Paleontology of Bears Ears National Monument (Utah, USA): history of exploration, study, and designation

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ABSTRACT

Bears Ears National Monument (BENM) is a new, landscape-scale national monument jointly administered by the Bureau of Land Management and the Forest Service in southeastern Utah 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. Here, we summarize prior paleontological work within the original BENM boundaries in order to provide a complete picture of the paleontological resources, and synthesize the data which were used to support paleontological resource protection. The fossil-bearing units in BENM comprise a nearly continuous depositional record from the Pennsylvanian Period (~340 Ma) through the middle of the Cretaceous Period (~115 Ma). Additional 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 periods 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 period 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 back to the 1870s (from 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 et al. 2016; W. Greyeyes, verbal communication, 2017). An astounding union of archaeology and paleontology, there is evidence in BENM of ancestral puebloans intentionally utilizing fossils in pueblo construction (Smith et al., 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 areas in BENM include deepening our understanding of the evolution of fully terrestrial ecosystems during the icehouse-hothouse transition preserved in the Cutler Group, generating a comprehensive unified stratigraphy and inventory across the 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, M.A., Stegner., personal observations; R. Hunt-Foster, verbal communication, 2017). Despite stronger enforcement and education of paleontological laws over the past several decades (United States vs. Larson, 1997; Public Law 111-11, Title VI, Subtitle D; 16 U.S.C. §§ 470aaa - 470aaa-11), looting of paleontological resources remains a prevalent problem in southeastern Utah, hindering resource preservation and past, present, and future geoscience research. In December 2016, President Barack Obama proclaimed in an executive order 1.35 million acres of southeastern Utah as Bears Ears National Monument (BENM) (Obama, 2016), under the 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)."

History of monument designation

The idea of federally protecting 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), and as awareness of the conservation value of the region increased, so too did scientific data on the fossils of the region increase, further supporting conservation. Heightened federal protection of this overall region has been piecemeal, with BENM the last major unit to be designated. In 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, and the majority of outreach regarding monument designation and conservation was centered on these resources. Two competing proposals both recognized the significance of paleontology within the area; one put forward by Utah's congressional delegation, known as "Utah's Public Lands Initiative" (or PLI) which 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 was a proposal put forward by a coalition of five Native American tribes with historic and prehistoric connections to the region, calling 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 presidential proclamation which incorporated language that explicitly protected paleontological resources and the localities in which those resources are found, or have potential to be found (Obama 2016).

After lengthy public discourse and a formal public comment period, at the recommendation of Secretary of the Interior Zinke, President Trump issued a new proclamation in December 2017, modifying and reducing the boundaries of BENM to include two management units: Indian Creek and Shaash Jáá (Trump 2017) (Figure 1). This boundary change, reducing the effective National Monument area by around 85%, excludes all paleontology resources from the Valley of the Gods, Cedar Mesa, White and Fry Canyons, the northern portion of Indian Creek, and Black Mesa, as well as Beef and Lockhart basins (Trump 2017), which remain largely un-prospected but with notable fossil-bearing potential (see discussion below). This modification is being contested by numerous conservation groups, businesses, non-profit organizations, and professional societies, and the final legal standing of this modification is currently unknown. A Monument Management Plan (MMP) planning process has begun for Indian Creek and Shaash Jáá units, a process that will likely take years to complete and the course of which may be altered by ongoing lawsuits.

Geographical and Geological Setting

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, roughly, Highway 191 to the east, BENM lies in the heart of what is known as Utah's Canyon Country (Figure 1). It is part of the larger Colorado Plateau uplift and has experienced local uplift as well, predominantly anticlines formed by salt tectonics (e.g., Doelling et al. 1988) and mid-Cenozoic laccolith intrusions (i.e., Abajo Mountains, Witkind, 1964). A prominent structural feature of the region is the Monument Upwarp, a broad north-south trending anticlinal fold, 110 miles long and 40-60 wide, which has been altered by smaller-scale anticlines and synclines, expressed most prominently at Comb and Elk ridges (Sears, 1956). Uplift events, millions of years of river downcutting, and erosion have carved the landscape into the stunning, unforgiving lands we see today (e.g., Barnes, 1993; Baars, 2000). In the last two millennia, this region gave rise to Ancestral Puebloan cultures, whose remaining structures, cultural features, and artifacts were one of the driving forces behind the creation of BENM (Obama, 2016).

Erosion in BENM has also exposed generally flat-lying to low-dipping exposures of nearly-continuous sedimentary strata spanning over 150 million years of geologic time, from the Pennsylvanian Paradox Formation to the Lower Cretaceous Burro Canyon Formation (Lewis et al., 2011) (Figure 2). Vertebrate, invertebrate, plant, and trace fossils are found throughout the majority of the geologic formations exposed 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)—which locally includes the Paradox and the Honaker Trail formations (Baker et al., 1933; Wengerd, 1958). For the majority of the Pennsylvanian, much of present-day Utah was close to the paleoequator and covered by a shallow tropical ocean, such that rocks deposited during that time are primarily marine and highly fossiliferous. During the late Pennsylvanian and Permian, uplift of the Ancestral Rocky Mountains was regionally manifested by the rising Uncompahgre highlands along the northeastern margins of the Paradox Basin (Stokes, 1986). Located along the Colorado-Utah border and oriented north-northwest to south-southeast, this uplift was rapid in geologic terms and, as a consequence, erosion rates were extremely high. The Paradox Basin formed immediately to the south and west of the uplift, and filled with eroded sediments of the Uncompahgre uplift, creating the Paradox Formation, which is poorly fossiliferous and comprises limestones and dolomites, sandstones, shales, and weathered gypsum **(**Stokes, 1986; Condon, 1997); it has however, produced important palynomorphs from a borehole in the Indian Creek area of BENM (Rueger, 1996). The overlying Honaker Trail Formation, with cyclically bedded limestone, sandstone, and shale, is known for its diversity of invertebrate fossils (Melton, 1972; Condon, 1997; Lewis et al., 2011). Fossils from the Honaker Trail Formation include multiple species of fusulinaceans, brachiopods, bryozoans, and conodonts, among other marine invertebrates (Williams, 1949; Melton, 1972; Condon, 1997; Ritter et al., 2002). Using conodont faunas in the Hermosa Group exposed along the San Juan River, Ritter et al. (2002) pioneered condont sequence biostratigraphy for regional correlations of Pennsylvanian cycles of the Paradox Basin. Further, establishment of these cycles allowed for successful correlation with Midcontinent cycle counterparts. Based on these fossils, the top of the Honaker Trail Formation in the vicinity of Valley of the Gods and the Glen Canyon Recreation Area has been correlated to the South Bend limestone (Lansing Group) at the top of the Missourian Midcontinental cyclothem sequence.

Overlying the Hermosa Group is the upper Pennsylvanian-lower Permian Cutler Group—sometimes regarded as a formation (Sears, 1956; Wengerd, 1958)—which preserves a relatively continuous record of transitional and non-marine rocks that provide a window into early life on land in western Pangea, and the late Paleozoic icehouse-greenhouse transition (e.g., Montañez et al., 2007; Montañez and Poulsen, 2013). Most early authors subdivided the formation into at least four major subunits: 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) revised the contacts and definitions of these units in the vicinity of Mexican Hat and Valley of the Gods (where the De Chelly Sandstone is absent), and Wengerd (1958) further revised their nomenclature, elevating the Cutler to group status and subsuming the transitional beds of the Pennsylvanian Rico Formation into the Cutler Group as the 'lower Cutler beds'. Further north, along the eastern and northern margins of Canyonlands National Park, these lower Cutler beds strata were initially assigned to both the Rico and Elephant Canyon formations (see Baars, 1962, 1975, 1987; Terrell, 1972; Campbell, 1987; Loope, 1984; Loope et al., 1990; Condon, 1997). In addition to a diverse invertebrate fauna, rocks of the lower Cutler beds (including the Halgaito Formation) record the rise of amniotes (egg-laying vertebrates having internal fertilization, which includes the common ancestor of modern reptiles and mammals and all of its descendants), and 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., Cain and Mountney, 2009, 2011; Jordan and Mountney, 2010, 2012; Mountney and Jagger, 2004; Wakefield and Mountney, 2013). Though paleosols and fossil plants in the lower Cutler beds suggest a cool, dry climate with some seasonal precipitation, the Permian environment became increasingly arid and vegetation sparse (Soreghan et al., 2002a, 2002b; DiMichele et al., 2014). The main dune fields are preserved as the Cedar Mesa Sandstone in BENM (e.g., Condon, 1997; Mountney and Jagger, 2004; Mountney, 2006). Additional erg deposits exist higher in the Cutler Group in the northwestern portions of BENM and Canyonlands National Park, including the White Rim Sandstone, although very little of this unit is present within the monument boundaries. During the earliest Permian, marine incursions from the west covered large portions of present-day Utah, resulting in beach and coastal dune deposits in BENM (Jordan and Mountney, 2010).

