Precursor to a Mass Extinction: Investigating Key Fossil Assemblages from the Upper Triassic Chinle Formation of the new Bears Ears National Monument, Utah

by

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RESEARCH NEEDS AND QUESTIONS ADDRESSED

Our multi-institutional team conducted a synergistic study of the paleontology and paleoenvironment of the Chinle Formation in the Indian Creek area (San Juan County), southeastern Utah.

Bears Ears National Monument in southeastern Utah preserves critical fossil assemblages from the beginning of the age of dinosaurs, during the Late Triassic Period (237-201 million years ago), a hothouse world with no polar ice caps and elevated carbon dioxide levels in the atmosphere. These fossils, from the Chinle Formation, not only document dinosaur origins in western North America, but they preserve ecosystems on land in the 10 million years just prior to the end-Triassic mass extinction at 201.5 million years ago, one of the five largest extinction events in Earth history. Thus, these fossils and their geologic context are critical to understanding whether ecosystems on land were already stressed by climate conditions prior to the extinction event. We are also interested in whether these ecosystems show regional differences with those further north and south at the same time, because during the Late Triassic, North America was subject to strong low-latitude climate gradients that may have controlled the faunal composition of these ecosystems.

Our major goal was to systematically prospect, inventory, and salvage paleontological resources from the Upper Triassic Chinle Formation within BENM, focusing on the Indian Creek area, and use these data to better understand Late Triassic ecosystem change.
Paleontological resources within BENM have never been systematically evaluated or inventoried, and the vast majority of Chinle Formation exposures within the Monument have never been prospected. As such, there is little knowledge of the number and quality of paleontological localities, but preliminary work suggests a diverse, extensive, and world-class record of the beginning of the age of dinosaurs. Therefore, we covered as much ground as possible during three weeks of fieldwork to identify as many paleontological sites and their geologic context, and where appropriate, collect significant fossil specimens that are at risk to erosion and weathering. In addition, we collected data to place these fossils in a geologic, paleoenvironmental, and well-constrained temporal context.

METHODOLOGY AND PERSONNEL

Field work was conducted by joint crews from the St. George Dinosaur Discovery Site at Johnson Farm (SGDS) and Natural History Museum of Utah (NHMU) along with selected

volunteers from Utah Friends of Paleontology (UFOP). Field camp was based at the mouth of Indian Creek and crews would either prospect on a daily basis, or assist in the excavation of key fossil sites.

Prospecting methods:
During inventory crews walked in teams of two to three abreast over exposed bedrock, recording in detail via GPS, notebooks, standardized forms, and photographed the location of any significant fossil resource encountered. Collection techniques consist of photo documenting the site and re-acquiring GPS data prior to collection, along with the recording of the rock context and associated fossils. Sites yielding more than one element are mapped using meter grids. Site maps are subsequently digitized for archival purposes.

Excavation methods:
All excavations required some removal of loose overburden using standard hand tools such as picks, shovels, and pry bars. Once down to solid bedrock, hammers, chisels, pry bars, sledge hammers, and portable gas-powered rock saws were used to dig down to levels slightly above the productive fossil layers. In removal of overburden, careful attention is taken to make sure fossils above the targeted stratigraphic level are recorded and/or collected.

Excavation of the fossil-bearing horizons are undertaken in a slower manner to reduce damage of specimens. Fossils are carefully uncovered and stabilized with consolidates (paraloid B-72 dissolved in acetone). The positions of fossils and larger blocks to be removed are mapped in detail using a one-meter grid, corresponding to an accurate GPS point (or datum), and a north-south trending datum line. Wet toilet paper is then applied to surfaces containing fossils and associated rock and then strips of burlap dipped in plaster-of-Paris are used to create protective jackets around fossils and salvaged matrix. Jackets are then numbered and inventoried, then transported to vehicles by hand, backpack, and/or medical backboards.

Geologic sampling methods:
To investigate atmospheric CO_2 via stable isotope analysis, we collected over 10-20 carbonate nodules from levels at 10 cm intervals through the vertical profile of each paleosol (fossil soil), comprising a total of over 60 samples. We also collected a small number of oriented hand samples to make petrographic thin sections to investigate the mineralogy of various facies.

