prehistoric American Southwest: KIVA—The Journal of Southwestern Anthropology and History, v. 75, p. 89–119.

Berman, D.S., Reisz, R., and Fracasso, M.A., 1981, Skull of the Lower Permian dissorophid amphibian *Platyhystrix rugosus*: Annals of Carnegie Museum, v. 50, p. 391–416.

Bernier, J.C., and Chan, M.A., 2006, Sedimentology, depositional environments, and paleoecological context of an early Late Jurassic sauropod, Tidwell Member, Upper Jurassic Morrison Formation, east-central Utah: The Mountain Geologist, v. 43, p. 313–332.

Betancourt, J.L., 1984, Late Quaternary plant zonation and climate in southeastern Utah: Great Basin Naturalist, v. 22, p. 1–35.

Betancourt, J.L., and Davis, O.K., 1984, Packrat middens from Canyon de Chelly, northeastern Arizona—paleoecological and archaeological implications: Quaternary Research, v. 21, p. 56–64.

Bishop, R., 2016, Bears Ears region: Online, robbishop.house.gov/uploadedfiles/bears_ears_region.pdf, accessed November 24, 2017.

Blackburn, T.J., Olsen, P.E., Bowring, S.A., McLean, N.M., Kent, D.V., Puffer, J., McHone, G., Rasbury, E.T., and Et-Touhami, M., 2013, Zircon U-Pb geochronology links the end-Triassic extinction with the Central Atlantic Magmatic Province: Science, v. 340, p. 941–945.

Blakey, R.C., 1974, Stratigraphic and depositional analysis of the Moenkopi Formation, southeastern Utah: Utah Geological Survey Bulletin 104, 81 p.

Blakey, R.C., 1978, Stratigraphy and origin of the lower Chinle Formation, Lisbon Valley, Utah, with a preliminary report on the lower Chinle Formation of the eastern Monument upwarp, Utah: Unpublished Report for Plateau Resources Limited, 18 p.

Blakey, R.C., 1994, Paleogeographic and tectonic controls on some Lower and Middle Jurassic erg deposits, Colorado Plateau, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 273–298.

Blakey, R.C., and Gubitosa, R., 1983, Late Triassic paleogeography and depositional history of the Chinle Formation, southern Utah and northern Arizona, *in* Reynolds, M.W., and Dolly, E.D., editors, Mesozoic paleogeography of west-central United States: Denver, Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 57–76.

Blakey, R.C., and Gubitosa, R., 1984, Controls of sandstone body geometry and architecture in the Chinle Formation (Upper Triassic), Colorado Plateau: Sedimentary Geology, v. 38, p. 51–86.

Blakey, R.C., Peterson, F., and Kocurek, G., 1988, Synthesis of late Paleozoic and Mesozoic eolian deposits of the Western Interior of the United States: Sedimentary Geology, v. 56, p. 3–125.

Brayard, A., Bylund, K.G., Jenks, J.F., Stephen, D.A., Olivier, N., Escarguel, G., Fara, E., and Vennin, E., 2013, Smithian ammonoid faunas from Utah—implications for Early Triassic biostratigraphy, correlation and basinal paleogeography: Swiss Journal of Palaeontology, v. 132, p. 141–219.

Britt, B.B., Chure, D.J., Engelmann, G.F., and Shumway, J.D., 2016, Rise of the erg—paleontology and paleoenvironments of the Triassic-Jurassic transition in northeastern Utah: Geology of the Intermountain West, v. 3, p. 1–32.

Brusatte, S.L., Nesbitt, S.J., Irmis, R.B., Butler, R.J., Benton, M.J., and Norell, M.A., 2010, The origin and early radiation of dinosaurs: Earth-Science Reviews, v. 101, p. 68–100.

Cain, S.A., and Mountney, N.P., 2009, Spatial and temporal evolution of a terminal fluvial fan system—the Permian Organ Rock Formation, south-east Utah, USA: Sedimentology, v. 56, p. 1774–1800.

Cain, S.A., and Mountney, N.P., 2011, Downstream changes and associated fluvial-eolian interactions in an ancient terminal fluvial system—the Permian Organ Rock Formation, SE Utah, U.S.A.: SEPM (Society for Sedimentary Geology) Special Publication, v. 97, p. 167–185.

Camp, C.L., 1930, A study of the phytosaurs with description of new material from western North America: Memoirs of the University of California, v. 10, 174 p.

Campbell, J.A., 1987, Stratigraphy and depositional facies—Elephant Canyon Formation, *in* Campbell, J.A., editor, Geology of Cataract Canyon and vicinity: Four Corners Geological Society Tenth Field Conference Guidebook, p. 91–98.

Carpenter, K., 2014, Where the sea meets the land—the unresolved Dakota problem in Utah, in MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, p. 357–372.

Carpenter, K., and Ottinger, L., 2018, Permo-Pennsylvanian shark teeth from the Lower Cutler beds near Moab, Utah: Geology of the Intermountain West, v. 5, p. 105–116.

Chaney, D.S., Lucas, S.G., and Elrick, S., 2013, New occurrence of an arthropleurid trackway from the Lower Permian of Utah, *in* Lucas, S.G., DiMichele, W.A., Barrick, J.E., Schneider, J.W., and Spielmann J.A., editors, The Carboniferous-Permian transition: New Mexico Museum of Natural History and Science Bulletin 60, p. 64–65.

Chure, D.J., Litwin, R., Hasiotis, S.T., Evanoff, E., and Carpenter, K., 2006, The fauna and flora of the Morrison Formation, *in* Foster, J.R., and Lucas, S.G., editors, Paleontology and geology of the Upper Jurassic Morrison Formation: New Mexico Museum of Natural History and Science Bulletin 36, p. 233–249.

Coats, L.L., Cole, K.L., and Mead, J.I., 2008, 50,000 years of vegetation and climate history on the Colorado Plateau, Utah and Arizona, USA: Quaternary Research, p. 70, v. 322–338.

Cole, K.L., 1990, Reconstruction of past desert vegetation along the Colorado River using packrat middens: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 76, p. 349–366.

Condon, S.M., 1997, Geology of the Pennsylvanian and Permian Cutler Group and Permian Kaibab Limestone in the Paradox Basin, southeastern Utah and southwestern Colorado: U.S. Geological Survey Bulletin 2000, p. 1–44.

Cornet, B., and Waanders, G., 2006, Palynomorphs indicate Hettangian (Early Jurassic) age for middle Whitmore Point Member of the Moenave Formation, Utah and Arizona, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, Terrestrial Triassic-Jurassic transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 390–406.

Cross, W., and Howe, E., 1905, Description of the Silverton quadrangle, Colorado: U.S. Geological Survey Geologic Atlas of the United States Folio, Silvertone Folio, no. 120, 34 p.

Davidson, L., 1991, Park idea dates back to the 1930s: Deseret News, 3 August 1991, online, https://www.deseretnews.com/article/176001/PARK-IDEA-DATES-BACK-TO-1930S.html?pg=all, accessed November 18, 2017.

Davis, B.M., Cifelli, R.L., and Rougier, G.W., 2018, A preliminary report of the fossil mammals from a new microvertebrate locality in the Upper Jurassic Morrison Formation, Grand County, Utah: Geology of the Intermountain West, v. 5, p. 1–8.

Dean, J.S., and Bowden, D.O., 1994, Dean - Kane Spring - PIED - ITRDB UT020: National Center for Environmental Information, National Atmospheric and Atmospheric Administration, online, https://www.ncdc.noaa.gov/paleo/study/3083, accessed November 5, 2017.

Dean, J.S., and Robinson, W.J.D., 1994, Milk Ranch Point - PIED - ITRDB UT024: National Center for Environmental Information, National Atmospheric and Atmospheric Administration, online, https://www.ncdc.noaa.gov/paleo/study/3085, accessed November 5, 2017.

DeBlieux, D., Kirkland, J.I., Hayden, M., and Hunt-Foster, R., 2017, Significant Mesozoic vertebrate fossil localities discovered during paleontological resource inventory and monitor on Bureau of Land Management land in the western Blanding Basin, southeastern Utah [abs.]: Journal of Vertebrate Paleontology Programs and Abstracts, v. 37 (Online Supplement), p. 103.

Delgado, Y., Heckert, A.B., and Foster, J.R., 2017, New occurrences of Upper Triassic (Adamanian-Revueltian?) fossils from the lower Chinle Group near Wingate Mesa, southeastern Utah—expanding Utah's Late Triassic fossil record [abs.]: Journal of Vertebrate Paleontology Programs and Abstracts, v. 37 (Online Supplement), p. 103.

Dickinson, W.R., and Gehrels, G.E., 2009, Use of U-Pb ages of detrital zircons to infer maximum depositional ages of strata—a test against a Colorado Plateau Mesozoic database: Earth and Planetary Science Letters, v. 288, p. 115–125.

DiMichele, W.A., Cecil, C.B., Chaney, D.S., Elrick, S.D., Lucas, S.G., Lupia, R., Nelson, W.J., and Tabor, N.J., 2011, Pennsylvanian-Permian vegetational changes in tropical Euramerica, *in* Martin, W.C., editor, Geology of the Pennsylvanian-Permian in the Dunkard Basin: Seventy-Sixth Annual Field Conference of Pennsylvanian Geologists Guidebook, p. 60-102.

DiMichele, W.A., Cecil, C.B., Chaney, D.S., Elrick, S.D., and Nelson, W.J., 2014, Fossil floras from the Pennsylvanian-Permian Cutler Group of southeastern Utah, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, p. 491–504.

Doelling, H.H., 2001, Geologic map of the Moab and eastern part of the San Rafael Desert 30' x 60' quadrangles, Grand and Emery Counties, Utah, and Mesa County, Colorado: Utah Geological Survey Map 180, 3 plates, scale 1:100,000.

Doelling, H.H., 2004, Geologic map of the La Sal 30' x 60' Quadrangle, San Juan, Wayne, and Garfield Counties, Utah, and Montrose and San Miguel Counties, Colorado: Utah Geological Survey Map 205, 2 plates, scale 1:100,000.