Based on 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 U.S. Geological Survey made brief collecting trips in the red beds near the Utah-Arizona border, followed by the University of California, Los Angeles in 1960 and subsequent years. Eventually, Vaughn (1962, 1973) described many fossils from 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 *Platyhystrix*, a possible nectridean, stem amniote diadectomorphs, and the non-mammalian synapsids *Ophiacodon* and *Sphenacodon.* Vertebrate fossils such as these, though rare, are found throughout the non-marine Carboniferous-Permian exposures of BENM, as are well-preserved plant remains (Vaughn, 1962; Berman et al., 1981; Lockley and Madsen, 1993; Sumida et al., 1999a, 1999b, 1999c; Hasiotis and Rasmussen, 2010; DiMichele et al., 2014).

During the 1990s and 2000s, work conducted in the vicinity of Valley of the Gods by California State University, San Bernardino, and Carnegie Museum of Natural History focused on the latest Pennsylvanian vertebrates of the Halgaito Formation, prompting revisions and producing additional records that included dipnoans, the osteolepiform *Lohsania*, limnoscelid diadectomorphs, *Edaphosaurus*, and an araeoscelid reptile (Frede et al., 1993; Sumida et al., 1999a, 1999b, 1999c, 2005; Scott, 2004, 2005, 2013; Huttenlocker et al., 2018). Chondrichthyians, actinopterygians, osteolepiforms (*Lohsania*?), and possible aïstopod (*Phlegethontia*?) fossils have also long been known 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 et al., 1999a, 1999b, 2005). These transitional and marine rocks also preserve abundant marine invertebrates and conodont gnathal elements (A.K.Huttenlocker, in preparation), making these time-transgressive facies of the lower Cutler beds in Arch Canyon our best chance to confidently 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*, suggesting that multiple assemblages may be distributed stratigraphically throughout the Cutler Group of Utah, some likely correlative to portions of the Permian Wichita Group in north-central Texas (Vaughn, 1964, 1966a, 1966b 1967, 1973; Sumida et al., 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, and is largely unproductive in body fossils.

Farther to the north, in the northeastern portion of BENM, rare fossil localities have been reported from the Cutler Group. Vaughn (1967: pg. 153) first reported, but did not describe, "shark teeth, marine invertebrates, and small vertebrae" from the lower Cutler beds of Indian Creek. Later, geological work by Stanesco and Campbell (1989: pg. 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, but did not publish any results; the log is currently on display in the museum's exhibits. Teams from the Smithsonian Institution's National Museum of Natural History subsequently 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 et al., 2014).

Though outside of BENM, 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, "shark teeth", and osteichthyan vertebrae have been described or reported (Vaughn, 1967; Terrell, 1972). Close to the boundary of the Honaker Trail Formation and lower Cutler beds, Tidwell (1988) described a diverse latest Pennsylvanian floral assemblage containing nearly twenty taxa, including leaf and stem impressions of lycopodiopsids, sphenophyllaleans, equisetaleans, marattialean pteridophytes, medullosalean pteridosperms, and cordaitaleans. Although these localities are outside BENM, they nevertheless inform what potential paleontological resources might be present in Lockhart Basin, 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 Permo-Triassic mass extinction. The oldest rocks of the Paradox Formation, though poorly fossiliferous, have produced biohermal dolomitic limestones and a diverse fauna of microfossils important for biostratigraphy (Wengerd, 1955). Most recently, Ritter et al. (2016) reported on 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, as well as the key evolutionary innovations evident in animals and plants during this time. Ongoing field investigations by the University of Southern California (USC), California State University, 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 of 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-Natural History Museum of Utah (UMNH) collaborative fieldwork at latest Carboniferous-Permian localities exposed in northern San Juan County just north of BENM, this work aims to 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 non-marine channel tributary; these records provide critical new data for the latest Carboniferous on the Colorado Plateau (Huttenlocker et al., 2018).

Investigation into the sedimentary environment, flora, and invertebrate fauna by teams from the National Museum of Natural History and Illinois State Geological Survey continues to shed light on the seasonally fluctuating riparian environments, having produced 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 (Chaney et al., 2013; DiMichele et al., 2011; 2014). Additional work on trace fossils led by University of Kansas has resulted in discovery of large-diameter burrows of possible vertebrate origin in the Cedar Mesa Sandstone (Hasiotis and Rasmussen, 2010), on which research is still ongoing. This and other work on the trace fossils is contributing to a more complete understanding of the record of early terrestrial life and environments in the Cutler Group (Dzenowski et al., 2013), and by extension early tetrapod life globally.

In 2009, UMNH began a 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 bones from the overlying lacustrine limestone. This material is currently under study by two of us (A.K. Huttenlocker and R.B. Irmis) and colleagues, but preliminary results indicate the tetrapod assemblage is dominated by the early synapsid *Sphenacodon*, and also includes a new species of the temnospondyl amphibian *Eryops* (Rasmussen et al., 2016). Elsewhere in the area, the USC-UMNH team has discovered plant and vertebrate material from both marine and non-marine horizons in the lower Cutler beds, and are working together on several other important sites elsewhere in northern San Juan County relevant to BENM. This work is in its earliest stages but already a faunal assemblage broadly consistent with other late Paleozoic localities in North America is emerging, though with some significant taxonomic differences.

EARLY-MIDDLE TRIASSIC

Geology and paleontology

During the Triassic Period, southwestern North America was located close to the equator, between the equator and ~15°N (Kent and Irving, 2010; Torsvik et al., 2012). At this time, western Utah comprised the coast and shallow marine shelf of the eastern margin of the Panthalassic Ocean. During the Early and Middle Triassic, central and eastern Utah comprised the coastal and non-marine fluvial siliciclastic deposits of the Moenkopi Formation (McKee, 1954; Stewart et al., 1972b; Blakey, 1974). Outcrops of the Moenkopi Formation are widespread in BENM, including the Indian Creek area, Dark Canyon Wilderness and further 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), making exact correlation to the marine stages of the geologic time scale difficult. Within BENM, in ascending order, the Moenkopi preserves the Hoskininni, Torrey and Moody Canyon members. Besides the coarse-grained Hoskininni Member at the base of the unit, the rest of the Moenkopi Formation in BENM comprises reddish deltaic and fluvial mudstones, siltstones, and fine-grained sandstones that are slope and ledge-forming units (McKee, 1954; Stewart et al., 1972b; Blakey, 1974). In terms of age constraints, further west and north in Utah, the Torrey Member overlies the marine Sinbad Member, which preserves an ammonoid assemblage characterized by *Anasibirites kingianus* (Stewart et al., 1972b; Blakey, 1974; Lucas et al., 2007; Brayard et al., 2013), suggesting a latest Smithian (middle Olenekian) age (e.g., Balini et al., 2010; Ogg, 2012). Thus, these data imply that the bulk of the Moenkopi Formation (i.e., Torrey and Moody Canyon members) are Spathian (middle-upper Olenekian) in age or later (i.e., Middle Triassic).

Published reports of fossils from the Moenkopi Formation of BENM are rare. McKee (1954) noted “plant fragments” and “good fish remains” from the upper Moenkopi Formation (~130 feet below the top of the unit) near Bears Ears proper; but did not figure or describe any specimens. Stewart et al. (1972b: pg. 68) briefly described actinopterygian scales, vertebrae and teeth from the upper Moenkopi Formation (25 feet below the top of the unit) of Fry Canyon, but again did not figure the specimens or mention repository/specimen number information. Nearby in White Canyon, just outside of the western boundary of BENM, McKee (1954: fig. 9) noted a bone-bearing conglomerate just above the base of the formation, but again provided no other details. He also mentioned “amphibian bones” from Bears Ears (~50 feet below fish-bearing unit mentioned above), and “vertebrate remains” from the Indian Creek area (McKee, 1954: pg. 69). Finally, McKee (1954: pg. 71) noted reptile tracks in his measured sections from Bears Ears and the Indian Creek area, but again 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 of 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 team discovered and excavated the complete skull and lower jaws of a capitosaurian temnospondyl amphibian in the upper Moenkopi Formation. Though he never described it, Welles (1967, 1969) twice mentioned and once figured (Welles 1967: pg. 14) the specimen, noting its striking similarity to *Parotosuchus helgolandicus* (Welles 1967: pg 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: pg. 6) again mentioned the specimen and stated it was from the Torrey Member without further explanation. Despite a lack of detailed description, formal taxonomic assignment, or stratigraphic data, Lucas and Schoch (2002: pg 101) stated that the specimen was assignable to *Parotosuchus helgolandicus* (without citing any supporting characters) and repeated Morales' statement that it was from the Torrey Member (they also incorrectly described the specimen as being found near Hite). These authors then used the specimen to correlate the the Moenkopi Formation with the Buntsandstein of Germany.

Ongoing work

Work on new Moenkopi Formation track sites (discovered in the 2016 and 2017 field seasons by R.J. Gay) 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. Additionally, one of us (R.B. Irmis) has recently relocated the site of Welles' *Parotosuchus*-like temnospondyl in the Indian Creek area, and is working on describing the specimen and placing it in a more precise geologic context. As the Moenkopi Formation in BENM has been poorly surveyed historically, these discoveries suggest that the unit may contain significant fossil localities in areas that remain unsurveyed.

