Casper College

Paleontology on Public Lands

25TH ANNUAL TATE CONFERENCE

and 11TH Conference on Fossil Resources

Casper College

125 College Drive • Casper, WY 82601

Sponsored by the Tate Geological Museum at Casper College and the Paleontology on Public Lands Alliance

May 30-June 2, 2019, in Casper, Wyoming
on the Casper College campus

Paleontology on Public Lands

25TH ANNUAL TATE CONFERENCE

and 11TH Conference on Fossil Resources

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Welcome to Casper and the Tate Geological Museum

Welcome to the 25th annual Tate Conference and the Tate Geological Museum. This year we are excited to partner with the Paleontology on Public Lands Alliance. While the museum has hosted a conference almost every year for the last 26 years, when Georgia Knauss proposed combining the two this year, we thought it was a great idea!

We hope this year's theme, "Paleontology on Public Lands," will be instructional as well as educational. In a world where laws and regulations continually change, it is through conferences like these that we can all remain up-to-date and knowledgeable about the resources that we work to protect. Communication is the key to being responsible stewards and in keeping with that theme, this year's speakers will cover fossil collecting, policies, management, education, and current research that affects us here, in the Rocky Mountain West.

THANK YOU

Thank You

This year we are doing the Tate Conference as a joint effort with the Conference on Fossil Resources. We owe a big thank you to all the organizers from that end of the spectrum. They include:

Georgia Knauss
Greg Liggett
Dennis Terry
Scott Foss
Sally Shelton

Eric Scott
Darrin Pagnac
Dale Hanson
Vince Santucci
Bruce Schumacher

Barbara Beasley
A few other BLM folks who have helped along the way:
Con Trumbull
Brent Breithaupt
Cullen Hardy

Casper College for supporting the Tate Geological Museum and the annual Tate Conference.

Sarah Schneider who helped organize all sorts of in-town and on-campus logistics.

Natrona County Roads and Parks for allowing us access and collecting permission to Hell's Half Acre.

Russell Hawley, as usual, for his drawings; including, the logo.

And of course, all the speakers and their superiors who allowed/encouraged them to present here.

Anton Wroblewski for a king donation.

The Fujita Family Student Scholarship

The Fujita Family Student Scholarship helps a Casper College student attend the Tate Conference. Started in 2017 by longtime Tate supporter Lisa Fujita in memory of her husband Rich and daughter Julien. Lisa's husband was a strong supporter of Casper College and wanted to help students whenever possible. One of his wishes was for Lisa to take on this role after his passing from cancer. Lisa got her associate degree in museum studies at Casper College and was employed at the Nicolaysen Art Museum here in Casper. She fondly remembers receiving scholarships as a student to attend museumology conferences, and wants to pass this opportunity along, and do it in honor of her family.

She has chosen to provide seed money to help Casper College geology students and we hope to be able to raise a bit more money to be able to sponsor a student's attendance for many years to come. We thank Lisa and son Sam, for providing this opportunity in memory of Rich and Julien.

Thanks also to anyone who would like to help grow this fund. We need support beyond the initial seed money to keep this fund going. If any conference participants would like to contribute any amount please talk to Museums Director Patti Wood Finkle. We just might pass the hat during the keynote dinner as well.

All events are located in the Sharon J. Nichols Auditorium, Room 160, McMurry Career Studies Center two buildings south of the Tate Geological Museum, unless otherwise noted.

Wednesday, May 29, 2019

9 a.m.-5 p.m.	Early check-in at the Tate Geological Museum

Thursday, May 30, 2019

Field trip; meet at the Tate Geological Museum

7:15-7:45 a.m.	Check-in at the Tate Geological Museum for field trip folks
7:45 a.m.	Load 'em up for field trip
8 a.m.	Leave on field trip to Alcova area
5 p.m.	Return to Tate
6-8 p.m.	Icebreaker at **The Science Zone** with dinner and a cash bar
9 a.m.-5 p.m.	Museum open all day for check-in for nonfield trippers