Doelling, H.H., Oviatt, C.G., and Huntoon, P.W., 1988, Salt deformation in the Paradox region: Utah Geological and Mineral Survey Bulletin 122, p. 1–93.

Doelling, H.H., Sprinkel, D.A., Kowallis, B.J., and Kuehne, P.A., 2013, Temple Cap and Carmel Formations in the Henry Mountains Basin, Wayne and Garfield Counties, Utah, *in* Morris, T.H., and Ressetar, R., editors, The San Rafael Swell and Henry Mountains Basin—geologic centerpiece of Utah: Utah Geological Association Publication 42, p. 279–318.

Donohoo-Hurley, L.L., Geissman, J.W., and Lucas, S.G., 2010, Magnetostratigraphy of the uppermost Triassic and lowermost Jurassic Moenave Formation, western United States—correlation with strata in the United Kingdom, Morocco, Turkey, Italy, and eastern United States: Geological Society of America Bulletin, v. 122, p. 2005–2019.

Downs, D.T., 2009, In search of the Triassic-Jurassic boundary—palynostratigraphy and carbon-isotope stratigraphy of the lower Dinosaur Canyon Member on the Colorado Plateau (Kanab, Utah): Carbondale, Southern Illinois University, M.S. thesis, 125 p.

Dubiel, R.F., 1983, Sedimentology of the lower part of the Upper Triassic Chinle Formation and its relationship to uranium deposits, White Canyon area, southeastern Utah: U.S. Geological Survey Open-File Report 83-459, 48 p.

Dubiel, R.F., 1987, Sedimentology of the Upper Triassic Chinle Formation, southeastern Utah—paleoclimatic implications: Journal of the Arizona-Nevada Academy of Science, v. 22, p. 35–45.

Dubiel, R.F., 1994, Triassic deposystems, paleogeography, and paleoclimate of the Western Interior, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region, USA: Denver, Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 133–168.

Dubiel, R.F., and Hasiotis, S.T., 2011, Deposystems, paleosols, and climatic variability in a continental system—the Upper Triassic Chinle Formation, Colorado Plateau, U.S.A: SEPM (Society for Sedimentary Geology) Special Publication 97, p. 393–421.

Dubiel, R.F., Blodgett, R.H., and Bown, T.M., 1987, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau: Journal of Sedimentary Petrology, v. 57, p. 512–521.

Dubiel, R.F., Blodgett, R.H., and Bown, T.M., 1988, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau—reply: Journal of Sedimentary Petrology, v. 58, p. 367–369.

Dubiel, R.F., Blodgett, R.H., and Bown, T.M., 1989, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau—reply: Journal of Sedimentary Petrology, v. 59, p. 876–878.

Dzenowski, N., Hasiotis, S.T., and Rasmussen, D.L., 2013, Vertebrate burrows within pedogenically modified deposits from the Lower Permian (Wolfcampian) Cedar Mesa Sandstone of southeastern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 45, no. 7, p. 326.

Eisenberg, L., 2003, Giant stromatolites and a supersurface in the Navajo Sandstone, Capitol Reef National Park, Utah: Geology, v. 31, p. 111–114.

Ekdale, A.A., and Picard, M.D., 1985, Trace fossils in a Jurassic eolianite, Entrada Sandstone, Utah, U.S.A: SEPM (Society for Sedimentary Geology) Special Publication 35, p. 3–12.

Ekdale, A.A., Bromley, R.G., and Loope, D.B., 2007, Ichnofacies of an ancient erg—a climatically influenced trace fossil association in the Jurassic Navajo Sandstone, southern Utah, USA., *in* Miller, W., III, editor, Trace fossils—concepts, problems, prospects: New York, Elsevier, p. 562–574.

Elias, S.A., Mead, J.I., and Agenbroad, L.D., 1992 Late Quaternary arthropods from the Colorado Plateau, Arizona and Utah: Great Basin Naturalist, v. 52, no. 1, p. 59-67.

Foster, J.R., 2003, Paleoecological analysis of the vertebrate fauna of the Morrison Formation (Upper Jurassic), Rocky Mountain region, U.S.A, *in* Foster, J.R., editor, Paleoecological analysis of the vertebrate fauna of the Morrison Formation (Upper Jurassic), Rocky Mountain region, U.S.A.: New Mexico Museum of Natural History and Science Bulletin 23, p. 1–95.

Foster, J.R., 2005, New sauropod dinosaur specimens found near

Moab, Utah, and the sauropod fauna of the Morrison Formation: Canyon Legacy, v. 55, p. 22–27.

Foster, J., 2007, Jurassic West—the dinosaurs of the Morrison Formation and their world: Bloomington, Indiana University Press, 416 p.

Foster, J.R., Hamblin, A.H., and Lockley, M.G., 2000, The oldest evidence of a sauropod dinosaur in the western United States and other important vertebrate trackways from Grand Staircase-Escalante National Monument, Utah: Ichnos, v. 7, p. 169–181.

Foster, J.R., and Lockley, M.G., 1997, Probable crocodilian tracks and traces from the Morrison Formation (Upper Jurassic) of eastern Utah: Ichnos, v. 5, p. 121–129.

Foster, J.R., and Lockley, M.G., 2006, The vertebrate ichnological record of the Morrison Formation (Upper Jurassic, North America), *in* Foster, J.R., and Lucas, S.G., editors, Paleontology and geology of the Upper Jurassic Morrison Formation: New Mexico Museum of Natural History and Science Bulletin 36, p. 203–216.

Foster, J.R., Titus, A.L., Winterfeld, G.F., Hayden, M.C., and Hamblin, A.H., 2001, Paleontological survey of the Grand Staircase-Escalante National Monument, Garfield and Kane Counties, Utah: Utah Geological Survey Special Study 99, 98 p.

Foster, J.R., Irmis, R.B., Trujillo, K.C., McMullen, S.K., and Gillette, D.D., 2016a, *Dystrophaeus viaemalae* Cope from the basal Morrison Formation of Utah—implications for the origin of eusauropods [abs.]: Journal of Vertebrate Paleontology Programs and Abstracts, v. 36 (Online Supplement), p. 138.

Foster, J.R., McHugh, J.B., Peterson, J.E., and Leschin, M.F., 2016b, Major bonebeds in mudrocks of the Morrison Formation (Upper Jurassic), northern Colorado Plateau of Utah and Colorado: Geology of the Intermountain West, v. 3, p. 33–66.

Fraser, N.C., Irmis, R.B., and Elliott, D.K., 2005, A procolophonid (Parareptilia) from the Owl Rock Member, Chinle Formation of Utah, USA: Palaeontologia Electronica, v. 8, no. 13A, p. 1–7.

Frede, S.E., Sumida, S.S., and Berman, D.S., 1993, New information on early Permian vertebrates from the Halgaito Tongue of the Cutler Formation of southeastern Utah: Journal of Vertebrate Paleontology, v. 13 (Supplement to 3), p. 36A.

Frederickson, J.A., and Davis, B.M., 2017, First reported actinopterygian from the Navajo Sandstone (Lower Jurassic, Glen Canyon Group) of southern Utah, USA: Journal of Paleontology, v. 91, p. 548–553.

Gay, R.J., and St. Aude, I., 2015, The first occurrence of the enigmatic archosauriform *Crosbysaurus* Heckert 2004 from the Chinle Formation of southern Utah: PeerJ, v. 3, no. e905, p. 1–14.

Gay, R.J., Jenkins, X., St. Aude, I., and Azouggagh, D., 2016, A new, diverse microvertebrate locality from the lower Chinle Formation of southeastern Utah (USA) [abs.]: Journal of Vertebrate Paleontology, v. 36 (Online Supplement), p. 143.

Gay, R.J., Jenkins, X.A., Milner, A.R.C., Van Vranken, N.E., Dewitt, D.M., and Lepore, T., 2017, A new Triassic bonebed from the Bears Ears region of Utah [abs.]: PaleoBios, v. 34 (Supplement), p. 6.

Gay, R.J., Uglesich, J., and Hunt-Foster, R., 2018, Looting of an Upper Triassic site in southeastern Utah [abs.]: PaleoBios, v. 35 (Supplement), p. 10.

Gibson, S.Z., 2013a, A new hump-backed ginglymodian fish (Neopterygii, Semionotiformes) from the Upper Triassic Chinle Formation of southeastern Utah: Journal of Vertebrate Paleontology, v. 33, p. 1037–1050.

Gibson, S.Z., 2013b, Biodiversity and evolutionary history of †*Lophionotus* (Neopterygii: †Semionotiformes) from the western United States: Copeia, v. 2013, p. 582–603.

Gibson, S.Z., 2015, Evidence of a specialized feeding niche in a Late Triassic ray-finned fish—evolution of multidenticulate teeth and benthic scraping in †*Hemicalypterus*: Science of Nature, v. 102, no. 10, p. 1–7.

Gillette, D.D., 1996a, Origin and early evolution of the sauropod dinosaurs of North America—the type locality and stratigraphic position of *Dystrophaeus viaemalae* Cope 1877, *in* Huffman, A.C., Lund, W.R., and Godwin, L.H., editors, Geology and Resources of the Paradox Basin: Utah Geological Association Publication 25, p. 313–324.

Gillette, D.D., 1996b, Stratigraphic position of the sauropod *Dystrophaeus viaemalae* Cope 1877 and its evolutionary implications: Museum of Northern Arizona Bulletin, v. 60, p. 59–68.

Gross, E.B., 1956, Mineralogy and paragenesis of the uranium ore, Mi Vida Mine, San Juan County, Utah: Economic Geology, v. 51, p. 632–648.

Hartley, A., and Evenstar, L., 2018, Fluvial architecture in actively deforming salt basins—Chinle Formation, Paradox Basin, Utah: Basin Research, v. 30, p. 148–166.

Harward, A., and Irmis, R., 2014, A new fossil skeleton from the Lower Jurassic Navajo Sandstone, southeastern Utah [abs.]: Journal of Vertebrate Paleontology, v. 34 (Online Supplement), p. 144.