LATE TRIASSIC

Geology

During the Late Triassic, Pangaea began to drift northward (Kent and Tauxe, 2005; Kent and Irving, 2010); as a result, what is now the southwestern US transitioned from semi-humid to semi-arid conditions (Kent and Tauxe, 2005; Whiteside et al., 2011, 2015). No strata are preserved in this area that document the late Middle Triassic and early Late Triassic, but base level change near the end of the Carnian (~228 Ma) (Atchley et al., 2013) initiated deposition of the fluvially-dominated sediments of the Chinle Formation (e.g., Blakey and Gubitosa, 1983; Dubiel, 1994; Riggs et al., 1996). As the climate of Utah became progressively more arid toward the end of the Triassic Period, the northwest-flowing rivers and floodplains of the Chinle Formation became increasingly better drained (e.g., Dubiel and Hasiotis, 2011; Martz et al., 2014). Ultimately, during the latest Triassic, fluvial deposition became ephemeral and sand dunes gradually encroached upon the eastern half of the state (Martz et al., 2014; Irmis et al., 2015; Britt et al., 2016). By the beginning of the Jurassic, dune fields formed across large portions of the Colorado Plateau, which are preserved as the overlying Wingate Sandstone (Stokes, 1986; Peterson, 1988, 1994; Blakey, 1994).

No other geologic formation in BENM has attracted more paleontological research attention than the Upper Triassic Chinle Formation (e.g., Parrish and Good, 1987; Parrish, 1999; Fraser et al., 2005; Gay and St. Aude, 2015, Martz et al., 2014, 2017; Figure 3). The lithostratigraphy of the Chinle Formation is complex, with frequent lateral facies changes. Within the southern BENM area, the Chinle Formation can be divided into six members, from oldest to youngest: Shinarump, Monitor Butte, Moss Black, Petrified Forest, Owl Rock, and Church Rock members (Stewart, 1957; Stewart et al., 1972a; Blakey and Gubitosa, 1983; Dubiel, 1994; Lewis et al., 2011). In the south-central and southeastern portions of BENM, near Bears Ears proper and Comb Ridge, the Monitor Butte and Moss Back members interfinger (Stewart et al., 1972a; Blakey and Gubitosa, 1983; Dubiel, 1994), making them difficult to differentiate (Lewis et al., 2011); in these areas, for stratigraphic convenience we refer to this portion of the formation as the Monitor Butte Member, following Gay and St. Aude (2015). To the north, in the Abajo Mountains and Indian Creek areas, the lower portion of the Chinle Formation is absent, and the base of the unit is equivalent to the Petrified Forest Member elsewhere (Blakey and Gubitosa, 1983; Martz et al., 2014, 2017). In these areas, the recognized subdivisions comprise from oldest to youngest: Kane Springs beds, Owl Rock Member, and Church Rock Member (Witkind, 1964; Blakey and Gubitosa, 1983, 1984; Martz et al., 2014, 2017).

The Shinarump Member comprises paleovalleys that were incised into the underlying Moenkopi Formation; this unit is dominated by coarse-grained braided stream deposits comprising large river systems flowing to the northwest (Blakey and Gubitosa, 1983, 1984; Dubiel, 1983a, 1987, 1994). The interfingering and overlying poorly-drained floodplain sediments of the Monitor Butte Member preserve marsh, pond, and small stream environments with a fluctuating water table (Blakey and Gubitosa, 1983; Dubiel, 1983a, 1987, 1994; Dubiel and Hasiotis, 2011). Laterally, they grade into and are overlain by the 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, 1983a, 1987, 1994). In southern BENM, the Moss Back is overlain by the well-drained paleosols and meandering stream deposits of the Petrified Forest Member, preserving the increasingly arid and seasonal conditions during the Norian (Blakey and Gubitosa, 1983; Dubiel, 1987, 1994; Dubiel and Hasiotis, 2011; Martz et al., 2017). In northern BENM and vicinity, the Kane Springs beds are at least partly correlative to the Petrified Forest Member and are the lowest Chinle unit in this area (Blakey and Gubitosa, 1983, 1984; Martz et al., 2014, 2017); these strata comprise a complex mix of poorly drained floodplain and meandering stream deposits that sometimes incise as paleovalleys into the underlying Moenkopi Formation (Blakey, 1978; Blakey and Gubitosa, 1983, 1984; Martz et al., 2014; Hartley and Evenstar, 2018). The Owl Rock Member overlies these two units throughout BENM, and also comprises well-drained overbank and minor channel deposits (Blakey and Gubitosa, 1983; Dubiel, 1994; Dubiel and Hasiotis, 2011); crayfish burrows extending from channel and levee facies into underlying finer-grained paleosols are common (Hasiotis and Mitchell, 1989, 1993; Hasiotis et al., 1993; Hasiotis, 1995). Inferences of widespread lacustine conditions in this unit are largely misinterpretations of carbonate-rich pedogenic horizons and coarser-grained layers with both diagenetic carbonate cement and intraformational clasts comprised of carbonate nodules (Tanner, 2000, 2003). The uppermost unit of the Chinle Formation in BENM is the Church Rock Member, which also is dominated by well-drained overbank deposits and flashy, ephemeral channel facies indicative of a highlys seasonal environment (Blakey and Gubitosa, 1983; Dubiel, 1987, 1994; Martz et al., 2014). Locally, at the boundary between the top of the Church Rock Member and the overlying Wingate Sandstone, there are fluvial sandstones and conglomerates that Martz et al. (2014) termed the Big Indian Rock beds. These indicate that the Chinle-Wingate transition was complex, and does not necessarily correlate with the onset of eolian deposition. As in northeastern Utah (cf. Irmis et al., 2015), the fossils in these beds indicate that the base of the Wingate Sandstone is still Triassic in age (Martz et al., 2014).

History of geological and paleontological exploration

The earliest publication on 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 et al., 2014; McCormick and Parker, 2017; authors personal observations). Thesese semi-aquatic, archosauriform reptiles superficially resemble modern crocodylians, and 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 generally focused on mineral and oil exploration along the San Juan River (e.g., Baker, 1933, 1936; Wengerd, 1952). As part of this work, a USGS geological field party collected fragmentary phytosaur bones from Moab in 1926 (Camp, 1930: pg. 12; Baker, 1933: pg. 41). Charles Camp of the University of California, Berkeley conducted 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). They collected some fragmentary phytosaur material as well as other bone fragments, which are briefly referenced in Camp's monograph on phytosaurs (Camp, 1930: pg. 13).

In the 1950s, exploration in the Chinle Formation shifted away from fossils and toward another resource: uranium. The post-World War II boom resulted in mining claims throughout southeastern Utah, and 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-1960s, the Atomic Energy Commission funded a large-scale study of non-marine Triassic lithostratigraphy by a team from the U.S. Geological Survey, resulting in two comprehensive monographs (Stewart et al., 1972a,b). Not only did this work provide fundamental insights into the stratigraphy and sedimentology of the Chinle Formation (Stewart, 1956, 1957; Stewart and Wilson, 1960; Stewart et al., 1959, 1972a), but some paleontological resources were discovered during the course of geological fieldwork. These include a number of sites from BENM and surrounding areas: molluscs from Fry Canyon, White Canyon, the Clay Hills, and Lisbon Valley (Stewart et al., 1972a: pgs. 78-79); crustaceans from White Canyon and Lisbon Valley (Stewart et al., 1972a: pgs. 79); temnospondyl amphibians from Fry Canyon (Stewart et al., 1972a: pg. 80); and phytosaurs from White Canyon and Deer Flat (Stewart et al., 1972a: pg. 82). They also reported a diversity of fossil leaf localities from the formation, 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 et al., 1972a: pg. 85-86). Many of these specimens were subsequently described in more detail by Ash (1975a,b, 1977, 2001; Ash et al., 1982; Ash and Litwin, 1996). Mullens (1960: pg. 287-288) mentioned gastropods, teeth, and bone fragments from the Clay Hills area, and O'Sullivan (1965: pg. 62) also reported fragmentary phytosaur remains from Comb Ridge. Just east of BENM in the Lisbon Valley area, geologists conducting uranium-related fieldwork (Isachsen, 1954; Isachsen and Evensen, 1956; Isachsen et al., 1955; Weir and Puffett, 1960) discovered several sites in the Church Rock Member (see Martz et al., 2014) preserving 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, as the Chinle Formation often forms steep, inaccessible badlands within BENM. Uranium readily replaces calcium in bone (Neuman et al., 1949) and often precipitates in association with organic material (Spirakis, 1996), and in areas with high concentrations of radioactive minerals, radioactive fossilized bone and wood are common (Steen et al., 1953; Gross, 1956; Isachsen and

Evensen, 1956; Trites et al., 1956; Weir and Puffett, 1960; Johnson and Thordarson, 1966; R.G., pers. observ.). Historical archaeological signs of the uranium boom, including mine shafts and assorted machinery, core holes and discarded core, mining haul roads, and abandoned camps can be found across BENM wherever Triassic strata are well-exposed. Moreover, the sites discovered during this time demonstrate that important paleontological resources are often intimately associated with extractive resources (e.g., uranium) in BENM and the surrounding area.