Friday, May 31, 2019

Sharon J. Nichols Auditorium, McMurry Career Studies Center, Casper College (CS 160)

7:30-8:20 a.m.	Check-in
8:30-8:40 a.m.	Welcome by the Tate Geological Museum Staff and Paleontology on Public Lands Alliance
8:45-9 a.m.	**Jean-Pierre Cavigelli**, Tate Geological Museum *"An Example of a Co-operative Venture; Tate and Bureau of Land Management"*
9:05-9:20 a.m.	**Darrin Pagnac,** South Dakota School of Mines and Technology **Georgia Knauss**, SWCA Environmental Consultants *"Let Us Try: Monitoring and Salvage Paleontology with the U.S. Army Corps of Engineers"*
9:25-9:40 a.m.	**Aubrey Bonde**, Great Basin Institute **Mark Slaughter**, U.S. Bureau of Reclamation **Mark Sappington**, National Park Service *"Bureau of Reclamation Lower Colorado Region is on Board with the Platte River Power Authority"*
9:45-10 a.m.	**Barbara A. Beasley**, USDA Forest Service *"Paleontological Resource Inventory of the Paragon Geophysical Services, Inc. Snowy 3D Seismic Project on the Fall River Ranger District, Buffalo Gap National Grassland, Fall River County, South Dakota"*
10-10:10 a.m.	Coffee break

SCHEDULE

10:10-10:25 a.m.	**Brent H. Breithaupt**, Bureau of Land Management **Neffra A. Matthews**, Bureau of Land Management **Philip A. Gensler**, Bureau of Land Management **Colin R. Dunn**, Bureau of Land Management **Spencer G. Lucas**, New Mexico Museum of Natural History and Science *"Prehistoric Trackways National Monument, New Mexico: Photogrammetric Ichnology of a Permian Trace-Fossil Lagerstätte"*
10:30-10:45 a.m.	**Colin R. Dunn**, Bureau of Land Management *"Methods and Initial Results of In-situ Monitoring Efforts at Prehistoric Trackways National Monument, Southern New Mexico"*
10:50-11:05 a.m.	**Cyrus C. Green**, White Sands National Monument **David Bustos**, White Sands National Monument **Mathew Bennett**, Bournemouth University **Thomas Urban**, Cornell University *"Preservation of Ephemeral Ice Age Mammal Trackways at White Sands National Monument"*
11:10-11:25 a.m.	**John R. Wood**, National Park Service **Vincent L. Santucci**, National Park Service **Andrew R.C. Milner**, St. George Dinosaur Discovery Site at Johnson Farm **Jeff Wolin**, Florissant Fossil Beds National Monument **Vince Rossi**, Smithsonian Institution *"Structure from Motion Photogrammetry Enhances Paleontological Resource Documentation, Research, Preservation, and Education Efforts from National Park Service Areas"*
11:30-11:45 a.m.	**Dennis O. Terry Jr.**, Temple University **Deborah W. Woodcock**, Marsh Institute of Clark University **Herbert W. Meyer**, Florissant Fossil Beds National Monument **Sarah E. Allen**, Penn State-Altoona *"Paleopedology of the Piedra Chamana Fossil Forest, Peru"*
11:50 a.m.-12:05 p.m.	**Herbert W. Meyer**, Florissant Fossil Beds National Monument **Conni J. O'Connor**, Florissant Fossil Beds National Monument **Michael M. Kelly**, Northern Arizona University *"Development of New Geologic Trail Exhibits and an Associated Mobile Application for Multilevel Interpretation of Geology at Florissant Fossil Beds National Monument"*
12:05-2 p.m.	Lunch at the Tate Geological Museum
2:05-2:20 p.m.	**Daniel N. Spivak**, Royal Tyrrell Museum of Palaeontology **Allison R. Vitkus**, Royal Tyrrell Museum of Palaeontology *"Canadian Fossil Legislation and the Alberta Historical Resources Act"*
2:25-2:40 p.m.	**Allison R. Vitkus**, Royal Tyrrell Museum of Palaeontology **Daniel N. Spivak**, Royal Tyrrell Museum of Palaeontology *"Alberta's Listing of Historic Resources: A Resource Management Tool for Identifying Areas of Known or Potential Paleontological Significance"*