Hasiotis, S.T., 1995, Crayfish fossils and burrows from the Upper Triassic Chinle Formation, Canyonlands National Park, Utah: National Park Service Technical Report NPS/NRPO/NRTR-95/16, p. 49–53.

Hasiotis, S.T., and Mitchell, C.E., 1989, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau—discussion – new evidence suggests origin by a burrowing decapod crustacean: Journal of Sedimentary Petrology, v. 59, p. 871–875.

Hasiotis, S.T., and Mitchell, C.E., 1993, A comparison of crayfish burrow morphologies—Triassic and Holocene fossil, paleo- and neo-ichnological evidence, and the identification of their burrowing signatures: Ichnos, v. 2, p. 291–314.

Hasiotis, S.T., Mitchell, C.E., and Dubiel, R.F., 1993, Application of morphologic burrow interpretations to discern continental burrow architects—lungfish or crayfish?: Ichnos, v. 2, p. 315–333.

Hasiotis, S.T., and Rasmussen, D.L., 2010, Enigmatic, large-and mega-diameter burrows in the Lower Permian Cedar Mesa Sandstone, Comb Ridge and Moqui Dugway, southeastern, Utah [abs.]: Geological Society of America Abstracts with Programs, v. 42, no. 3, p. 2.

Hasiotis, S.T., Wellner, R.W., Martin, A.J., and Demko, T.M., 2004, Vertebrate burrows from Triassic and Jurassic continental deposits of North America and Antarctica—their paleoenvironmental and paleoecological significance: Ichnos, v. 11, no. 1–2, p. 103-124.

Heckert, A.B., Lucas, S.G., Rinehart, L.F., Celeskey, M.D., Spielmann, J.A., and Hunt, A.P., 2010, Articulated skeletons of the aetosaur *Typothorax coccinarum* Cope (Archosauria: Stagonolepididae) from the Upper Triassic Bull Canyon Formation (Revueltian: early-mid Norian), eastern New Mexico, USA: Journal of Vertebrate Paleontology, v. 30, p. 619–642.

Herries, R.D., 1993, Contrasting styles of fluvial-aeolian interaction at a downwind erg margin—Jurassic Kayenta-Navajo transition, northeastern Arizona, USA: Geological Society of London Special Publication, v. 73, p. 199–218.

Hintze, L.F., and Kowallis, B.J., 2009, Geologic history of Utah: Brigham Young University Geology Studies Special Publication 9, 225 p.

Hintze, L.F., Willis, G.C., Laes, D.Y.M., Sprinkel, D.A., and Brown, K.D., 2000, Digital geologic map of Utah: Utah Geological Survey Map 179DM, compact disc, 17 p., scale 1:500,000.

Hounslow, M.W., and Muttoni, G., 2010, The geomagnetic polarity timescale for the Triassic—linkage to stage boundary definitions: Geological Society of London Special Publication 334, p. 61–102.

Hunt, A.P., Lucas, S.G., and Spielmann, J.A., 2005, The postcranial skeleton of *Revueltosaurus callenderi* (Archosauria: Crurotarsi) from the Upper Triassic of Arizona and New Mexico, USA, *in* Heckert, A.B., and Lucas, S.G., editors, Vertebrate paleontology in Arizona: New Mexico Museum of Natural History and Science Bulletin 29, p. 66–75.

Hunt-Foster, R.K., Lockley, M.G., Milner, A.R.C., Foster, J.R., Matthews, N.A., Breithaupt, B.H., and Smith, J.A., 2016, Tracking dinosaurs in BLM canyon country, Utah: Geology of the Intermountain West, v. 3, p. 67–100.

Huttenlocker, A.K., Henrici, A., Nelson, W.J., Elrick, S., Berman, D.S., Schlotterbeck, T., and Sumida, S.S., 2018, A multitaxic bonebed near the Carboniferous-Permian boundary (Halgaito Formation, Cutler Group) in Valley of the Gods, Utah, USA—vertebrate paleontology and taphonomy: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 499, p.72–92.

Imlay, R.W., 1948, Characteristic marine Jurassic fossils from the Western Interior of the United States: U.S. Geological Survey Professional Paper, v. 214-B, p. 13–33.

Imlay, R.W., 1964, Marine Jurassic pelecypods from central and southern Utah: U.S. Geological Survey Professional Paper 483-C, 42 p.

Irmis, R.B., 2005a, The vertebrate fauna of the Upper Triassic Chinle Formation in northern Arizona: Mesa Southwest Museum Bulletin, v. 9, p. 63–-88.

Irmis, R.B., 2005b, A review of the vertebrate fauna of the Lower Jurassic Navajo Sandstone in Arizona: Mesa Southwest Museum Bulletin, v. 11, p. 55–71.

Irmis, R.B., 2011, Evaluating hypotheses for the early diversification of dinosaurs: Earth and Environmental Science Transactions of the Royal Society of Edinburgh, v. 101, p. 397–426.

Irmis, R.B., Martz, J.W., Parker, W.G., and Nesbitt, S.J., 2010, Re-evaluating the correlation between Late Triassic terrestrial vertebrate biostratigraphy and the GSSP-defined marine stages: Albertiana, v. 38, p. 40–52.

Irmis, R.B., Chure, D.J., Engelmann, G.F., Wiersma, J.P., and Lindström, S., 2015, The alluvial to eolian transition of the Chinle and Nugget Formations in the southern Uinta Mountains, northeastern Utah, *in* Vanden Berg, M.D., Ressetar, R., and Birgenheier, L.P., editors, The Uinta Basin and Uinta Mountains: Utah Geological Association Publication 44, p. 13–48.

Isachsen, Y.W., 1954, Ore deposits of the Big Indian Wash-Lisbon Valley area, *in* Stokes, W.L., editor, Uranium deposits and general geology of southeastern Utah: Utah Geological Society Guidebook to the Geology of Utah 9, p. 95–105.

Isachsen, Y.W., and Evensen, C.G., 1956, Geology of uranium deposits of the Shinarump and Chinle Formations on the Colorado Plateau: U.S. Geological Survey Professional Paper 300, p. 263–280.

Isachsen, Y.W., Mitcham, T.W., and Wood, H.B., 1955, Age and sedimentary environments of uranium host rocks, Colorado Plateau: Economic Geology, v. 50, p. 127–134.

Jenkins, X.A., Foster, J.R., and Gay, R.J., 2017, First unambiguous dinosaur specimen from the Upper Triassic Chinle Formation in Utah: Geology of the Intermountain West, v. 4, p. 231–242.

Johnson, H.S., Jr., and Thordarson, W., 1966, Uranium deposits of the Moab, Monticello, White Canyon, and Monument Valley districts, Utah and Arizona: U.S. Geological Survey Bulletin 1222-H, p. H1–H53.

Jordan, O.D., and Mountney, N.P., 2010, Styles of interaction between aeolian, fluvial and shallow marine environments in the Pennsylvanian to Permian lower Cutler beds, south-east Utah, USA: Sedimentology, v. 57, p. 1357–1385.

Jordan, O.D., and Mountney, N.P., 2012, Sequence stratigraphic evolution and cyclicity of an ancient coastal desert system—the Pennsylvanian-Permian lower Cutler beds, Paradox Basin, Utah, U.S.A.: Journal of Sedimentary Research, v. 82, p. 755–780.

Kent, D.V., and Irving, E., 2010, Influence of inclination error in sedimentary rocks on the Triassic and Jurassic apparent pole wander path for North America and implications for Cordilleran tectonics: Journal of Geophysical Research, v. 115, no. B10103, p. 1–25.

Kent, D.V., and Tauxe, L., 2005, Corrected Late Triassic latitudes for continents adjacent to the North Atlantic: Science, v. 307, p. 240–244.

Kent, D.V., Olsen, P.E., and Muttoni, G., 2017, Astrochronostratigraphic polarity time scale (APTS) for the Late Triassic and Early Jurassic from continental sediments and correlation with standard marine stages: Earth-Science Reviews, v. 166, p. 153–180.

Kent, D.V., Olsen, P.E., Rasmussen, C., Lepre, C., Mundil, R., Irmis, R.B., Gehrels, G.E., Giesler, D., Geissman, J.W., and Parker, W.G., 2018, Empirical evidence for stability of the 405-kiloyear Jupiter-Venus eccentricity cycle over hundreds of millions of years: Proceedings of the National Academy of Sciences, v. 115, p. 6153–6158.

Kirkland, J.I., DeBlieux, D.D., Hunt-Foster, R.K., Foster, J.R., Trujillo, K.C., and Finzel, E., 2020, The Morrison Formation and its bounding strata on the western side of the Blanding Basin, San Juan County, Utah: Geology of the Intermountain West, v. 7, p. 137–195, https://doi.org/10.31711/giw. v7.pp137–195.

Kirkland, J.I., and Milner, A.R.C., 2006, The Moenave Formation at the St. George Dinosaur Discovery Site at Johnson Farm, St. George, southwestern Utah, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, The Triassic-Jurassic Terrestrial Transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 289–309.

Kirkland, J.I., and Madsen, S.K., 2007, The Lower Cretaceous Cedar Mountain Formation, eastern Utah—the view up an always interesting learning curve, *in* Lund, W.R., editor, Field guide to excursions in southern Utah: Utah Geological Association Publication 35, p. 1–108.

Kirkland, J.I., Milner, A.R.C., Olsen, P.E., and Hargrave, J.E., 2014, The Whitmore Point Member of the Moenave Formation in its type area in northern Arizona, age, and correlation with the section in St. George, Utah—evidence for two major lacustrine sequences, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, p. 321–356.

Kirkland, J.I., Suarez, M., Suarez, C., and Hunt-Foster, R., 2016, The Lower Cretaceous in east-central Utah—the Cedar Mountain Formation and its bounding strata: Geology of the Intermountain West, v. 3, p. 101–228.