Following the seminal work on Chinle stratigraphy by Stewart et al. (1972a), paleontological reconnaissance of the Chinle Formation across southeastern Utah was performed during the mid-1980's by Michael Parrish, Steven Good, and Russell Dubiel. Prior to field excursions by Parrish and colleagues, fossil occurrences in the Chinle of what is now BENM had been limited and isolated, largely due to the rough terrain and lack of systematic prospecting, and were largely restricted to finds made during the course of geological work (see above). During their surveys, Parrish and colleagues discovered vertebrate fossils in the Shinarump, Monitor Butte, Moss Back, and Petrified Forest members of the Chinle in southeastern Utah (Parrish and Good, 1987; Parrish, 1999), including metoposaurid temnospondyls, phytosaurs, and aetosaurs (Parrish and Good, 1987). The discovery of the phytosaur "*Rutiodon tenuis*" (=*Machaeroprosopus pristinus* - see Long and Murry, 1995) and a partial osteoderm of the aetosaur *Typothorax* caused 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, consistent with lithostratigraphic correlations (e.g., Stewart et al., 1972a; Blakey and Gubitosa, 1983; Martz et al., 2017). Parrish and colleagues also discovered numerous invertebrate fossils, including bivalves, gastropods, ostracods, and conchostracans, reporting the occurrence of the molluscs *Triasamnicola assiminoides*, *Diplodon gregori*, *Antediplodon sp.*, and *Unio sp.* (Parrish and Good, 1987).

The most significant discoveries from the 1980s fieldwork were two separate localities that preserve small vertebrates, both of which were 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 distinct from crocodylomorphs assigned to Archosauriformes. None of the 'crocodylomorph' material are actually assignable to that clade; instead, the osteoderms (Parrish, 1999: fig. 1) and possibly some of the postcrania (Parrish, 1999: fig. 2-3) appear to be referable to the early suchian *Revueltosaurus* (R.B. Irmis., personal observation; cf. Parker et al., 2005; Hunt et al., 2005). Similarly, the indeterminate archosauriform osteoderms are nearly identical to those of the archosauriform *Acaenasuchus* from the Blue Mesa Member of eastern Arizona (R.B. Irmis, personal observation; cf. Long and Murry, 1995: figs. 117-118; Irmis, 2005a: fig. 6d). This region, including Parrish's locality, was included in the original monument proposal (Bears Ears Intertribal Coalition, 2016) but omitted in the final declaration (Obama, 2016). The second locality, in the Petrified Forest Member of the Chinle Formation in White Canyon, produced vertebrae and claws from a possible theropod dinosaur and a fragmentary right mandible from a possible ornithischian dinosaur (Parrish, 1999). These represented the only published occurrence of dinosaur body fossils from the Triassic of Utah for nearly two decades, and as such are potentially highly significant, though recent work has cast doubt on their assignment to Dinosauria (Jenkins et al., 2017). This site and the surrounding region are within the original boundaries of BENM (Obama, 2016), but excluded from the revised boundaries (Trump, 2017).

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

Other paleontological work in the area occurred sporadically throughout the 1980s and 1990s. Litwin (1986; Litwin and Skog, 1991; Litwin et al., 1991) described diverse palynological assemblages from the Shinarump Member of Kigalia Point (north of Bears Ears Buttes), and from the Petrified Forest Member of Copper Point (east of White Canyon). These palynomorphs helped with regional biostratigraphic correlation of the Chinle Formation (Litwin et al., 1991).

Just east of the BENM area, 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 of Lisbon Valley. Dubiel and colleagues (Dubiel et al., 1987, 1988, 1989) described lungfish burrows from the Monitor Butte and Owl Rock members of the Chinle Formation in the White Canyon area, but it was quickly realized by Hasiotis and others (McAllister, 1988; Hasiotis and Mitchell, 1989, 1993; Hasiotis et al., 1993; Hasiotis, 1995) that these were crayfish burrows, and that they were identical to abundant crayfish burrows containing rare crayfish body fossils in the Owl Rock Member of Indian Creek; these ichnofossils provided evidence for a fluctuating water table during the Norian in this area. Finally, Lockley (1986; Lockley and Hunt 1995) briefly described the Shay Canyon tracksite from the same area. This major 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; see Heckert et al., 2010; Lucas and Heckert, 2011), but *Atreipus*-like tridactyl prints are also preserved (Lockley and Hunt 1995; Hunt-Foster et al., 2016).

Ongoing work

Parrish and colleagues were the first researchers to document the potential for significant Chinle sites within BENM. Three decades later, the list of institutions involved in active research in the Chinle Formation in BENM has grown significantly. Fieldwork by the Museums of Western Colorado, the Museum of Moab, 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 are currently systematically prospecting Chinle Formation outcrops in BENM and surrounding areas. In a large collaborative effort that is becoming the new direction in paleontological research, paleontologists from these institutions are working to fill in the gaps in our understanding of the Late Triassic Period (Martz et al., 2014; Gay et al., 2017).

Recent and ongoing work by these teams has generated substantial collections from BENM and the surrounding area, much of which awaits preparation and research. Work in the southern area has discovered a diverse microvertebrate assemblage from the base of the Chinle

Formation at Comb Ridge (Gay et al., 2016). This site has already produced hundreds of specimens from surface collection alone (with screenwashing occurring in 2018), and the taxonomic diversity is greater than any published Upper Triassic microvertebrate sites in Utah, and similar in diversity to other sites of the same age within the United States (293 specimens as of 2017, representing 14 clades). Finally, Gay et al. (2017) report a bonebed in the Chinle Formation of the Red Canyon area, which 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 suggests that the bonebed is a laterally-extensive assemblage unlike anything previously discovered in BENM or elsewhere in the Chinle Formation of Utah. It was also apparent that illegal collections have been made at the site within the past two decades, highlighting the fragility of this extremely significant locality and others like it (Gay et al., 2018).

In the northern portion of BENM, particularly in the Indian Creek area, joint fieldwork from 2013-present by the St. George Dinosaur Discovery Site (SDGS) and Natural History Museum of Utah (UMNH) has discovered over 200 new fossil localities in the Chinle Formation, preserving important records of plants, molluscs, and vertebrates. These sites are found throughout the stratigraphic sequence, with material found in the Kane Springs beds, Owl Rock Member, and Church Rock Member (see Martz et al., 2014: fig. 12, pgs. 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 et al., 2016). To the east, just outside of the BENM area, the same joint team has discovered a similar fossil assemblage in the Kane Springs beds and Church Rock Member in Lisbon Valley, recording 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 et al., 2006, 2011; Gibson, 2013a, 2013b, 2015; Ash et al., 2014; Martz et al., 2014; Hunt-Foster et al., 2016: figs. 6-12, table 1). The fossil records of the Indian Creek area of BENM and further east in Lisbon Valley together comprise the most abundant fossil assemblages from the Chinle Formation of Utah, and one of the richest records from the uppermost part of the formation (i.e., 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 et al., 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, which were extruded on land as the Atlantic margins of North America, South America, Europe, and Africa began to rift apart (e.g., Schoene et al., 2010; Whiteside et al., 2010; Blackburn et al., 2013; Percival et al., 2017). Although the extinction event is relatively well-characterized in marine ecosystems, its severity and timing in non-marine environments is still controversial (e.g., Pálfy et al., 2000; Olsen et al., 2002; Tanner et al., 2004; Whiteside et al., 2007, 2010; Lindström et al., 2017). The main difficult with non-marine records is that their geochronology is poorly constrained (e.g., Mundil et al., 2010; Irmis et al., 2010). In North America, the only exception is the tetrapod footprint record from the Newark Supergroup along the east coast (e.g., Olsen et al., 2002), which is tied to the Newark-Harford Astrochronostratigraphic Time-Scale (Kent et al., 2017) and now verified by high-precision U-Pb ages from the Chinle Formation (Kent et al., 2018).