NHMU staff included Dr. Randall Irmis (Curator), Tylor Birthisel (Fossil Preparator & Field Manager), and Carolyn Levitt-Bussian (Collections Manager). SGDS staff included Andrew R.C. Milner (Site Paleontologist and Curator) and Jaleesa Buchwitz (Assistant Curator).

The total field crew comprised: Randall Irmis, Andrew Milner, Tylor Birthisel, Carolyn Levitt-Bussian, Jaleesa Buchwitz, Connor Bennett, Matt Bennett, Aiden Beukema, Paul Breeding, Jimena Diaz, Marcus Donivan, Robert Douglass, Catherine Groseclose, Joshua Heaps, Rena Jansen, Cathleen McKenzie, Alan Novey, Epiphany Pecchia-Bekkum, Eliza Peterson, Robert Rock, David Slauf, Dustin Slauf, Lucas Slauf, John Tripi, Lori Tripi, and Bradford Windley. The people listed above are either staff or volunteers from NHMU, SGDS, and UFOP, or researchers working with Milner and Irmis on specific projects.

PROJECTED RESULTS

1. Prospect for, inventory, collect, and research these diverse new plant, invertebrate, and vertebrate fossil assemblages. Comprehensive prospecting in the large amount of unexplored outcrop within BENM will undoubtedly yield additional major discoveries, which will be crucial to understand the latest Triassic vertebrate faunal dynamics in these regions, and how they compare to elsewhere in North America.

2. Place these fossils in a detailed geologic and stratigraphic framework. To understand any ecosystem and environmental changes that may have occurred through time in the strata, we will place these data into detailed measured stratigraphic sections at meter-scale accuracy. We will collect samples for paleomagnetic analysis and U-Pb zircon radioisotopic dating to develop precise age constraints for these fossils.

3. Reconstruct the paleoenvironmental context of this biota using new data from sedimentology, plant fossils, invertebrate fossils, and carbon stable isotopes. Additionally, ancient soils are ideal for developing an carbon stable isotope record. The changing ratio through time of ^{13}C to ^{12}C tracks changes in greenhouse gasses (i.e., CO_2); thus, it is an important quantitative proxy for paleoenvironmental change.

4. Compare these data to similar records we have developed from contemporaneous strata in Ghost Ranch, New Mexico to test whether latitudinally-influenced environmental differences promoted and maintained biotic differences during the closing days of the Triassic Period, just before one of the five largest mass extinctions in earth history.

ACTUAL RESULTS

Despite a major interruption by the COVID-19 pandemic, thanks to a no-cost extension from CNHA, we were able to spend 23 days conducting fieldwork between 2020-2021, and our team was very successful in achieving our goals. ***We conducted 384 person hours (or 48 person days) of fieldwork in March 2020 over one week, and 1264 person hours of fieldwork (or 158 person days) over two weeks in August-September 2021.*** Major results are as follows:

1. Our 2020-21 work focused on the Upper Triassic Chinle Formation in the Indian Creek area of San Juan County: particularly in Lockhart Basin, along both sides of Lavender Creek, and the areas around North & South Six Shooter Peaks. This work was done under BLM paleontology permit UT07-023S-SW.

We recorded 166 new paleontological sites, collected 47 significant vertebrate specimens, 5 significant invertebrate fossil specimens and 8 significant fossil plant specimens. In 2020, we conducted a single one-week trip during mid-March just before the COVID-19 global pandemic shut down the state of Utah. Our crews prospected the Chinle Formation exposures along the south side of Bridger Jack Mesa (east of Cathedral Butte), west side of Bridger Jack Mesa (tributary canyon of Lavender Canyon), and east side of North Cottonwood Creek. Though our fieldwork was disrupted by rain showers that caused us to lose parts of 2 days of field time, we were still successful in prospecting a significant amount of outcrop. Particularly notable is the discovery of the first record of tanystropheids, a rare small aquatic reptile, from Utah at a microsite found the previous year (UMNH VP Loc 2793). We also

discovered important additional remains of metoposaurid amphibians and aetosaurian reptiles (e.g., UMNH VP Locs 2913 and 2917), both of which are very rare in the Chinle Formation of southern Utah. Finally, we found one significant tracksite in a down-dropped block of the overlying Wingate Sandstone (MD 2020-2).