Kowallis, B.J., Britt, B.B., Greenhalgh, B.W., and Sprinkel, D.A., 2007, New U-Pb zircon ages from an ash beds in the Brushy Basin Member of the Morrison Formation near Hanksville, Utah, *in* Willis, G.C., Hylland, M.D., Clark, D.L., and Chidsey, T.C., Jr., editors, Central Utah—diverse geology of a dynamic landscape: Utah Geological Association Publication 36, p. 75–80.

Kowallis, B.J., Christiansen, E.H, Deino, A.L., Peterson, F., Turner, C.E., Kunk, M.J., and Obradovich, J.D., 1998, The age of the Morrison Formation: Modern Geology, v. 22, p. 235–260.

Kowallis, B.J., Christiansen, E.H, Deino, A.L., Zhang, C., and Everett, B.H., 2001, The record of Middle Jurassic volcanism in the Carmel and Temple Cap Formations of southwestern Utah: Geological Society of America Bulletin, v. 113, p. 373–387.

Langer, M.C., Ezcurra, M.D., Bittencourt, J.S., and Novas, F.E., 2010, The origin and early evolution of dinosaurs: Biological Reviews, v. 85, p. 55–110.

Lewis, R.Q., Sr., Campbell, R.H., Thaden, R.E., Krummel, W.J., Jr., Willis, G.C., and Matyjasik, B., 2011, Geologic map of Elk Ridge and vicinity, San Juan County, Utah (modified from U.S. Geological Survey Professional Paper 474-b): Utah Geological Survey Miscellaneous Publication 11-1DM, 12 p., 1 plate, scale 1:62,500.

Lindström, S., van de Schootbrugge, B., Hansen K.H., Pedersen, G.K., Alsen, P., Thibault, N., Dybkjær, K., Bjerrum, C.J., and Nielsen, L.H., 2017, A new correlation of Triassic-Jurassic boundary successions in NW Europe, Nevada and Peru, and the Central Atlantic Magmatic Province—a time-line for the end-Triassic mass extinction: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 478, p. 80–102.

Litwin, R.J., 1986, The palynostratigraphy and age of the Chinle and Moenave Formations, southwestern U.S.A: State College, Pennsylvania State University, Ph.D. dissertation, 256 p.

Litwin, R.J., and Skog, J.E., 1991, Morphology and palynostratigraphy of the genus *Camerosporites* Leschik 1956: Palynology, v. 15, p. 5–28.

Litwin, R.J., Traverse, A., and Ash, S.R., 1991, Preliminary palynological zonation of the Chinle Formation, southwestern U.S.A., and its correlation to the Newark Supergroup (eastern U.S.A.): Review of Palaeobotany and Palynology, v. 68, p. 269–287.

Litwin, R.J., Turner, C.E., and Peterson, F., 1998, Palynological evidence on the age of the Morrison Formation, Western Interior U.S.: Modern Geology, v. 22, p. 297–319.

Liu, L., and Gurnis, M., 2010, Dynamic subsidence and uplift of the Colorado Plateau: Geology, v. 38, p. 663–666.

Lockley, M.G., 1986, A guide to dinosaur tracksites of the Colorado Plateau and American southwest: University of Colorado at Denver Geology Department Magazine, Special Issue, v. 1, p. 1–56.

Lockley, M.G., 1991, The Moab megatracksite—a preliminary description and discussion of millions of Middle Jurassic tracks in eastern Utah, *in* Averett, W.R., editor, Guidebook for dinosaur quarries and tracksites tour, western Colorado and eastern Utah: Grand Junction, Grand Junction Geological Society, p. 59–65.

Lockley, M.G., Hunt, A., Paquette, M., Bilbey, S.A., and Hamblin, A., 1998a, Dinosaur tracks from the Carmel Formation, northeastern Utah—implications for Middle Jurassic paleoecology: Ichnos, v. 5, p. 255–267.

Lockley, M., Foster, J., and Hunt, A., 1998b, A short summary of dinosaur tracks and other fossil footprints from the Morrison Formation: Modern Geology, v. 23, p. 277–290.

Lockley, M., Dos Santos, V.F., Meyer, C., and Hunt, A., 1998c, A new dinosaur tracksite in the Morrison Formation, Boundary Butte, southeastern Utah: Modern Geology, v. 23, p. 317–330.

Lockley, M.G., and Gierliński, G.D., 2006, Diverse vertebrate ichnofaunas containing *Anomoepus* and other unusual trace fossils from the Lower Jurassic of the western United States—implications for paleoecology and palichnostratigraphy, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, The Triassic-Jurassic terrestrial transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 176–191.

Lockley, M.G., and Gierliński, G.D., 2014a, A new *Otozoum*-dominated tracksite in the Glen Canyon Group (Jurassic) of eastern Utah, *in* Lockley, M.G., and Lucas, S.G., editors, Fossil footprints of western North America: New Mexico Museum of Natural History and Science Bulletin 62, p. 211–214.

Lockley, M., and Gierliński, G., 2014b, Jurassic tetrapod footprint ichnofaunas and ichnofacies of the Western Interior, USA: Volumina Jurassica, v. 12, p. 133–150.

Lockley, M., and Hunt, A.P., 1995, Dinosaur tracks and other fossil footprints of the western United States: New York, Columbia University Press, 360 p.

Lockley, M.G., Hunt, A.P., and Lucas, S.G., 1996, Vertebrate track assemblages from the Jurassic Summerville Formation and correlative deposits, *in* Morales, M., editor, The continental Jurassic: Museum of Northern Arizona Bulletin 60, p. 249–254.

Lockley, M.G., Lucas, S.G., Hunt, A.P., Gaston, R., 2004, Ichnofossils from the Triassic-Jurassic boundary sequences of the Gateway area, western Colorado—implications for faunal composition and correlations with other areas: Ichnos, v. 11, p. 89–102.

Lockley, M.G., and Madsen, J.H., Jr., 1993, Early Permian vertebrate trackways from the Cedar Mesa Sandstone of eastern Utah—evidence of predator-prey interaction: Ichnos, v. 2, no. 2, p. 147–153.

Lockley, M.G., and Mickelson, D.L., 1997, Dinosaur and pterosaur tracks in the Summerville and Bluff (Jurassic) beds of eastern Utah and northeastern Arizona, *in* Anderson, O., Kues, B., and Lucas, S.G., editors, Mesozoic geology and paleontology of the Four Corners area: New Mexico Geological Society Guidebook 48, p. 133–138.

Lockley, M.G., Yang, S.Y., Matsukawa, M., Fleming, F., and Lim, S.K., 1992, The track record of Mesozoic birds—evidence and implications: Philosophical Transactions of the Royal Society of London, Series B, v. 336, p. 113–134.

Long, R.A., and Murry, P.A., 1995, Late Triassic (Carnian and Norian) tetrapods from the southwestern United States: New Mexico Museum of Natural History and Science Bulletin 4, p. 1–254.

Longwell, C.R., Miser, H.D., Moore, R.C., Bryan, K., and Paige, S., 1925, Rock Formations in the Colorado Plateau of southeastern Utah and northern Arizona: U.S. Geological Survey Professional Paper 132-A, p. 1–23.

Loope, D.B., 1984, Eolian origin of upper Paleozoic sandstones, southeastern Utah: Journal of Sedimentary Petrology, v. 54, no. 2, p. 563–580.

Loope, D.B., 2006a, Dry-season tracks in dinosaur-triggered grainflows: Palaios, v. 21, p. 132–142.

Loope, D.B., 2006b, Burrows dug by large vertebrates into rain-moistened Middle Jurassic sand dunes: Journal of Geology, v. 114, p. 753–762.

Loope, D.B., 2008, Life beneath the surfaces of active Jurassic dunes—burrows from the Entrada Sandstone of south-central Utah: Palaios, v. 23, p. 411–419.

Loope, D.B., and Rowe, C.M., 2003, Long-lived pluvial episodes during deposition of the Navajo Sandstone: Journal of Geology, v. 111, p. 223–232.

Loope, D.B., Eisenberg, L., and Waiss, E., 2004, Navajo sand sea of near-equatorial Pangea—tropical westerlies, slumps, and giant stromatolites, *in* Nelson, E.P., and Erslev, E.A., Field trips in the southern Rocky Mountains, USA: Geological Society of America Field Guide 5, p. 1–13.

Loope, D.B., Sanderson, G.A., and Verville, G.J., 1990, Abandonment of the name "Elephant Canyon Formation" in southeastern Utah—physical and temporal implications: The Mountain Geologist, v. 27, no. 4, p. 119–130.

Lowrey, R.O., 1976, Paleoenvironment of the Carmel Formation at Sheep Creek Gap, Daggett County, Utah: Brigham Young University Geology Studies, v. 23, pt. 1, p. 173–203.

Lucas, F.A., 1898, A new crocodile from the Trias of southern Utah: American Journal of Science, v. 4, no. 6, p. 399–400.

Lucas, S.G., Goodspeed, T.H., and Estep, J.W., 2007, Ammonoid biostratigraphy of the Lower Triassic Sinbad Formation, east-central Utah, *in* Lucas, S.G., and Spielmann, J.A., editors, Triassic of the American West: New Mexico Museum of Natural History and Science Bulletin 40, p. 103–108.

Lucas, S.G., and Heckert, A.B., 2011, Late Triassic aetosaurs as the trackmaker of the tetrapod footprint ichnotaxon *Brachychirotherium*: Ichnos, v. 18, p. 197–208.

Lucas, S.G., Heckert, A.B., and Tanner, L.H., 2005, Arizona's Jurassic fossil vertebrates and the age of the Glen Canyon Group, *in* Heckert, A.B., and Lucas, S.G., editors, Vertebrate paleontology in Arizona: New Mexico Museum of Natural History and Science Bulletin 29, p. 94–103.

Lucas, S.G., Gobetz, K.E., Odier, G.P., McCormick, T., and Egan, C., 2006a, Tetrapod burrows from the Lower Jurassic Navajo Sandstone, southeastern Utah, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, The Triassic-Jurassic terrestrial transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 147–154.