2:45-3 p.m.	**Gregory A. Liggett**, Bureau of Land Management *"ArcGIS Online and the Future of Paleontology Data Collection"*
3-3:10 p.m.	Leg-stretching break, with afternoon snacks
3:10-3:25 p.m.	**Scott E. Foss**, Bureau of Land Management **Kathy Hollis**, Smithsonian National Museum of Natural History *"Confidentiality and Open Science: A Best Practice for Sharing Paleontological Locality Information"*
3:30-3:45 p.m.	**Andrew Stanton**, Utah Valley University *"The Good, the Bad and the Ugly – Using Federal Planning Documents as a Measure of Paleontological Resource Management"*
3:50-4:05 p.m.	**Scott E. Foss**, Bureau of Land Management *"A MAP to Manage Paleontology"*
4:10-4:25 p.m.	**Gregory A. Liggett**, Bureau of Land Management **Philip A. Gensler**, Bureau of Land Management *"The Potential Fossil Yield Classification (PFYC), Present Status Within BLM"*
4:25-5:30 p.m.	Unwind break/on your own

At the Lyric, 230 West Yellowstone, downtown Casper

5:30-6 p.m.	Happy hour
6-7 p.m.	Dinner served
7-8:30 p.m.	**Keynote talk** **Andrew Farke**, Raymond M. Alf Museum of Paleontology at The Webb Schools *"What Will You do With Your Moment in Time? Paleontological History, Research, and Education at the Raymond M. Alf Museum of Paleontology"*

Saturday, June 1, 2019

8:30-9:30 a.m.	**Sally Shelton,** South Dakota School of Mines **Helene Gaddie**, Generations Indigenous Ways, Pine Ridge Reservation **Marcia Pablo**, Tribal Coordinator for the Bureau of Land Management *Panel discussion on fossils on Indian reservation lands*
9:35-9:50 a.m.	**Douglas G. Wolfe**, Zuni Dinosaur Institute for Geosciences *"Minding the Neighborhood: Insights from Two Decades of Paleontological Research on Public Lands"*
9:55-10:10 a.m.	**Emmett Evanoff**, University of Northern Colorado *"Locating Fossil Localities in the White River Badlands Using Historic Journals, Sketches, and Photographs of Past Paleontologists"*

10:15-10:30 a.m.	**Dale E. Greenwalt**, National Museum of Natural History *“Characterization of a New Eocene Lagerstätte Along the Wild and Scenic Flathead River”*
10:30-10:40 a.m.	Coffee break
10:40-10:55 a.m.	**Barbara A. Beasley**, USDA Forest Service *“Summary and Lessons Learned Regarding U.S. Forest Service Program Administration and Law Enforcement and Investigations for Paleontological Resources”*
11-11:15 a.m.	**Robin L. Hansen**, Bureau of Land Management **H. Gregory McDonald**, Bureau of Land Management *“Establishing a Baseline of the Elemental Composition of Fossil Bone from the Morrison Formation Using a Portable X-ray Fluorescence Spectrometer (XRF): Possible Use in Paleoforensics”*
11:20-11:35 a.m.	**E.N. Starck**, University of Northern Colorado **Emmett Evanoff**, University of Northern Colorado *“Big Buffalo I: Deterring Degradation of a Scientifically Significant Fossil Locality at Badlands National Park”*
11:40-11:55 a.m.	**Erin E. Eichenberg**, Tule Springs Fossil Beds National Monument *“Tule Springs Fossil Beds National Monument’s Vanishing Treasures: An Historic Preservation Approach to Preserving Historic Fossil Sites”*
11:55 a.m.-1:55 p.m.	Lunch at the Tate Geological Museum
1:55-2:55 p.m.	Poster session at Tate Geological Museum (See poster listing at the end of this schedule)
2:55-3:10 p.m.	**Justin S. Tweet**, National Park Service **Vincent L. Santucci**, National Park Service *“Paleontology of St. Croix National Scenic Riverway, Minnesota/Wisconsin”*
3:15-3:30 p.m.	**John Gallucci**, Temple University **Paul V. Ullmann**, Rowan University **Dennis O. Terry Jr.**, Temple University *“Soft Tissue Preservation in Late Eocene-Early Oligocene Vertebrate Fossils of the White River Group”*
3:35-3:50 p.m.	**Dennis O. Terry Jr.**, Temple University *“A Quick and Dirty Guide for the Application of Paleopedology to Vertebrate Taphonomy”*
3:55-4:10 p.m.	**Eric Scott**, Cogstone Resource Management, Inc. and California State University “Haringtonhippus francisci*, a ‘stilt-legged’ Late Pleistocene Horse from Gypsum Cave, Mojave Desert, Southern Nevada”*
4:15-5:15 p.m.	Federal Agencies Townhall Discussion – open to all
	Evening free