Although not a primary objective of this grant, during this 2020 trip, we also prospected the lowermost exposures of the Lower Permian Cedar Mesa Sandstone of the Cutler Group, just south of Indian Creek (the stream itself). Despite being limited to two afternoons, we found a number of key new sites, including multiple early synapsid tracksites (UMNH VP Loc 2906, AM 2020-9, and RBI20/3) that are the first report of vertebrate tracks for this unit in the area, and some beautifully-preserved plant fossils (UMNH PB Locs 197 and 198). This complements our ongoing work in the area to better understand the ecosystems preserved in the Cutler Group of northern San Juan and southern Grand counties, which are virtually unknown.

Our 2021 work focused exclusively on the Upper Triassic Chinle Formation in the Indian Creek area of San Juan County. Fieldwork was conducted during a two-week trip at the end of August through Labor Day. During the first week, we prospected Chinle Formation exposures in the Lockhart Basin area; to our knowledge this is the first time this area has been systematically surveyed for paleontological resources. Although less dense than in other areas of Indian Creek, we discovered dozens of new paleontological sites. Highlights include several blocks with well-preserved swim tracks including skin impressions (UMNH VP Loc 3081), a well-preserved *Typothorax* osteoderm (UMNH VP Loc 3084), a well-preserved example of the leaf *Sanmiguelia* (UMNH PB Loc 208), and 'tree-fern' like petrified wood (UMNH PB locs 205 & 206). In the second week, we continued our work surveying outcrops on either side of Bridger Jack Mesa (Lavender Canyon and North Cottonwood Creek). Despite repeated prospecting, these areas continue to be quite fossil-rich in multiple stratigraphic intervals of the Chinle Formation. The most notable sites include a well-preserved nearly complete phytosaur lower jaw (UMNH VP Loc 3102), a nearly complete osteoderm of the rare aetosaur *Rioarribasuchus* (UMNH VP Loc 3100), and a series of slabs containing well-preserved small reptile tracks (UMNH VP Loc 3110).

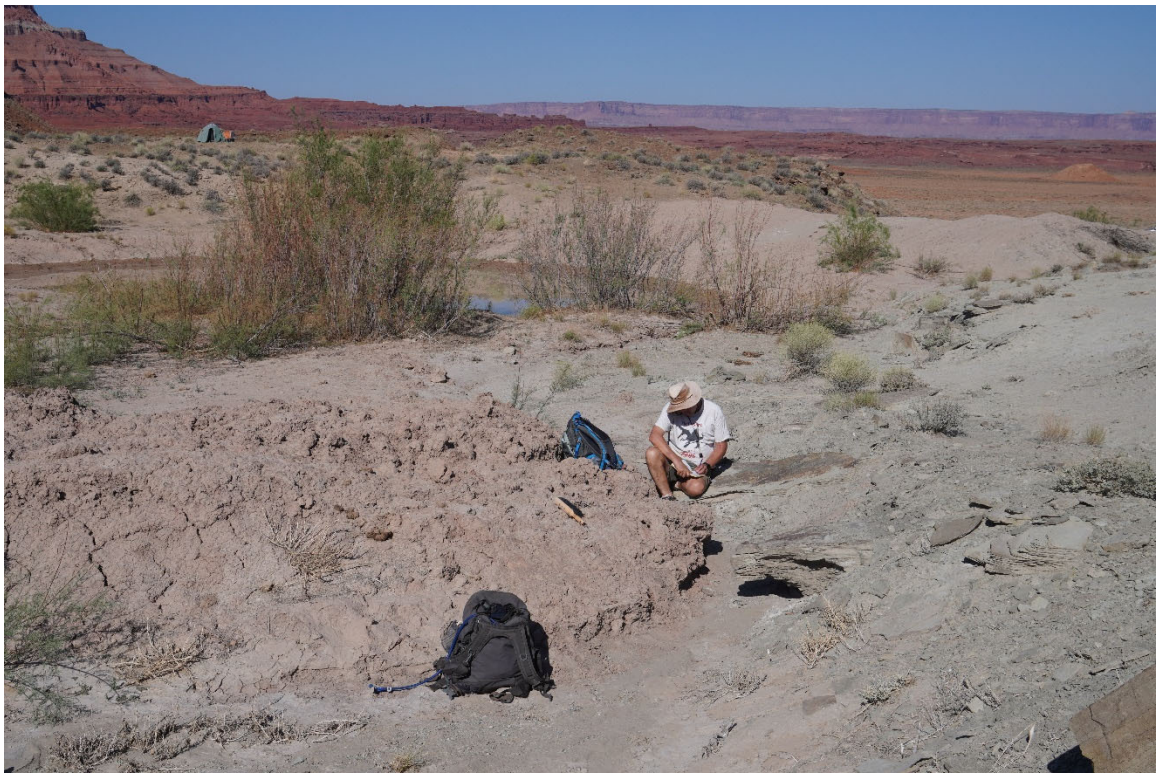
All fossil specimen and locality details were reported to the BLM and Utah Geological Survey at the end of 2020 & 2021 and are on file with these agencies as well as SDGS and NHMU.