The uppermost Chinle Formation and Glen Canyon Group on the Colorado Plateau has potential to compliment the Newark record, because it preserves an abundant footprint and body fossil record (e.g., Sues et al., 1994; Irmis, 2005b; Lucas et al., 2005a; Tykoski, 2005; Milner et al., 2012) and contains a much longer post-extinction record (cf. Marsh, 2015; Marsh et al., 2014). However, the main limitation has been the lack of geochronologic constraints, with considerable debate over the stratigraphic placement of the Triassic-Jurassic boundary (e.g., Lucas et al., 2005b, 2006b,c, 2011; Kirkland and Milner, 2006; Lucas & Tanner, 2007; Donohoo-Hurley et al., 2010; Milner et al., 2012; Kirkland et al., 2014; Suarez et al., 2017). Nonetheless, it has become clear that in a number of areas across the Colorado Plateau (Lucas et al., 2006c; Sprinkel et al., 2011a; Martz et al., 2014; Irmis et al., 2015; Britt et al., 2016; Suarez et al., 2017), and specifically in BENM and the surrounding area, the Triassic-Jurassic transition is preserved without significant gaps in deposition (Molina-Garza et al., 2003; Lewis et al., 2011). Thus, the Glen Canyon Group in and around BENM has the potential to provide important insights into the end-Triassic extinction on land, the subsequent ecological recovery of non-marine ecosystems, and the final stages of the rise of dinosaurs (e.g., Brusatte et al., 2010; Langer et al., 2010; Irmis, 2011).

Geology and paleontology

In the BENM area, 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 et al., 1963; Witkind, 1964; O'Sullivan and MacLachlan, 1975; Martz et al., 2014, 2017). Although predominantly an eolian sandstone, the base of this unit locally preserves fluvially-deposited sands (e.g., Martz et al., 2014). Thus, unit represents the onset of the Early Jurassic continental erg (e.g., Blakey, 1994; Blakey et al., 1988; Peterson, 1988, 1994; Sprinkel et al., 2011a; Irmis et al., 2015; Britt et al., 2016), a massive and sustained desertification event across western North American during this time, driven in part by the breakup of Pangea and the northward drift of the continent (Kent and Irving, 2010). Paleontologic (Lockley et al., 2004; Lucas et al., 2006c; Martz et al., 2014; Hunt-Foster et al., 2016), geochronologic (Molina-Garza et al., 2003), and lithostratigraphically-correlative units (Sprinkel et al., 2011a; Irmis et al., 2015; Britt et al., 2016; Suarez et al., 2017) all indicate that the Triassic-Jurassic boundary is preserved well within the Wingate Sandstone.

With the exception of vertebrate body fossils found at the Chinle-Wingate contact in the aforementioned fluvial sandstones (Morales and Ash, 1993; Martz et al., 2014), the Wingate Sandstone has yet to produce diagnostic body fossils. No Wingate sites have been published from within BENM; however, numerous Wingate tracksites have been found just north and west of BENM, as well as to the south in northeastern Arizona (Longwell et al., 1925: pg. 13; Baker 1936: pg. 50; Lockley and Hunt, 1995; Schults-Pittman et al., 1996; Lockley et al., 2004; Smith and Foster, 2004; Lockley and Gierliński, 2006; Lucas et al., 2006c; Hunt-Foster et al., 2016). At these sites, the presence of *Brachychirotherium* and absence of *Eubrontes* in the lower Wingate 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 somewhere in the middle of the formation (Lockley et al., 2004; Lucas et al., 2006c).

Ongoing Work

Current joint SDGS-UMNH fieldwork in the Indian Creek area has discovered a number of important Wingate Sandstone footprint sites in down-dropped blocks covering the slope-forming Chinle Formation. These include tracks of *Brachychirotherium*, *Eubrontes*, and a spectacularly vertically oriented block covered in dozens of tracks of *Evazoum* and *Grallator* (Hunt-Foster et al., 2016: pgs. 88-89, figs. 16f, 17). Although not in stratigraphic position, these records indicate the presence of important footprint assemblages in the Wingate Sandstone in BENM, and are again consistent with the hypothesis that this formation contains a record of the end-Triassic extinction and Triassic-Jurassic boundary.

JURASSIC

Geology and paleontology

Within the Glen Canyon Group, overlying the Wingate Sandstone is the fluvial-dominated Kayenta Formation, which itself is overlain and interfingers with the eolian Navajo Sandstone (Middleton and Blakey, 1983; Herries, 1993; Blakey, 1994; Peterson, 1994). Both units are extensively exposed throughout the BENM area, but are often difficult to access 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 et al., 2010; Suarez et al., 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 et al., 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 et al., 2002; Ogg and Hinnov, 2012).

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

The only age constraints for the Navajo Sandstone are those from the aforementioned conformably-underlying units and the unconformably-overlying Middle Jurassic (Aalenian) Temple Cap Formation (Kowallis et al., 2001; Sprinkel et al., 2011b; Doelling et al., 2013). These constraints broadly suggest a Toarcian age for the unit. The most remarkable discovery from the Navajo Sandstone in BENM is the type and only known specimen of the early sauropodomorph dinosaur *Seitaad ruessi* (Sertich and Loewen, 2011) from Comb Ridge. This is the geologically oldest dinosaur identified to the species level described from Utah, and comprises an articulated postcranial skeleton missing the neck and tail. This is one of just a handful of vertebrate body fossil specimens from the entire formation, which elsewhere preserves 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 both abundant and diverse; Rainforth (1997) documented sites from the BENM area near Comb Ridge, Indian Creek, and Kane Springs Canyon, including footprints of *Grallator*, *Eubrontes*, *Anomoepus*, and *Otozoum*.

Outside of the BENM area in southern Utah, Navajo Sandstone invertebrate and vertebrate traces are numerous, including an important and extensive trackway locality at the Kayenta-Navajo boundary in Lisbon Valley (Stokes, 1978; Lockley et al., 1992; Lockley and Hunt, 1995; Rainforth, 1997; Loope and Rowe, 2003; Loope, 2006a; Ekdale et al., 2007). Particularly notable are spring-fed interdunal pond deposits that are associated with fossils of large conifer logs, leaves, ostracods, invertebrate and vertebrate burrows, and dinosaur tracks (Eisenberg, 2003; Loope et al., 2004; Lucas et al., 2006a; Parrish and Falcon-Lang, 2007; Riese et al., 2011; Parrish et al., 2017).

The Middle-Upper Jurassic San Rafael Group unconformably overlies the Glen Canyon Group. In the BENM area, Middle Jurassic and younger strata are only exposed on the eastern and western margins, because post-Lower Jurassic units have been removed by erosion throughout the Monument Upwarp (e.g., Hintze et al., 2000; Doelling et al., 2013: fig. 1). Here, the lowest unit in the San Rafael Group is the Carmel Formation, which is dated radioisotopically and biostratigraphically to the Bajocian through lower Callovian (Sprinkel et al., 2011b; Doelling et al., 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 (e.g., Imlay, 1948, 1964; Lowrey, 1976; Bagshaw, 1977) and dinosaur footprints have been reported from coastal deposits in northeastern Utah (Lockley and Hunt, 1995; Lockley et al., 1998a). The Carmel Formation is conformably overlain by the eolian Entrada Sandstone, which is thought to be late Callovian in age (Sprinkel et al., 2011b; Doelling et al., 2013). No fossils have been reported from the Entrada in BENM, but the surrounding area to the west and north includes invertebrate burrows (Ekdale and Picard, 1985), vertebrate burrows (Loope, 2006b, 2008), and theropod and sauropod dinosaur footprints (Foster et al., 2000). Along the eastern margin of GSENM the San Rafael Group includes the Moab Tongue; this used to be considered part of the Entrada Formation, but is now considered part of the Curtis Formation (Doelling, 2002, 2004; O'Sullivan 2010a). The Curtis Formation is thought to be latest Callovian or earliest Oxfordian in age, because the base of the overlying Morrison Formation is middle-late Oxfordian (Trujillo and Kowallis, 2015; cf. Pellenard et al., 2013; Muttoni et al., 2018), and this is consistent with U-Pb detrital zircon ages from the Curtis (Dickinson and Gehrels, 2009).

Though no fossils have been reported from it in BENM, just to the north, the top of the Moab Tongue contains abundant dinosaur tracks, many of which form a “mega-tracksite”, as well as tracks of the controversial archosaur ichnotaxon *Pteraichnus* (Lockley, 1991; Lockley and Hunt, 1995; Lockley and Gierliński, 2014b). The Oxfordian Summerville Formation directly overlies the Moab Tongue in eastern BENM, and its age is also mainly constrained by the fact it underlies the Morrison Formation. The Butler Wash area of BENM preserves an important theropod dinosaur tracksite in the upper Summerville Formation, and similar footprints plus *Pteraichnus* are found in an equivalent stratigraphic interval west of BENM, north of Ticaboo (Lockley et al., 1996; Lockley and Mickelson, 1997).

Towards the close of the Jurassic Period, a broad network of river and stream channels, floodplains, and ponds developed across the Western Interior. These strata, the Upper Jurassic Morrison Formation, comprise variegated mudstones, siltstones and sandstones and preserve one of the richest sequences of dinosaur-bearing fossil assemblages in the North America (e.g., Turner and Peterson, 1999, 2004; Chure et al., 2006; Foster, 2003, 2007). In the BENM area, the Morrison is best exposed along the eastern portion of the monument, from the Bluff area to north of Monticello. In the southern portion of these outcrops, the formation comprises in ascending stratigraphic order the Bluff Sandstone, Recapture and Salt Wash members, and Brushy Basin Member; in the north, the Tidwell, Salt Wash, and Brushy Basin members crop out (Peterson, 1994; Turner and Peterson, 2004, 2010; O’Sullivan, 2010b). The lowermost portions of the formation (i.e., the Tidwwell Member) have been radioisotopically dated to ~157 Ma, during the middle-late Oxfordian, and the top of the formation dates to ~150 Ma, close to the Kimmeridgian-Tithonian boundary (Kowallis et al., 1998, 2007; Trujillo et al., 2014; Trujillo and Kowallis, 2015; Pellenard et al., 2013; Muttoni et al., 2018).