Sunday, June 3, 2018

Field trip; meet at the Tate Geological Museum

8 a.m.	Meet at The Tate for the field trip to Hell's Half Acre and more
8:15 a.m.	Hit the road, Jack
5 p.m.	Return to the Tate

Posters and presenters to be present Saturday after lunch at the Tate

- **Phil Gensler**, Bureau of Land Management
  Gary Morgan, New Mexico Museum of Natural History
  Scott Aby, Muddy Spring Geology
  Garrett R. Williamson, private consultant
  "New Additions to the Miocene Vertebrate Fauna of the Tesuque Formation, Española Basin, New Mexico"
- **Theodore Fremd**, University of Oregon
  Vincent Santucci, National Park Service
  "The Tragedy of the Paleontological Commons"
- **Susan E. Hertfelder**, Tule Springs Fossil Beds National Monument
  Erin Eichenberg, Tule Springs Fossil Beds National Monument
  "*Developing a Fossil Management Program at Tule Springs Fossil Beds National Monument"*
- **Neffra A. Matthews**, Bureau of Land Management
  ReBecca K. Hunt-Foster, Dinosaur National Monument
  Brent H. Breithaupt, Bureau of Land Management
  Martin G. Lockley, University of Colorado-Denver
  "*Ten Years of Ichnological Research and Photogrammetric Documentation at the BLM Mill Canyon Dinosaur Tracksite, Utah"*
- **Laura Vietti**, University of Wyoming Geological Museum
  "Who's the Best? A Cross-State Comparison of Fossil Vertebrate Richness, Temporal Completeness, and Biodiversity in the USA"
- **Joey T. Raum**, Paleo Solutions, Inc.
  Paul C. Murphey, Paleo Solutions, Inc.
  "The Sifter: A New Mechanical Wet and Dry Matrix Sieving Machine, With a Comparison to the Traditional Manual Wet Sieving Method"

FIELD TRIPS

Thursday, May 30, 2019

The May 30 field trip will take us southwest of Casper for a day in the Alcova area. We will be visiting the Alcova Dinosaur Trail – an in situ public dinosaur exhibit in the Morrison Formation on Bureau of Reclamation land – a second in situ sauropod partially collected by the Tate Museum, a pterosaur track site, and arm waving at two other sites where the Tate has collected vertebrate material on BLM land. These include a large ichthyosaur from the Sundance Formation and some *Barosaurus* bones from the Morrison on the eastward extension of the same ridge. These two sites require a hefty climb to access them, so the arm-waving stops. If time allows we may explore some Eocene outcrops between Alcova and Casper.

We will leave from the Tate Geological Museum at 8 a.m. Please show up closer to 7:30, no later than 7:45 a.m. We plan to be back around 5 p.m.