Lucas, S.G., Lockley, M.G., Hunt, A.P., Milner, A.R.C., and Tanner, L.H., 2006b, Tetrapod footprint biostratigraphy of the Triassic-Jurassic transition in the American Southwest, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, The Triassic-Jurassic terrestrial transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 105–108.

Lucas, S.G., Lockley, M.G., Hunt, A.P., and Tanner, L.H., 2006c, Biostratigraphic significance of tetrapod footprints from the Triassic-Jurassic Wingate Sandstone on the Colorado Plateau, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, The Triassic-Jurassic terrestrial transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 109–117.

Lucas, S.G., and Schoch, R.R., 2002, Triassic temnospondyl biostratigraphy, biochronology and correlation of the German Buntsandstein and North American Moenkopi Formation: Lethaia, v. 35, p. 97–106.

Lucas, S.G., and Tanner, L.H., 2007, Tetrapod biostratigraphy and biochronology of the Triassic-Jurassic transition on the southern Colorado Plateau, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 244, p. 242–256.

Lucas, S.G., Tanner, L.H., Donohoo-Hurley, L.L., Geissman, J.W., Kozur, H.W., Heckert, A.B., and Weems, R.E., 2011, Position of the Triassic-Jurassic boundary and timing of the end-Triassic extinctions on land—data from the Moenave Formation on the southern Colorado Plateau, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 302, p. 194–205.

Marsh, A.D., 2015, Preliminary U-Pb detrital zircon dates from the Kayenta Formation of Arizona [abs.]: PaleoBios, v. 31, no. 1 (Supplement), p. 10.

Marsh, A.D., Rowe, T., Simonetti, A., Stockli, D., and Stockli, L., 2014, The age of the Kayenta Formation of northeastern Arizona—overcoming the challenges of dating fossil bone [abs.]: Journal of Vertebrate Paleontology, v. 34 (Supplement 2), p. 178.

Marsh, A.D., Smith, M.E., Parker, W.G., Irmis, R.B., and Kligman, B.T., in press, Skeletal anatomy of *Acaenasuchus geoffreyi* Long and Murry, 1995 (Archosauria: Pseudosuchia) and its implications for the origin of the aetosaurian carapace: Journal of Vertebrate Paleontology.

Martz, J.W., Irmis, R.G., and Milner, A.R.C., 2014, Lithostratigraphy and biostratigraphy of the Chinle Formation (Upper Triassic) in southern Lisbon Valley, southeastern Utah, *in* MacLean, J.S., Biek, R.F., and Huntoon, J.E., editors, Geology of Utah's far south: Utah Geological Association Publication 43, p. 397–446.

Martz, J.W., Kirkland, J.I., Milner, A.R.C., Parker, W.G., and Santucci, V.L., 2017, Upper Triassic lithostratigraphy, depositional systems, and vertebrate paleontology across southern Utah: Geology of the Intermountain West, v. 4, p. 99–180.

Mayor, A., 2005, Fossil legends of the first Americans: Princeton, New Jersey, Princeton University Press, 488 p.

McAllister, J.A., 1988, Lungfish burrows in the Upper Triassic Chinle and Dolores Formations, Colorado Plateau—comments on the recognition criteria of fossil lungfish burrows: Journal of Sedimentary Petrology, v. 58, p. 365–367.

McCormack, L., and Parker, W., 2017, A new occurrence of the phytosaur (Archosauriformes, Phytosauria) *Pravusuchus hortus* from the Monitor Butte Member (Upper Triassic; Chinle Formation) of Utah [abs.]: Journal of Vertebrate Paleontology Programs and Abstracts, p. 161.

McKee, E.D., 1954, Stratigraphy and history of the Moenkopi Formation of Triassic age: Geological Society of America Memoir 61, p. 1–133.

McIntosh, J.S., 1997, The saga of a forgotten sauropod dinosaur, *in* Wolberg, D., and Stump, E., editors, Dinofest International Proceedings: Pennsylvania, Philadelphia Academy of Natural Sciences, p. 7–12.

Mead, J.I., Agenbroad, L.D., Phillips, A.M., III, and Middleton, L.T., 1987, Extinct mountain goat (*Oreamnos harringtoni*) in southeastern Utah: Quaternary Research, v. 27, p. 323–331.

Mead, J.I., Sharpe, S.E., and Agenbroad, L.D., 1991, Holocene bison from Arches National Park, southeastern Utah: Great Basin Naturalist, v. 51, p. 336–342.

Melton, R.A., 1972, Paleoecology and paleoenvironment of the upper Honaker Trail Formation near Moab, Utah: Brigham Young University Geology Studies, v. 19, pt. 2, p. 45–88.

Middleton, L.T., and Blakey, R.C., 1983, Processes and controls on the intertonguing of the Kayenta and Navajo Formations, northern Arizona—eolian-fluvial interactions: Developments in Sedimentology, v. 38, p. 613–634.

Milàn, J., and Chiappe, L.M., 2009, First American record of the Jurassic ichnospecies *Deltapodus brodricki* and a review of the fossil record of stegosaurian footprints: Journal of Geology, v. 117, p. 343–348.

Milàn, J., Chiappe, L.M., Loope, D.B., Kirkland, J.I., and Lockley, M.G., 2015, First report on dinosaur tracks from the Burro Canyon Formation, San Juan County, Utah, USA—evidence of a diverse, hitherto unknown Lower Cretaceous dinosaur fauna: Annales Geologorum Poloniae, v. 85, p. 515–525.

Milner, A.R.C., 2006, Plant fossils from the Owl Rock or Church Rock Members, Chinle Formation, San Juan County, Utah, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, The Triassic-Jurassic terrestrial transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 410–413.

Milner, A.R.C., Birthisel, T.A., Kirkland, J.I., Breithaupt, B.H., Matthews, N.A., Lockley, M.G., Santucci, V.L., Gibson, S.Z., DeBlieux, D.D., Hurlburt, M., Harris, J.D., and Olsen, P.E., 2012, Tracking Early Jurassic dinosaurs across southwestern Utah and the Triassic-Jurassic transition: Nevada State Museum Paleontological Papers, v. 1, p. 1–107.

Milner, A.R., Gay, R.J., Irmis, R., Overkamp, F., and Santella, M., 2017, New southwestern Utah paleontological locality from the Lower Jurassic Kayenta Formation reveals a diverse vertebrate fauna based on teeth and tracks [abs.]: Journal of Vertebrate Paleontology, v. 37 (Online Supplement), p. 164.

Milner, A., Irmis, R., Martz, J., Birthisel, T., and Lockley, M., 2011, New information on Late Triassic terrestrial ecosystems of Utah—tetrapod fossils from the Chinle Formation of Lisbon Valley [abs.]: Journal of Vertebrate Paleontology, v. 31 (Online Supplement), p. 158–159.

Milner, A.R.C., Kirkland, J.I., and Birthisel, T.A., 2006, The geographic distribution and biostratigraphy of Late Triassic-Early Jurassic freshwater fish faunas of the southwestern United States, *in* Harris, J.D., Lucas, S.G., Spielmann, J.A., Lockley, M.G., Milner, A.R.C., and Kirkland, J.I., editors, The Triassic-Jurassic terrestrial transition: New Mexico Museum of Natural History and Science Bulletin 37, p. 522–529.

Mocho, P., and Chiappe, L., 2018, Diplodocines of the Gnatalie Quarry, a new bone-bed accumulation from southern Utah (Morrison Fm., USA) [abs.], *in* Marzola, M., Mateus, O., and Moreno-Azanza, M., editors, Abstract book of the XVI annual meeting of the European Association of Vertebrate Palaeontology: Caparica, Portugal, p. 15.

Mocho, P., Ortega, F., Escaso, F., Goodreau, D., and Chiappe, L., 2014, Preliminary evaluation of sauropod remains from a new dinosaur bone bed of the Morrison Formation in southeastern Utah (USA) [abs.]: Journal of Vertebrate Paleontology, v. 34 (Online Supplement), p. 190.

Molina-Garza, R.S., Geissman, J.W., and Lucas, S.G., 2003, Paleomagnetism and magnetostratigraphy of the lower Glen Canyon and upper Chinle groups, Jurassic-Triassic of northern Arizona and northeast Utah: Journal of Geophysical Research B, v. 108, p. 1–23.

Montañez, I.P., and Poulsen, C.J., 2013, The late Paleozoic ice age—an evolving paradigm. Annual Review of Earth and Planetary Sciences, v. 41, p. 629–656.

Montañez, I.P., Tabor, N.J., Niemeier, D., DiMichele, W.A., Frank, T.D., Fielding, C.R., Isbell J.L., Birgenheier, L.P., and Rygel, M.C., 2007, CO_2-forced climate and vegetation instability during late Paleozoic deglaciation: Science, v. 315, p. 87–91.

Morales, M., 1987, Terrestrial fauna and flora from the Triassic Moenkopi Formation of the southwestern United States: Journal of the Arizona-Nevada Academy of Science, v. 22, p. 1–19.

Morales, M., and Ash, S.R., 1993, The last phytosaurs?, *in* Lucas, S.G., and Morales, M., editors, The nonmarine Triassic: New Mexico Museum of Natural History and Science Bulletin 3, p. 357–358.

Moreau, M-G., Bucher, H., Bodergat, A-M., and Guex, J., 2002, Pliensbachian magnetostratigraphy—new data from Paris Basin (France): Earth and Planetary Science Letters, v. 203, p. 755–767.

Mountney, N.P., 2006, Periodic accumulation and destruction of aeolian erg sequences in the Permian Cedar Mesa Sandstone, White Canyon, southern Utah, USA: Sedimentology, v. 53, p. 789–823.

Mountney, N.P., and Jagger, A., 2004, Stratigraphic evolution of an aeolian erg margin system—the Permian Cedar Mesa Sandstone, SE Utah, USA: Sedimentology, v. 51, p. 713–743.

Mullens, T.E., 1960, Geology of the Clay Hills area, San Juan County, Utah: U.S. Geological Survey Bulletin 1087-H, p. 259–336.