Chinle Formation microsite (UMNH VP Loc 2793) where the first tanystropheid reptile fossils in Utah were discovered.



Wingate Sandstone block containing *Grallator* footprints (MD 2020-2).



Andrew R.C. Milner sitting next to blocks containing swim tracks at UMNH VP Loc 3081. View is looking to the west-southwest.



The main sandstone block containing swim tracks at UMNH VP Loc 3081.



Close-up view of an example of skin impressions at UMNH VP Loc 3081.



Phytosaur lower jaw (lower left, above lens cap) at UMNH VP Loc 3102.



View of UMNH VP Loc 3110 looking to the south, with footprint slabs in the foreground.



One of several slabs preserving small reptile footprints from UMNH VP Loc 3110.



View of Cutler Group site AM 2020-9 looking north; tracks discovered in overhang by people.



Example footprint from Cutler Group site AM 2020-9.



Carolyn Levitt-Bussian pointing to location of fossil leaf at UMNH PB Loc 198.



Close-up of fossil leaf from UMNH PB Loc 198 in the Cutler Group.

2. Every newly discovered fossil site was placed in precise stratigraphic context by noting key marker beds in the vicinity. In 2020, we measured a detailed stratigraphic section at tracksite UMNH VP Loc 2828 (discovered in 2019) in preparation for publishing fossil data from it (Milner et al. 2021). Not only do these data help place where in time the fossil site is, they provide key sedimentological data for understanding the depositional environment in which these beautiful tracks are preserved. Although after the conclusion of this grant, in 2022 we measured six detailed stratigraphic sections throughout the Indian Creek area, so as to precisely place in stratigraphy all of the key fossil sites we have discovered in the Chinle Formation so far.

3. Our fieldwork discovered 8 new paleobotanical sites and 5 new invertebrate paleontological sites in Indian Creek. These data will be crucial for reconstructing the paleoenvironment of this area between 220-200 million years ago. We collected over 60 geochemical samples from fossil soil (paleosols) profiles in the Owl Rock Member of the Chinle Formation in Indian Creek for laboratory analysis of their stable isotope geochemistry. Specifically, the $\delta^{13}C_{org}$, $\delta^{13}C_{carb}$, and $\delta^{18}O_{carb}$ values of these samples will allow us to better characterize the paleoenvironment at the time of deposition, thus providing new insights into the climate in which the above organisms lived. In particular, these data will allow us to reconstruct changes in atmospheric carbon dioxide (CO_2) levels during the Late Triassic Period; undergraduate student Aiden Beukema presented preliminary results at the 2022 Rocky Mountain/Cordilleran section Geological Society of America conference (Beukema et al., 2022). These data have relevance beyond study of the Triassic Period; our work demonstrates how sampling can bias the interpretation of these geochemical datasets. We also collected several geologic samples, including representative rock samples to make petrographic thin sections to study their mineralogy. These samples were processed and analyzed in 2021-2022.

4. In 2020, we published a peer-reviewed synthesis of the paleontological resources of Bears Ears National Monument (Gay et al. 2020). This work was also featured on museum social media and on the website (https://nhmu.utah.edu/articles/2023/08/fossils-bears-ears). The next year, we also published a peer-reviewed scientific paper describing the first occurrence of the track type "*Chirotherium*" *lulli* in the Chinle Formation (and all of western North America) (Milner et al. 2021), fossils discovered in 2019 thanks to funding from CNHA.