Sunday, June 2, 2019

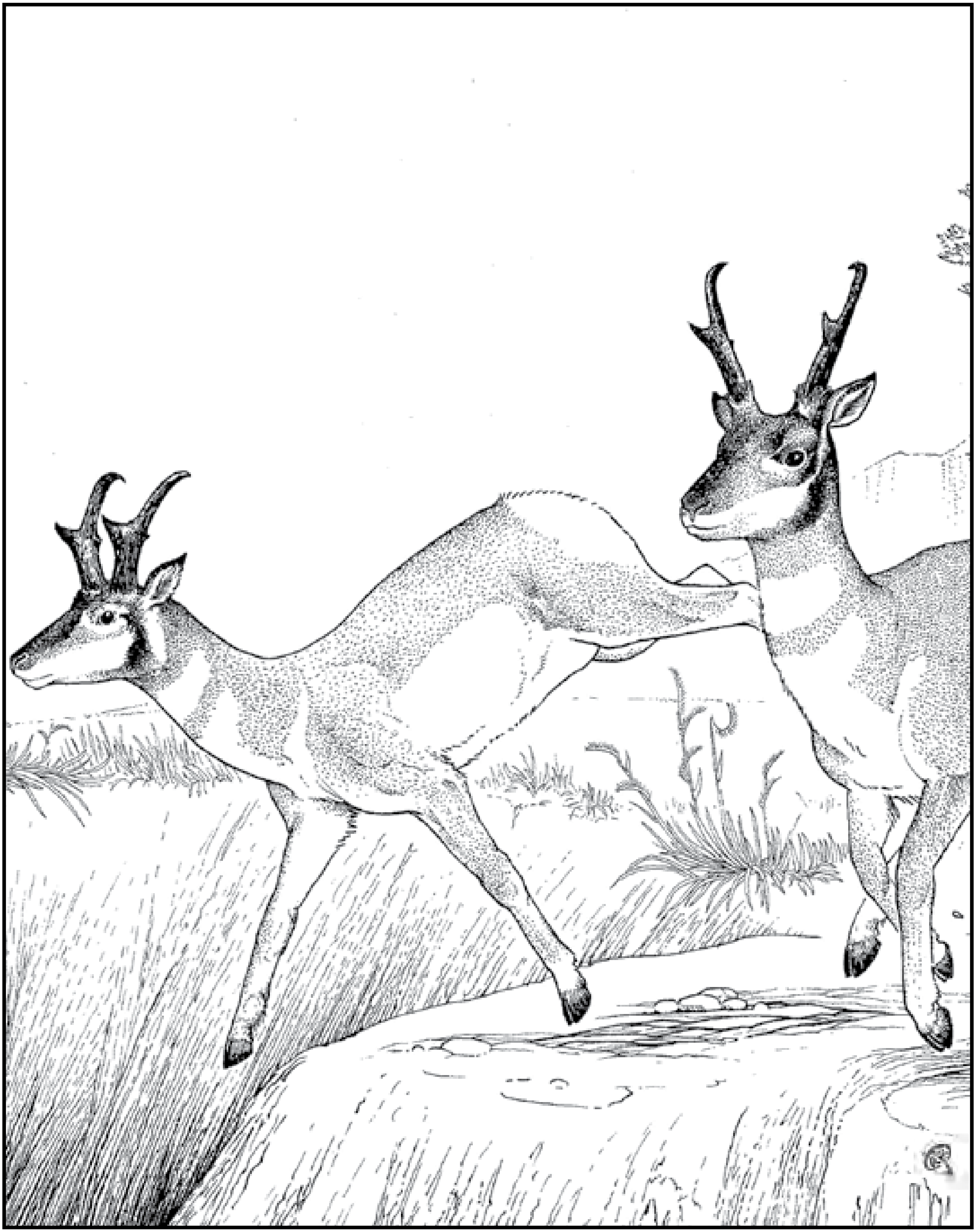
The June 2 field trip will be west of Casper. We will start at the BLM ORV Park where traces have been found including potential swimming mosasaur traces and "squid kisses," the impressions of ammonites on the sea floor preserved in the Mowry Shale. The second stop will be at a Campanian microvertebrate site in the Mesa Verde Formation at Fales Rocks. These two sites are on BLM land. Any specimens collected will be reposited at the Tate. The bulk of the afternoon will be spent exploring the Eocene outcrops of Hell's Half Acre. There has not been much paleontological collecting done at Hell's Half Acre. We have been there twice in the past eight years with Tate Geological Museum members. We are hoping to develop a reasonable collection at the Tate. We have permission to collect the fossils, but please leave any arrowheads and other Paleo Indian remains in place.