Mundil, R., Pálfy, J., Renne, P.R., and Brack, P., 2010, The Triassic time scale—new constraints and a review of geochronological data: Geological Society of London Special Publication, v. 334, p. 41–60.

Muttoni, G., Visconti, A., Channell, J.E.T., Casellato, C.E., Maron, M., and Jadoul, F., 2018, An expanded Tethyan Kimmeridgian magneto-biostratigraphy from the S'Adde section (Sardinia)—implications for the Jurassic timescale: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 503, p. 90–101.

Neuman, W.F., Neuman, M.W., Main, E.R., and Mulryan, B.J., 1949, The deposition of uranium in bone—IV—adsorption studies in the deposition of uranium: Journal of Biological Chemistry, v. 179, p. 325–333.

Newberry, J.S., 1876, Report of the exploring expedition from Santa Fé, New Mexico, to the junction of the Grand and Green Rivers of the great Colorado of the West, in 1859, under the command of Capt. J.N. Macomb, with geological report: Washington, D.C., Engineer Department, U.S. Army, 148 p.

O'Sullivan, R.B., 1965, Geology of the Cedar Mesa-Boundary Butte area, San Juan County, Utah: U.S. Geological Survey Bulletin 1186, p. 1–128.

O'Sullivan, R.B., 2010a, Correlation of the upper part of the Middle Jurassic San Rafael Group in northeast Arizona, northwest New Mexico, and southeast Utah, *in* Fassett, J.E., Zeigler, K.E., and Lueth, V., editors, Geology of the Four Corners country: New Mexico Geological Society Guidebook 61, p. 91–100.

O'Sullivan, R.B., 2010b, The lower and upper contacts of the Upper Jurassic Bluff Sandstone Member of the Morrison Formation in southeastern Utah, *in* Fassett, J.E., Zeigler, K.E., and Lueth, V., editors, Geology of the Four Corners country: New Mexico Geological Society Guidebook 61, p. 101–106.

O'Sullivan, R.B., and MacLachlan, M.E., 1975, Triassic rocks of the Moab-White Canyon area, southeastern Utah, *in* Fassett, J., and Wengerd, S.A., editors, Canyonlands country: Four Corners Geological Society Eighth Field Conference Guidebook, p. 129–142.

Obama, B.H., II, 2016, Proclamation 9558—establishment of the Bears Ears National Monument: Federal Register, v. 82, no. 3, p. 1139–1147.

Ogg, J.G., 2012, Triassic, *in* Gradstein, F.M., Ogg, J.G., Schmitz, M.D., and Ogg, G.M., editors, The geologic time scale 2012: Amsterdam, Elsevier, p. 681–730.

Ogg J.G., and Hinnov, L.A., 2012, Jurassic, *in* Gradstein, F.M., Ogg, J.G., Schmitz, M.D., and Ogg, G.M., editors, The geologic time scale 2012: Amsterdam, Elsevier, p. 731–791.

Olsen, P.E., Kent, D.V., Sues, H-D., Koeberl, C., Huber, H., Montanari, A., Rainforth, E.C., Fowell, S.J., Szajna, M.J., and Hartline, B.W., 2002, Ascent of dinosaurs linked to an iridium anomaly at the Triassic-Jurassic boundary: Science, v. 296, p. 1305–1307.

Orkild, P.P., 1955, Photogeologic map of the Bluff-6 quadrangle, San Juan County, Utah: U.S. Geological Survey Miscellaneous Investigations Map 1-53, 1 plate, scale 1:24,000.

Pálfy, J., Mortensen, J.K., Carter, E.S., Smith, P.L., Friedman, R.M., and Tipper, H.W., 2000, Timing the end-Triassic mass extinction—first on land, then in the sea?: Geology, v. 28, p. 39–42.

Parker, W.G., Irmis, R.B., Nesbitt, S.J., Martz, J.W., and Browne, L.S., 2005, The Late Triassic pseudosuchian *Revueltosaurus callenderi* and its implications for the diversity of early ornithischian dinosaurs: Proceedings of the Royal Society of London, Biological Sciences, v. 272, p. 963–969.

Parrish, J.M., 1999, Small fossil vertebrates from the Chinle Formation (Upper Triassic) of southern Utah, *in* Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 45–50.

Parrish, J.T., and Falcon-Lang, H.J., 2007, Coniferous trees associated with interdune deposits in the Jurassic Navajo Sandstone Formation, Utah, USA: Palaeontology, v. 50, no. 4, p. 829–843.

Parrish, J.T., Hasiotis, S.T., and Chan, M.A., 2017, Carbonate deposits in the Lower Jurassic Navajo Sandstone, southern Utah and northern Arizona, U.S.A.: Journal of Sedimentary Research, v. 87, p. 740–762.

Parrish, J.T., and Good, S.C., 1987, Preliminary report on vertebrate and invertebrate fossil occurrences, Chinle Formation (Upper Triassic), southeastern Utah, *in* Campbell, J.A., editor, Geology of Cataract Canyon and vicinity: Four Corners Geological Society Tenth Field Conference Guidebook, p. 109–116.

Parrish, J.T., Peterson, F., and Turner, C.E., 2004, Jurassic "savannah"—plant taphonomy and climate of the Morrison Formation (Upper Jurassic, western USA): Sedimentary Geology, v. 167, p. 137–162.

Pederson, J.L., 2008, The mystery of the pre-Grand Canyon Colorado River—results from the Muddy Creek Formation: GSA Today, v. 18, p. 4–10.

Pederson, G.T., Gray, S.T., Woodhouse, C.A., Betancourt, J.L., Fagre, D.B., Littell, J.S., Watson, E., Luckman, B.H., and Graumlich, L.J., 2011, The unusual nature of recent snowpack declines in the North American Cordillera: Science, v. 333, p. 332–335.

Pellenard, P., Nomade, S., Martire, L., de Oliviera Ramalho, F., Monna, F., and Guillou, H., 2013, The first ^{40}Ar-^{39}Ar date from Oxfordian ammonite-calibrated volcanic layers (bentonites) as a tie-point for the Late Jurassic: Geological Magazine, v. 150, p. 1136–1142.

Percival, L.M.E., Ruhl, M., Hesselbo, S.P., Jenkyns, H.C., Mather, T.A., and Whiteside, J.H., 2017, Mercury evidence for pulsed volcanism during the end-Triassic mass extinction: Proceedings of the National Academy of Sciences, v. 114, p. 7829–7934.

Peterson, F., 1988, Pennsylvanian to Jurassic eolian transportation systems in the western United States: Sedimentary Geology, v. 56, p. 207–260.

Peterson, F., 1994, Sand dunes, sabkhas, streams, and shallow seas—Jurassic paleogeography in the southern part of the Western Interior Basin, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., editors, Mesozoic systems of the Rocky Mountain region: Denver, Rocky Mountain Section, SEPM (Society for Sedimentary Geology), p. 233–272.

Pierce, K.L., 2003, Pleistocene glaciations of the Rocky Mountains:

Developments in Quaternary Science, v. 1, p. 63–76.

Public Law 111-11, Title VI, Subtitle D; 16 U.S.C. §§ 470aaa - 470aaa-11. March 30, 2009: Online, https://www.gpo.gov/fdsys/pkg/PLAW-111publ11/pdf/PLAW-111publ11.pdf, accessed November 11, 2017.

Rainforth, E.C., 1997, Vertebrate ichnological diversity and census studies, Lower Jurassic Navajo Sandstone: Boulder, University of Colorado, M.S. thesis, 49 p.

Rasmussen, C., Huttenlocker, A.K., and Irmis, R., 2016, New species of *Eryops* from the lower Permian Cedar Mesa Sandstone (Cutler Group) of southeastern Utah and its implications for the phylogeny and biogeography of eryopids [abs.]: Journal of Vertebrate Paleontology Programs and Abstracts, p. 211.

Raup, D.M., 1994, The role of extinction in evolution: Proceedings of the National Academy of Sciences, v. 91, p. 6758–6763.

Reheis, M.C., Reynolds, R.L., Goldstein, H., Roberts, H.M., Yount, J.C., Axford, Y., Cummings, L.S., and Shearin, N., 2005, Late Quaternary eolian and alluvial response to paleoclimate, Canyonlands, southeastern Utah: Geological Society of America Bulletin, v. 117, p. 1051–1069.

Richmond, G.M., 1962, Quaternary stratigraphy of the La Sal Mountains, Utah: U.S. Geological Survey Professional Paper 324, p. 1–134.

Richmond, G.M., and Fullerton, D.S., 1986, Summation of Quaternary glaciations in the United States of America: Quaternary Science Reviews, v. 5, p. 183–196.

Riese, D.J., Hasiotis, S.T., and Odier, G.P., 2011, Synapsid burrows and associated trace fossils in the Lower Jurassic Navajo Sandstone, southeastern Utah, U.S.A, indicates a diverse community living in a wet desert ecosystem: Journal of Sedimentary Research, v. 81, no. 4, p. 299–321.

Riggs, N.R., Lehman, T.M., Gehrels, G.E., and Dickinson, W.R., 1996, Detrital zircon link between headwaters and terminus of the Upper Triassic Chinle-Dockum paleoriver system: Science, v. 273, p. 97–100.

Ringholz, R.C., 1989, Uranium frenzy—boom and bust on the Colorado Plateau: New York, W.W. Norton & Company, 310 p.

Ritter, S.M., Barrick, J.E., and Skinner, M.R., 2002, Conodont sequence biostratigraphy of the Hermosa Group (Pennsylvanian) at Honaker Trail, Paradox Basin, Utah: Journal of Paleontology, v. 76, no. 3, p. 495–517.

Ritter, S., Rasmussen, D., and Waltman, J., 2016, Conodont age control on westward shedding of limestone cobbles from the incipient Uncompahgre uplift, Salt Valley anticline, NE Paradox Basin, Utah [abs.]: Geological Society of America Abstracts with Programs, v. 48, no. 7, paper number 114-8, doi: 10.1130/abs/2016AM-286903.