The vast majority of fossils from the Morrison Formation are found in the Salt Wash and Brushy Basin members (e.g., Turner and Peterson, 1999; Foster, 2003). One exception is just east of the Indian Creek area of BENM, where the type and only known specimen of the enigmatic sauropod dinosaur *Dystrophaeus viaemalae* was discovered in 1859 in the Tidwell Member (Gillette, 1996a,b; McIntosh, 1997; Bernier and Chan, 2006); this specimen comprises the geologically oldest known skeletal remains of a eusauropod dinosaur from North America, and the site is currently under renewed excavation by the Museum of Moab and UMNH (e.g., Foster et al., 2016a). Four to five million years later, during Salt Wash and Brushy Basin time, iconic dinosaurs such as *Allosaurus*, *Camarasaurus*, *Brachiosaurus*, *Apatosaurus*, and *Stegosaurus* lived across this 700,000 square mile basin across which Morrison sediments were deposited, leaving behind footprints and dozens of multispecies bone beds (Turner and Peterson, 1999, 2004; Foster and Lockley, 2006; Foster et al., 2016b). Though important Salt Wash and Brushy Basin sites are numerous in the formation throughout Utah (Turner and Peterson, 1999; Foster, 2003), few have been documented in the immediate BENM area, mostly because of a lack of systematic prospecting. An unpublished fragmentary sauropod specimen (UMNH VP 29894) from just east of BENM in the White Mesa area (UMNH VP Loc. 2391) was collected in 1979 from the Brushy Basin Member as part of a survey project for the White Mesa Uranium Mill. The Blanding Dinosaur Museum also has some Morrison Formation sauropod material in its collection, including a fragmentary pelvis from near Blanding, and a *Camarasaurus* humerus. Sites nearby BENM's northern boundary document the presence of 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 et al., 2018). Tetrapod footprints are also well-represented in the Salt Wash and Brushy Basin members of the Morrison Formation (e.g., Lockley et al., 1998b; Foster and Lockley, 2006), but only a single site has been published from within BENM; Milàn and Chiappe (2009) described the first North American occurrence of the ?stegosaur footprint ichnotaxon *Deltapodus* from the Brushy Basin Member in between Blanding and Bluff. Despite the rarity of documented sites within BENM, sites just to the south (Lockley et al., 1998c) and east (Foster and Lockley, 2006) of the monument preserve footprints of crocodyliforms, ornithopod dinosaurs, sauropod dinosaurs, and theropod dinosaurs in the Salt Wash Member, including the type localities of *Dinehichnus socialis* (Lockley et al., 1998c) and *Hatcherichnus sanjuanensis* (Foster and Lockley, 1997).

Among Morrison Formation plant localities in and around the monument (Parrish et al., 2004; DeBlieux et al., 2017), perhaps the most important documented Morrison paleontological locality in the BENM area is in the Brushy Basin Member near Montezuma Creek. Here, fine-grained tuffaceous deposits have produced fossils of wood, palynomorphs, leaves, conchostracans, fish, and invertebrate traces (Ash, 1994; Ash and Tidwell, 1998; Litwin et al., 1998; Hasiotis et al., 2004; Parrish et al., 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 has been $^{40}Ar/^{39}Ar$ dated to between 149-152 Ma (Kowallis et al., 1998; Trujillo and Kowallis, 2015), during the late Kimmeridgian-earliest Tithonian (cf. Muttoni et al., 2018). Baker (1933: pg. 52) mentions petrified wood from the Salt Wash Member in the northern BENM area, but did not give specific locality information.

Ongoing Work

The Morrison Formation across Utah has been hard-hit by illegal fossil collection over the last several decades, with several looted sites discovered 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 et al., 2019), outcrops within BENM are only now being extensively surveyed by professional paleontological field crews (DeBlieux et al., 2017). Since late 2016, the Utah Geological Survey has been actively surveying BENM Morrison Formation outcrop; given the richness of the Morrison formation in other areas where it is exposed and the initial results of limited sampling, it is certain that significant paleontological resources are likely to be discovered (DeBlieux et al., 2017). Preliminary survey results demonstrate that ongoing and future explorations within BENM will continue to expand the depth and breadth of our paleontological knowledge of Jurassic biodiversity within the region, especially in little-studied units such as the Recapture Member and Bluff Sandstone. This idea is bolstered by the presence of a significant sauropod-dominated bonebed located just outside the boundaries of BENM, currently being excavated by crews from the Natural History Museum of Los Angeles County (Mocho et al., 2014; Mocho and Chiappe, 2018).

EARLY CRETACEOUS

Although the vast majority of BENM fossils are known from mid-Mesozoic and older rocks, some exposures of Cretaceous terrestrial deposits exist with the monument boundaries. A lateral equivalent of the Lower Cretaceous Cedar Mountain Formation (Kirkland and Madsen, 2007; Kirkland et al., 2016), the Burro Canyon Formation is exposed on the eastern side of BENM, in the vicinity of, and capping the Black Mesa area. Just beyond the monument boundaries, east of Blanding, abundant vertebrate trace fossils are known from the Burro Canyon Formation (Milàn et al., 2015), including footprints of theropods, sauropods, and ornithischians. Survey work of this formation by the Utah Geological Survey and others is in early phases. Baker (1933: pg. 55) mentioned unidentified leaf fossils from the "Dakota (?) sandstone", a unit now assigned to the Naturita Formation (e.g., Kirkland et al., 2016), but did not provide any locality information. Ash and colleagues (1976: pg. 12) described petrified wood specimens of the tree fern *Tempskya* from both the Burro Canyon and Naturita formations around Moab, just north of BENM.

QUATERNARY

Geology and paleontology

Beginning in the latest Cretaceous and throughout the Paleogene, Laramide tectonics uplifted the Colorado Plateau (e.g., Liu and Gurnis, 2010). During the Oligocene, the laccolithic Abajo and La Sal mountains formed and the uplift of these ranges and the Colorado Plateau as a whole, paired with the establishment of the modern Colorado River drainage (e.g., Pederson, 2008) and subsequent glacial-interglacial cycles during the Quaternary, was the primary driver of the erosional process that carved canyon country. The La Sals were glaciated repeatedly during the glacial-interglacial cycles of the Quaternary; the slightly older and lower-latitude Abajos were either not glaciated, or glaciers there were considerably smaller. Each interglacial period induced a sequence of glacial melting, followed by alluviation, and finally erosion (Richmond, 1962; Richmond and Fullerton, 1986; Stokes, 1986; Barnes, 1993; Pierce, 2003).

There are no pre-Quaternary Cenozoic deposits in BENM because of the aforementioned uplift, but Quaternary cave and alcove deposits are abundant across the region. Packrat middens from across the Southwest document past insect, vertebrate, and plant diversity, and because these sites are extremely common in desert environments, networks of middens can be used to understand past life and ecology, including biogeography, species-environment interactions, demographic and population changes, diets of extinct and extant mammals, etc. (Tweet et al. 2012). In BENM, caves and alcoves large enough to accumulate packrat middens for thousands of years are found in eolian strata, including the Pennslyvanian-Permian Cutler Group (primarily White Rim and Cedar Mesa sandstones), Lower Jurassic Navajo Sandstone, and Middle Jurassic Entrada Sandstone. Fossil-bearing Quaternary gravels have been reported in the region, but little research on these has been conducted to date (M.A.S., R.G., pers. observ.).

During the last glacial period of the Pleistocene (before ~14 ka), the Colorado Plateau was considerably cooler and more mesic than it is today. In BENM and surrounding regions, modern plant communities were 700-900 m lower in elevation during the last glacial maximum than they are now (Cole, 1990; Anderson et al., 2000). Climatically, the early Holocene was cooler than today, but more mesic than the Late Glacial Maximum (LGM) because the summer monsoon was strengthened (Weng and Jackson, 1999); this is also when the modern monsoon boundary was established (Betancourt, 1984). This cool, mesic period gave way to an arid and warm mid-Holocene, from about 8.5-6 ka (Weng and Jackson, 1999; Reheis et al., 2005). From ~6-3 ka, cool-wet conditions returned (Betancourt, 1984; Reheis et al., 2005). Fossil pollen from the Abajo Mountains suggests that maize agriculture was present in the vicinity of BENM around 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 set in, as evidenced by greater mobility of eolian sand (Reheis et al., 2005).