Although we are still in the midst of the research on collected fossils and geological samples from the 2020-21 field season, these data continue to reinforce preliminary conclusions from previous field seasons. Phytosaur specimens from Indian Creek are new species to science, and different from similar forms found in northern Arizona and northern New Mexico (e.g., Ghost Ranch). In contrast, the aetosaurs (*Typothorax* and *Rioarribasuchus*) and the aquatic reptiles (tanystropheids and *Vancleavea*) appear to be the same species as those found in New Mexico and Arizona. Fish sites from Indian Creek preserve a minimum of 4 new species. Documented tracksites are some of the most abundant and well-preserved in southeastern Utah, and include a track type ("*Chirotherium*" *lulli*) unique to Indian Creek among western US sites. Available geochemical and sedimentological data indicate that the Triassic dry season in southeastern Utah was even more intense than what we have observed in northern New Mexico, consistent with a latitudinal difference in climate. Initial carbon isotope data suggest atmospheric CO_2 concentrations of 3000-4000 ppm; ten times the amount in today's atmosphere (Beukema et al. 2022).

CONCLUSIONS & APPLICATION OF RESEARCH RESULTS TO FUTURE EDUCATIONAL AND INTERPRETIVE EFFORTS

This research has been spectacularly successful. In approximately 1650 person hours of fieldwork (~200 person days), we discovered over 160 new significant paleontological sites, collected over 50 important fossil specimens, and investigated the detailed paleoenvironment and geological context of these ancient organisms from 200-220 million years ago in southeastern Utah. We were able to complete excavation of two major sites discovered during prior work; these fossils are now under preparation at NHMU and SGDS. These data will be critical in understanding how latitudinal differences in climate affected ecosystems on land in the run-up to the end-Triassic mass extinction. Furthermore, they are critical in documenting and preserving the unique paleontological resources in BENM and vicinity.

Fossils discovered during this project are on display to the public at the fossil preparation labs at both SDGS (~55,000 visitors per year) and NHMU (~300,000 visitors per year). Despite disruptions during the pandemic, specimens were also on display at NHMU's Behind the Scenes and DinoFest collections open house events in 2021-2022, which saw over 4000 visitors come through the collections and preparation lab over each weekend. As fossil preparation and research are completed in the near future, these data will be presented in scientific talks and posters at conferences, published in peer-reviewed journals, and featured in new special exhibits at SDGS and NHMU. We also hope to include casts (replicas) of some specimens in the Teaching Toolboxes and the Museum on the Move programs run by NHMU, which reach nearly 40,000 elementary school children across Utah each year.

We discussed results from 2020-2021 fieldwork in the following presentations:

Invited Presentations

- Irmis, R.B. – Darwin Day, University of Utah (2020)
- Irmis, R.B. – Western Division of American Fisheries Society Annual Meeting (2021)
- Irmis, R.B. – Board of Advisors, Natural History Museum of Utah (2021)
- Irmis, R.B. – Department of Geology & Geophysics, University of Utah (2023)
- Irmis, R.B. – DinoFest, Natural History Museum of Los Angeles (2023)
- Irmis, R.B. – Utah Geological Association (2023)

FUTURE RESEARCH NEEDS

Despite the spectacular volume of new fossil sites and specimens from our work in 2015, we have systematically prospected no more than 5% of the Chinle Formation exposures in Bears Ears National Monument. These outcrops clearly have very high potential to produce incredibly important new fossils, but they are at continued risk from erosion, weathering, and human impact. Therefore, a continued long-term project is necessary to systematically document these fossil resources and collect and excavate significant specimens for study and preservation. These discoveries also need to continue to be placed in detailed geologic context, as they are critical for understanding climate change, biogeography, and extinction during the beginning of the age of dinosaurs. Future research support is necessary to understand what these new fossils tell us about such lost ecosystems (e.g., are they new species, how abundant/diverse was each species,

what was their ecology, etc.), and to support museum collections visits to compare them with previous discoveries from other Triassic fossil assemblages.

The discoveries made from the latest Carboniferous-earliest Permian Cutler Group during this and previous CNHA-funded projects (2018 & 2019) directly led to a major National Science Foundation multi-year grant awarded in 2022 (https://www.nsf.gov/awardsearch/showAward?AWD_ID=2219947). In addition to furthering research on the world-class fossils and environments of the Carboniferous-Permian transition (~300 million years ago) preserved in Bears Ears National Monument, this grant provides funding to develop K-12 teaching toolboxes, run teacher professional development workshops, and host community outreach events in underserved areas of San Juan and Grand counties. All of this education and outreach features fossils from Bears Ears NM and adjacent areas.

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