Rueger, B.F., 1996, Palynology and its relationship to climatically induced depositional cycles in the Middle Pennsylvanian (Desmoinesian) Paradox Formation of southeastern Utah: U.S. Geological Survey Bulletin 2000-K, p. K1–K22.

Schaeffer, B., 1967, Late Triassic fishes from the western United States: Bulletin of the American Museum of Natural History, v. 135, no. 6, p. 285–342.

Schoene, B., Guex, J., Bartolini, A., Schaltegger, U., and Blackburn, T.J., 2010, Correlating the end-Triassic mass extinction and flood basalt volcanism at the 100 ka level: Geology, v. 38, p. 387–390.

Schultz-Pittman, R.J., Lockley, M.G., and Gaston, R., 1996, First reports of synapsid tracks from the Wingate and Moenave Formations, Colorado Plateau region: Museum of Northern Arizona Bulletin, v. 60, p. 271–273.

Scott, K.M., 2005, Cohesion, water vapor, and floral topography—significance for the interpretation of the depositional mechanisms of the late Paleozoic Halgaito Formation, Cutler Group, southeastern Utah, *in* Lucas, S.G., and Zeigler, K.E., editors, The nonmarine Permian: New Mexico Museum of Natural History and Science Bulletin 30, p. 296–301.

Scott, K.M., 2013, Carboniferous-Permian boundary in the Halgaito Formation, Cutler Group, Valley of the Gods and surrounding area, southeastern Utah, *in* Lucas, S.G., DiMichele, W.A., Barrick, J.E., Schneider, J.W., and Spielmann, J.A., editors, The Carboniferous-Permian transition: New Mexico Museum of Natural History and Science Bulletin 60, p. 398–407.

Scott, K.M., and Sumida, S., 2004, Permo-Carboniferous vertebrate fossils from the Halgaito Shale, Cutler Group, southeastern Utah [abs.]: Geological Society of America Abstracts with Programs, v. 36, no. 5, p. 230.

Sears, J.D., 1956, Geology of Comb Ridge and vicinity north of San Juan River, San Juan County, Utah: U.S. Geological Survey Bulletin 1021-E, p. 167–207.

Sertich, J.J., and Loewen, M.A., 2010, A new basal sauropodomorph dinosaur from the Lower Jurassic Navajo Sandstone of southern Utah: PLoS ONE, v. 5, no. 3, p. e9789.

Smith, J., and Foster, J., 2004, First report of vertebrate tracks from the Wingate Sandstone (Triassic–Jurassic) of Colorado National Monument, Colorado [abs.]: Journal of Vertebrate Paleontology, v. 24, no. 3, p. 78A.

Smith, J.A., Hunt-Foster, R.K., Gay, R., Conner, C., Miracle, Z., and Foster, J.R., 2016, The novel occurrence of a lintel stone containing vertebrate ichnofossils in a Pueblo III structure in Utah [abs.]: Geological Society of America Abstracts with Programs, v. 48, no. 7, doi:10.1130/abs/2016AM-287099.

Soreghan, G.S., Elmore, R.D., and Lewchuk, M.T., 2002a, Sedimentologic-magnetic record of western Pangean climate in upper Paleozoic loessite (lower Cutler beds, Utah): Geological Society of America Bulletin, v. 114, no. 8, p. 1019–1035.

Soreghan, M.J., Soreghan, G.L., and Hamilton, M.A., 2002b, Paleowinds inferred from detrital-zircon geochronology of upper Paleozoic loessite, western equatorial Pangea: Geology, v. 30, no. 8, p. 695–698.

Spirakis, C.S., 1996, The roles of organic matter in the formation of uranium deposits in sedimentary rocks: Ore Geology Reviews, v. 11, no. 1–3, p. 53–69.

Sprinkel, D.A., Kowallis, B.J., and Jensen, J.A., 2011a, Correlation and age of the Nugget Sandstone and Glen Canyon Group, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 131–149.

Sprinkel, D.A., Doelling, H.H., Kowallis, B.J., Waanders, G., and Kuehne, P.A., 2011b, Early results of a study of Middle Jurassic strata in the Sevier fold and thrust belt, Utah, *in* Sprinkel, D.A., Yonkee, W.A., and Chidsey, T.C., Jr., editors, Sevier thrust belt—northern and central Utah and adjacent areas: Utah Geological Association Publication 40, p. 151–172.

Stahle, D.W., Cook, E.R., Burnette, D.J., Villanueva, J., Cerano, J., Burns, J.N., Griffin, D., Cook, B.I., Acuna, R., Torbenson, M.C.A., Sjezner, P., and Howard, I.M., 2016, The Mexican drought atlas—tree-ring reconstructions of the soil moisture balance during the late pre-Hispanic, colonial, and modern eras: Quaternary Science Reviews, v. 149, p. 34–60.

Stanesco, J.D., and Campbell, J.A., 1989, Eolian and noneolian facies of the Lower Permian Cedar Mesa Sandstone Member of the Cutler Formation, southeastern Utah: U.S. Geological Survey Bulletin 1808-F, p. F1–F13.

Stegner, M.A., 2015, Spatial and temporal variation in mammalian diversity of the Colorado Plateau (USA): Berkeley, University of California, Ph.D. dissertation, 107 p.

Stegner, M.A., 2016, Stasis and change in Holocene small mammal diversity during a period of aridification in southeastern Utah: Holocene, v. 27, no. 7, p. 1005–1019.

Stegner, M.A., and Stidham, T.A., 2018, New and extralimital tetrapods from middle-late Holocene packrat middens on public lands in the Bears Ears region of southeastern Utah, USA [abs.]: Journal of Vertebrate Paleontology Programs and Abstracts, p. 221.

Steen, C.A., Dix, G.P., Jr., Hazen, Jr., S.W., and McLellan, R.R., 1953, Uranium-mining operations of the Utex Exploration Company in the Big Indian District, San Juan County, Utah: U.S. Bureau of Mines Information Circular 7669, 13 p.

Steiner, M., and Tanner, L.H., 2014, Magnetostratigraphy and paleopoles of the Kayenta Formation and the Tenney Canyon Tongue: Volumina Jurassica, v. 12, p. 31–38.

Stewart, J.H., 1956, Triassic strata of southeastern Utah and southwestern Colorado, *in* Peterson, J.A., editor, Geology and economic deposits of east central Utah: Intermountain Association of Petroleum Geologists Seventh Annual Field Conference, p. 85–92.

Stewart, J.H., 1957, Proposed nomenclature of part of Upper Triassic strata in southeastern Utah: American Association of Petroleum Geologists Bulletin, v. 41, p. 441–465.

Stewart, J.H., Poole, F.G., Wilson, R.F., Cadigan, R.A., Thordarson, W., and Albee, H.F., 1972a, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 690, p. 1–336.

Stewart, J.H., Poole, F.G., Wilson, R.F., and Cadigan, R.A., 1972b, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 691, p. 1–195.

Stewart, J.H., and Wilson, R.F., 1960, Triassic strata of the Salt anticline region, Utah and Colorado, *in* [editors not listed], Geology of the Paradox basin fold and fault belt: Four Corners Geological Society Guidebook 3, p. 98–106.

Stewart, J.H., Williams, G.A., Albee, H.F., and Raup, O.B., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region: U.S. Geological Survey Bulletin 1046-Q, p. 487–576.

Stocker, M.R., and Butler, R.J., 2013, Phytosauria: Geological Society of London Special Publication, v. 379, p. 91–117.

Stokes, W.L., 1978, Animal tracks in the Navajo-Nugget Sandstone: Contributions to Geology, University of Wyoming, v. 16, p. 103–107.

Stokes, W.L., 1986, Geology of Utah: Utah Museum of Natural History Occasional Paper Number 6, 280 p.

Suarez, C.A., Knobbe, T.K., Crowley, J.L., Kirkland, J.I., and Milner, A.R.C., 2017, A chronostratigraphic assessment of the Moenave Formation, USA using C-isotope chemostratigraphy and detrital zircon geochronology—implications for the terrestrial end Triassic extinction: Earth and Planetary Science Letters, v. 475, p. 83–93.

Sues, H-D., 2012, Early Mesozoic continental tetrapods and faunal changes, *in* Brett-Surman, M.K., Holtz, T.R., and Farlow, J.O., editors, The complete dinosaur: Bloomington, Indiana University Press, p. 989–1002.

Sues, H-D., Clark, J.M., and Jenkins, F.A., Jr., 1994, A review of the Early Jurassic tetrapods from the Glen Canyon Group of the American southwest, *in* Fraser, N.C., and Sues, H-D., editors, In the shadow of the dinosaurs—Early Mesozoic tetrapods: Cambridge, Cambridge University Press, p. 284–294.

Sumida, S.S., Albright, G.M., and Rega, E.A., 1999a, Late Paleozoic fishes of Utah, *in* Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 13–20.

Sumida, S.S., Walliser, J.B., and Lombard, R.E., 1999b, Late Palaeozoic amphibian-grade tetrapods of Utah, *in* Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 21–30.

Sumida, S.S., Lombard, R.E., Berman, D.S., and Henrici, A.C., 1999c, Late Paleozoic amniotes and their near relatives from Utah and northeastern Arizona, with comments on the Permian-Pennsylvanian boundary in Utah and northern Arizona, *in* Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 31–43.

Sumida, S.S., Scott, K.M., and Wideman, N., 2005, New crossopterygian material from the late Paleozoic of southeastern Utah, *in* Lucas, S.G., and Zeigler, K.E., editors, The nonmarine Permian: New Mexico Museum of Natural History and Science Bulletin 30, p. 307–314.

Szurlies, M., 2007, Latest Permian to Middle Triassic cyclo-magnetostratigraphy from the Central European Basin, Germany—implications for the geomagnetic polarity timescale: Earth and Planetary Science Letters, v. 261, p. 602–619.

Tanner, L.H., 2000, Palustrine-lacustrine and alluvial facies of the (Norian) Owl Rock Formation (Chinle Group), Four Corners region, southwestern U.S.A.—implications for Late Triassic paleoclimate: Journal of Sedimentary Research, v. 70, p. 1280–1289.