In the 1980s and 1990s, crews from Northern Arizona University and the USGS documented cave deposits generated by packrats across the Four Corners region, concentrated on National Park units, and many sites were documented in the Needles District of Canyonlands National Park just northeast of BENM (Elias et al., 1992; Tweet et al., 2012). Although these southeastern Utah sites contain small vertebrate skeletal elements, large mammals (e.g. Mead et al., 1987; Mead et al. 1991) and plant macrofossils (e.g., Betancourt, 1984; Cole, 1990; Coats et al. 2008) were the primary focus, and the small vertebrates remain unpublished. Remains of

Oreamnos harringtoni, an extinct mountain goat, were discovered alongside packrat middens in a rockshelter in Natural Bridges National Monument, an NPS unit surrounded by BENM (Mead et al., 1987). Plant macrofossils and dung reveal 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 found locally today, and others that are now extralocal, including hackberry (*Celtis reticulata*), common juniper (*Juniperus communis*), Englemann spruce (*Picea englemanii*), and limber pine (*Pinus flexilis*) (Mead et al., 1987). Two important plant macrofossil localities, specifically Allen Canyon Cave in the southern Abajo Mountains and and Fishmouth Cave at Comb Ridge (Betancourt, 1984; Coats et al., 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*) didn’t appear until the mid-Holocene (Betancourt, 1984; Coats et al., 2008). These sites were historically important for shaping our understanding of high desert plant communities. Additional dendrochronological work in Beef Basin (Pederson et al., 2011), White Canyon, Natural Bridges National Monument (Dean and Bowden, 1994; Stahle, 2016), and near the northernmost extent of Comb Ridge (Dean and Robinson, 1994) indicate aridification of BENM and surrounding areas during the Late Holocene. Paired with extensive archaeological research, dendrochronological research reveals a series of multi-decadal “megadroughts,” beginning around 870-820 ybp, which has been a crucial to understanding why Ancestral Puebloans who lived in southeastern Utah and western Colorado migrated out of the region, an event that concluded around 650 ybp (Grahame and Sisk, 2002; Benson and Berry, 2009).

Ongoing Work

In the last 5 years, work conducted by University of California Museum of Paleontology researchers has concentrated on the vertebrate faunas in mid- and late Holocene packrat middens from BENM (Stegner, 2015; Stegner, 2016; Stegner, unpublished data). Four small cave deposits--two less than 1 km north of BENM in the area called Dry Valley, and two northwest of the Abajo Mountains, within BENM--have been excavated and extensively radiocarbon-dated by one of us (M.A.S.) since 2013. These sites have begun to reveal how small vertebrates responded to environmental change during the period of Holocene climate warming and aridification. In the next several years, 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. Unpublished sites excavated in 2014 and 2015 by Stegner are currently under study, and record the presence of extant species, like *Notiosorex crawfordii,* not found in BENM today. The coracoid of a parakeet-sized parrot recovered from deposits less than 6000 years old at the northeastern edge of BENM is also currently under study. The specimen is from a juvenile or sub-adult, indicating that it must have been nesting in the region. Furthermore, this specimen is too small to belong to any of the geographically closest species (in southern Arizona), and is not a macaw, which were associated with Ancestral Puebloan avian trade (Stegner and Stidham, 2018). Because these deposits are young and the bones are extraordinarily well-preserved (M.A. Stegner, 2016, personal observation), they could be used for ancient DNA studies that would deepen our understanding of Colorado Plateau biogeography.

RESEARCH TRAJECTORIES

Research productivity in BENM has been increasing since the 1990s and on-going work in the region promises a continued increase (Figure 3). This is attributable to both increased attention to the region overall as well as an increase in the number of researchers in the field. Furthermore, formations targeted for uranium exploration are also associated with the highest research productivity (Figure 3). Specifically the Upper Triassic Chinle Formation (30% of total paleontology publications from BENM) , is also the rock unit most heavily prospected and mined for uranium resources. Notably, there was a spike in publications from BENM during the time of the "Uranium Boom" on the Colorado Plateau (1950s-1960s), with the majority of papers published in those decades also focusing on the Chinle Formation (Figure 3), illustrating the importance of access and "eyes on the ground" to finding new localities.

The Lower Triassic Moenkopi Formation and the Upper Jurassic Morrison Formation both have high fossil yield potentials (Bureau of Land Management and Department of Energy, 2015), based on work conducted elsewhere in the region. Both units are widely exposed within BENM, lending themselves to future work. In contrast, study of the rise of the dinosaurs in the

Lower Jurassic is hampered access: Wingate and Navajo sandstones are typically very steep, and the Kayenta Formation--which is known to be fossiliferous elsewhere in the region--is typically thin and difficult to access.

PALEONTOLOGICAL RESOURCE PROTECTION

Fossils in southeastern Utah have have been the target of looting, illegal sale, and private collecting for decades (United States vs. Jared Ehlers, 2014; Gay et al., 2018; R. Hunt-Foster, J. Kirkland, verbal communications; J. Uglesich 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 initiative 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 programming into neighboring schools and community centers, and to instill a sense of stewardship in these communities.

The BENM area, and more broadly the BLM’s Canyon Country District, comprise over 3.6 million acres, with abundant and diverse paleontological resources that are being studied by over a dozen different permitted researchers. As such it is critical that robust staff, financial, and support resources continue to be allocated to manage and protect these paleontological resources, as well as to provide guidance and oversight for the research occuring on these lands. Regardless of land status, these areas preserve important world-class paleontological resources that require protection, preservation, and study. In many cases this means that, where possible, specimens are collected by and curated in a publicly-accessible repository for scientific study and public enjoyment. This requires continued staffing and resources from relevant land management agencies.

CONCLUSIONS

The Bears Ears National Monument region records numerous significant time periods, including major events in the history 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 the 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 during the end of the latest period of glaciation. The fossil resources in BENM are important and unique for a variety reasons. Several taxa are known exclusively from within BENM, or their occurrence within BENM represents a major range extension, including the sauropodomorph *Seitaad ruessi*, the archosauromorph *Crosbysaurus harrisae*, and the phytosaur *Pravusuchus hortus.* Additionally, both the significant Pennsylvanian-Permian and Triassic-Jurassic transitions are preserved within BENM, signifying a potential for significant discoveries yet to come.

Research spanning the geological time scale from rock units across BENM is being conducted by many researchers and institutions, and these ongoing projects will, in many cases, take years to decades to bring to fruition. As survey and excavation work continues in the future, the number of fossil taxa known from BENM will increase, adding to our growing knowledge of Earth's history and the history of life itself. Thus, long-term protection of paleontological resources is vital to advancing our understanding of these segments of Earth's history.

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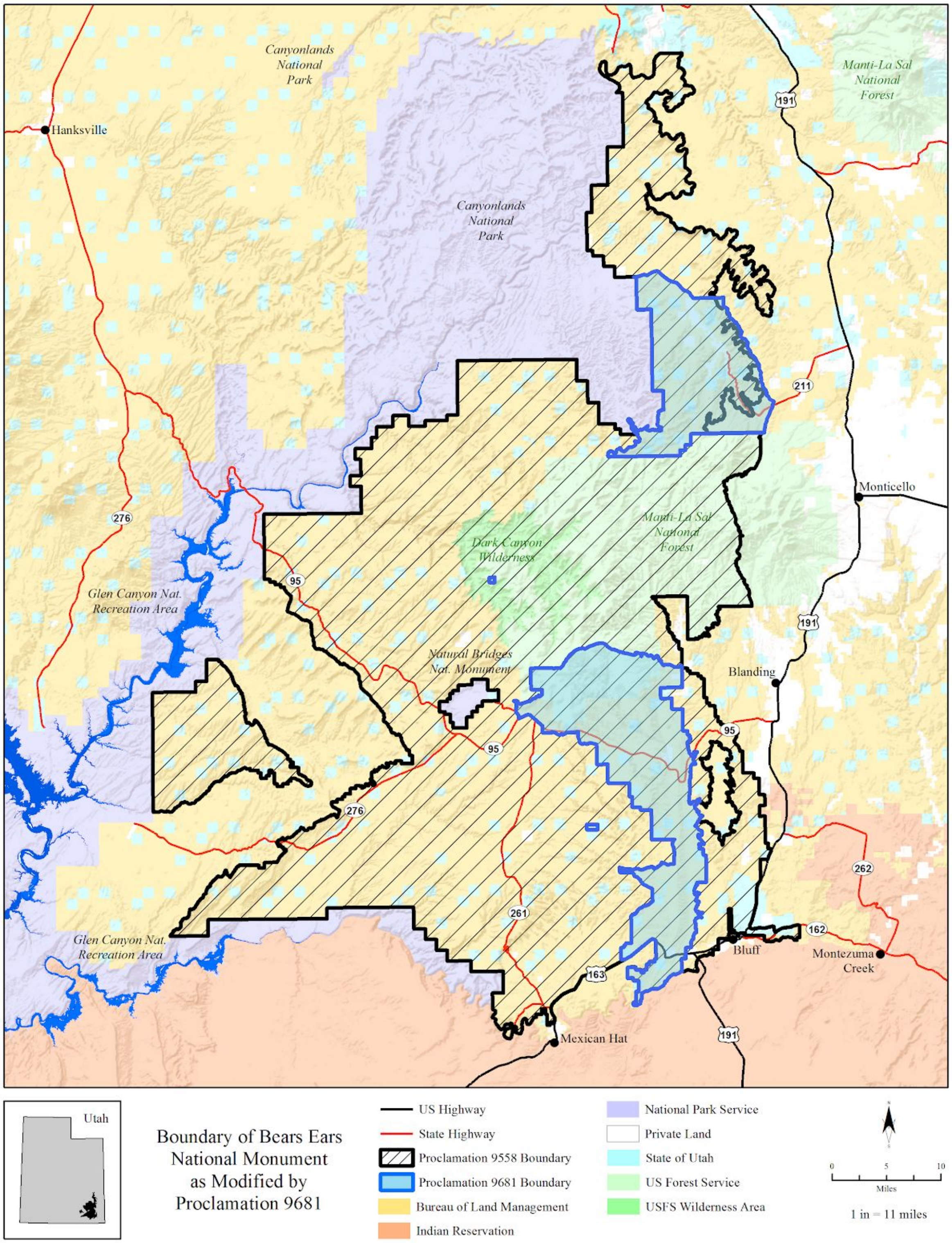
Canyonlands National Park
Manti-La Sal National Forest
191
Hanksville
Canyonlands National Park
211
Monticello
276
Manti-La Sal National Forest
Dark Canyon Wilderness
95
Glen Canyon Nat. Recreation Area
191
Natural Bridges Nat. Monument
Blanding
95
95
276
262
261
162
Glen Canyon Nat. Recreation Area
Bluff
Montezuma Creek
163
191
Mexican Hat
Utah
Boundary of Bears Ears National Monument as Modified by Proclamation 9681
US Highway
State Highway
Proclamation 9558 Boundary
Proclamation 9681 Boundary
Bureau of Land Management
Indian Reservation
National Park Service
Private Land
State of Utah
US Forest Service
USFS Wilderness Area
0 5 10
Miles
1 in = 11 miles