Tanner, L.H., 2003, Pedogenic features of the Chinle Group, Four Corners region—evidence of Late Triassic aridification, *in* Lucas, S.G., Semken, S., Berglof, W., and Ulmer-Scholle, D.S., editors, Geology of the Zuni Plateau: New Mexico Geological Society Guidebook, v. 54, p. 269–280.

Tanner, L.H., Lucas, S.G., and Chapman, M.G., 2004, Assessing the record and causes of Late Triassic extinctions: Earth-Science Reviews, v. 65, p. 103–139.

Terrell, F.M., 1972, Lateral facies and paleoecology of Permian Elephant Canyon Formation, Grand County, Utah: Brigham Young University Geology Studies, v. 19, pt. 1, p. 3–44.

Tidwell, W.D., 1988, A new upper Pennsylvanian or lower Permian flora from southeastern Utah: Brigham Young University Geology Studies, v. 35, p. 33–56.

Thomson, T.J., and Lovelace, D.M., 2014, Swim track morphotypes and new track localities from the Moenkopi and Red Peak Formations (Lower-Middle Triassic) with preliminary interpretations of aquatic behaviors, *in* Lockley, M.G., and Lucas, S.G., editors, Fossil footprints of western North America: New Mexico Museum of Natural History and Science Bulletin 62, p. 103–128.

Torsvik, T.H., Van der Voo, R., Preeden, U., Niocaill, C.M., Steinberger, B., Doubrovine, P.V., van Hinsbergen, D.J.J., Domeier, M., Gaina, C., Tohver, E., Meert, J.G., McCausland, P.J.A., and Cocks, L.R.M., 2012, Phanerozoic polar wander, palaeogeography and dynamics: Earth-Science Reviews, v. 114, p. 325–368.

Trites, A.F., Jr., Finnell, T.L., and Thaden, R.E., 1956, Uranium deposits in the White Canyon area, San Juan County, Utah: U.S. Geological Survey Professional Paper 300, p. 281–284.

Trujillo, K.C., and Kowallis, B.J., 2015, Recalibrated legacy $^{40}Ar/^{39}Ar$ ages for the Upper Jurassic Morrison Formation, Western Interior, U.S.A: Geology of the Intermountain West, v. 2, p. 1–8.

Trujillo, K.C., Foster, J.R., Hunt-Foster, R.K., and Chamberlain, K.R., 2014, A U/Pb age for the Mygatt-Moore Quarry, Upper Jurassic Morrison Formation, Mesa County, Colorado: Volumina Jurassica, v. 12, p. 107–114.

Trump, D.J., 2017, Proclamation 9681—modifying the Bears Ears National Monument: Federal Register, v. 82, no. 235, p. 58081–58087.

Turner, C.E., and Peterson, F., 1999, Biostratigraphy of dinosaurs in the Upper Jurassic Morrison Formation of the Western Interior, U.S.A., *in* Gillette, D.D., editor, Vertebrate paleontology in Utah: Utah Geological Survey Miscellaneous Publication 99-1, p. 77–114.

Turner, C.E., and Peterson, F., 2004, Reconstruction of the Upper Jurassic Morrison Formation extinct ecosystem—a synthesis: Sedimentary Geology, v. 167, p. 309–355.

Turner, C.E., and Peterson, F., 2010, Jurassic rocks of the Four Corners area—first day road log from Cortez, Colorado, to Bluff, Utah, and return via the Four Corners, *in* Anderson, O.J., Kues, B.S., and Lucas, S.G., editors, Mesozoic geology and paleontology of the Four Corners region: New Mexico Geological Society Guidebook 61, p. 1–34.

Tykoski, R.S., 2005, Vertebrate paleontology in the Arizona Jurassic: Mesa Southwest Museum Bulletin, v. 11, p. 72–93.

Tweet, J.S., Santucci, V.L., and Hunt, A.P., 2012, An inventory of packrat (*Neotoma* spp.) middens in National Park Service area, *in* Hunt, A.P., Milàn, J., Lucas, S.G., and Spielmann, J.A., editors, Vertebrate coprolites: New Mexico Museum of Natural History and Science Bulletin 57, p. 355–368.

United States Court of Appeals, Eighth Circuit, 1997, United States of America, Appellee, v. Peter Larson, Appellant.

United States District Court, District of Utah, Central Division, 2014, United States of America, Plaintiff, v. Jared Ehlers, Defendant.

Uglesich, J., and Hunt-Foster, R., 2016, Respect and protect—inspiring wonder and stewardship at BLM public fossil sites in Utah [abs.]: Geological Society of America Abstracts with Programs, v. 48, no. 7, paper number 236-13, doi: 10.1130/abs/2016AM-287449 .

Vaughn, P.P., 1962, Vertebrates from the Halgaito Tongue of the Cutler Formation, Permian of San Juan County, Utah: Journal of Paleontology, v. 36, no. 3, p. 529–539.

Vaughn, P.P., 1964, Vertebrates from the Organ Rock Shale of the Cutler Group, Permian of Monument Valley and vicinity, Utah and Arizona: Journal of Paleontology, v. 38, no. 3, p. 567–583.

Vaughn, P.P., 1966a, *Seymouria* from the Lower Permian of southeastern Utah, and possible sexual dimorphism in that genus: Journal of Paleontology, v. 40, no. 3, p. 603–612.

Vaughn, P.P., 1966b, Comparison of the Early Permian vertebrate faunas of the Four Corners region and north-central Texas: Los Angeles County Museum of Natural History Contributions in Science, v. 105, p. 1–13.

Vaughn, P.P., 1967, Evidence of ossified vertebrae in actinopterygian fish of Early Permian age, from southeastern Utah: Journal of Paleontology, v. 41, no. 1, p. 151–160.

Vaughn, P.P., 1973, Vertebrates from the Cutler Group of Monument Valley and vicinity, *in* James, H.L., editor, Guidebook of Monument Valley and vicinity, Arizona and Utah: New Mexico Geological Society 24th Field Conference, p. 99–105.

Wakefield, O.J.W., and Mountney, N.P., 2013, Stratigraphic architecture of back-filled incised-valley systems—Pennsylvanian-Permian lower Cutler beds, Utah, USA: Sedimentary Geology, v. 298, p. 1–16.

Weir, G.W., and Puffett, W.P., 1960, Similarities of uranium-vanadium and copper deposits in the Lisbon Valley area, Utah-Colorado, U.S.A: Proceedings of the 21st International Geological Congress, v. 15, p. 133–148.

Welles, S.P., 1967, Arizona's giant amphibians: Pacific Discovery, v. 20, no. 4, p. 10-15.

Welles, S.P., 1969, Collecting Triassic vertebrates in the Plateau province: Journal of the West, v. 8, no. 2, p. 231–246.

Weng, C., and Jackson, S.T., 1999, Late glacial and Holocene vegetation history and paleoclimate of the Kaibab Plateau, Arizona: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 153, p. 179–201.

Wengerd, S.A., 1951, Reef limestones of Hermosa Formation, San Juan Canyon, Utah: American Association of Petroleum Geologists Bulletin, v. 35, no. 5, p. 1038–1051.

Wengerd, S.A., 1955, Biohermal trends in Pennsylvanian strata of San Juan Canyon, Utah, *in* Cooper, J.C., editor, Geology of parts of Paradox, Black Mesa and San Juan Basins: Four Corners Geological Society Guidebook 1, p. 70–77.

Wengerd, S.A., 1958, Pennsylvanian stratigraphy, southwest shelf, Paradox Basin, *in* Sanborn, A.F., editor, Guidebook to the geology of the Paradox Basin: Intermountain Association of Petroleum Geologists Ninth Annual Field Conference, p. 109–134.

Whiteside, J.H., Grogan, D.S., Olsen, P.E., and Kent, D.V., 2011, Climatically driven biogeographic provinces of Late Triassic tropical Pangea: Proceedings of the National Academy of Sciences, v. 108, p. 8972–8977.

Whiteside, J.H., Lindström, S., Irmis, R.B., Glasspool, I.J., Schaller, M.F., Dunlavey, M., Nesbitt, S.J., Smith, N.D., and Turner, A.H., 2015, Extreme ecosystem instability suppressed tropical dinosaur dominance for 30 million years: Proceedings of the National Academy of Sciences, v. 112, p. 7909–7913.

Whiteside, J.H., Olsen, P.E., Eglinton, T., Brookfield, M.E., and Sambrotto, R.N., 2010, Compound-specific carbon isotopes from Earth's largest flood basalt province directly link eruptions to the end-Triassic mass extinction: Proceedings of the National Academy of Sciences, v. 107, p. 6721–6725.

Whiteside, J.H., Olsen, P.E., Kent, D.V., Fowell, S.J., and Et-Touhami, M., 2007, Synchrony between the Central Atlantic Magmatic Province and the Triassic-Jurassic mass-extinction event?: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 244, p. 345–367.

Williams, J.S., 1949, Paleontology of the Leadville, Hermosa, and Rico Formations (p. 17–24), *in* Eckel, E.B., editor, Geology and ore deposits of the La Plata District, Colorado: U.S. Geological Survey Professional Paper 219, 179 p.

Williams, J.W., and Jackson, S.T., 2007, Novel climate, no-analog communities, and ecological surprises: Frontiers in Ecology and the Environment, v. 5, no. 9, p. 475–482.

Witkind, I.J., 1964, Geology of the Abajo Mountains area, San Juan County, Utah: U.S. Geological Survey Professional Paper 453, 110 p.

Witkind, I.J., Thaden, R.E., Malde, H.E., and Johnson, D.H., 1963, Geology and uranium-vanadium deposits of the Monument Valley area, Apache and Navajo Counties, Arizona, with sections on serpentine at Garnet Ridge and mineralogy and paragenesis of the ore deposit at the Monument no. 2 and Cato Sells Mines: U.S. Geological Survey Bulletin 1103, 171 p.