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.

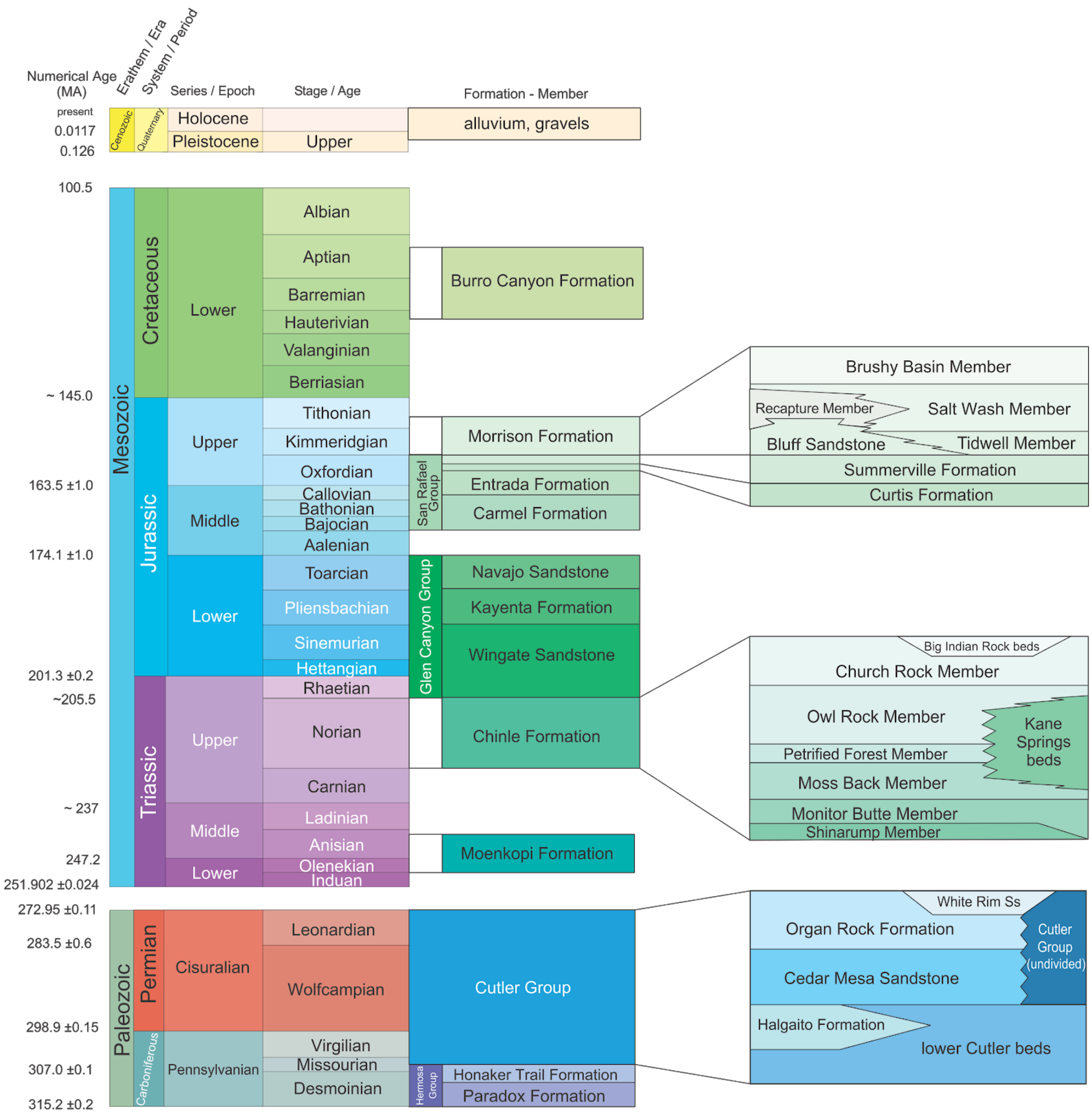

Figure 2. Stratigraphic column of rocks exposed within BENM.

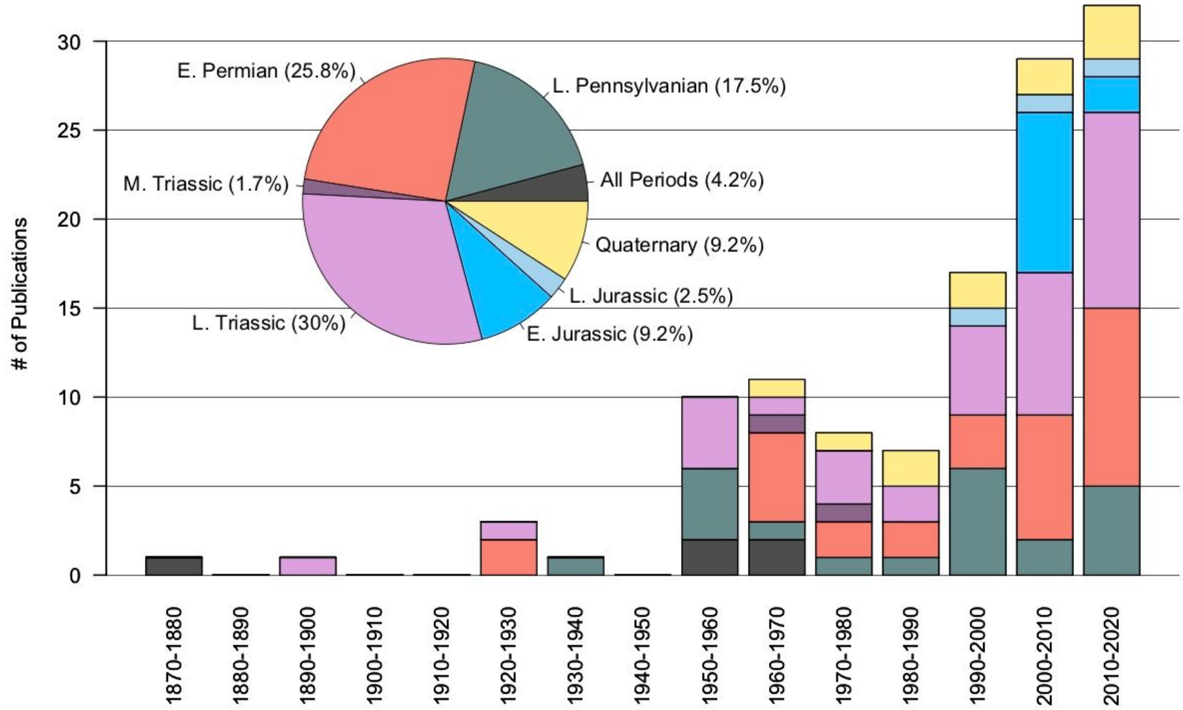

Figure 3: Graph showing both the distribution of publication topics from within BENM as well as a chronological plot showing number of papers produced per decade on data derived partially or wholly from within the initial boundaries of BENM.