We will leave from the Tate at 8 a.m. Please show up closer to 7:30, no later than 7:45 a.m. We plan to be back around 5 p.m.

All collecting on BLM lands will be under the Tate Museum's BLM surface collecting permit. Specimens collected will be reposited in the Tate collections. Collecting at Hell's Half Acre (Natrona County land) is with the understanding that fossils collected will remain at the Tate.

Transportation and lunch are provided to field trip participants.

Note: For the sake of site confidentiality, photos of these sites may NOT be published or posted on any social media.



KEYNOTE

Andrew Farke

Andrew A. Farke

Andy Farke discovered his interest in paleontology while growing up in rural South Dakota, and was able to develop his first research in the field thanks to the long-distance mentorship of many professionals and amateurs. He received a B.Sc. in geology from the South Dakota School of Mines and Technology in 2003 and completed his Ph.D. in anatomical sciences at Stony Brook University in 2008. He joined the staff at the Alf Museum in June 2008, as Augustyn Family Curator, and was appointed director of research and collections in 2015. In addition to his duties at the museum, Farke is on the science faculty for The Webb Schools, where he teaches courses in paleontology for high school students.

Farke's research interests focus on exploring the Cretaceous continental ecosystems of North America, particularly the ceratopsian (horned) dinosaurs, with active fieldwork in Utah, California, and Wyoming. He is a journal editor and blogger and maintains active interests in the paleontological aspects of education, public policy, and science communication.

What Will You Do with Your Moment in Time? Paleontological History, Research, and Education at the Raymond M. Alf Museum of Paleontology

Andrew A. Farke, Raymond M. Alf Museum of Paleontology at The Webb Schools

The Raymond M. Alf Museum of Paleontology, unlike any other facility of its type, is located on a high school campus, that of The Webb Schools in Claremont, California. With a history spanning over 80 years and a collection encompassing over 170,000 fossils, the museum is uniquely positioned to engage students in the practice of paleontology while advancing research and educating the broader community. The museum began in 1936, as a personal project of high school biology teacher Ray Alf. Through a series of fortuitous fossil discoveries and personal encounters with paleontologists, Alf amassed a significant fossil collection, published scientific research, and inspired many of his students to pursue a career in the sciences. The museum achieved national accreditation in the 1990s, alongside a push to modernize the facility, expand staffing, enhance research efforts, and offer a broad range of educational opportunities for high school students.

Today, the Alf Museum has a comprehensive program that engages high school students in all facets of the paleontological process, including fieldwork, preparation, curation, research, and outreach. Ninth graders take a unit of paleontology as part of their evolutionary biology class, and interested 10th graders (around 15 to 20 annually) take a more in-depth course on the basics of paleontology and research. This includes not just scientific content, but also legal and ethical issues related to the field. A primary goal is to help students see the connections between science and broader societal concerns. As a capstone course, advanced students undertake original research in collaboration with museum scientists, with many students presenting at scientific conferences or co-authoring peer-reviewed papers.

Since its founding, collaborative work on public lands has been a major part of the Alf Museum's program. The museum is a federal repository, with many of these specimens found and/or collected with high school students. Most recently, the museum's field research has focused on BLM-managed lands from the Cretaceous of Grand Staircase-Escalante National Monument, the Miocene of the Barstow Formation, and the Paleocene of the Goler Formation in southern California, among others. These fossils, in turn, support original research, outreach efforts, and exhibits. Although some of the participating high school students do pursue careers in the sciences, creating new paleontologists is not a primary goal of the Alf Museum. Instead, it is hoped that all students and museum visitors, no matter what their path, better understand the scientific process, appreciate the connection between paleontology and society, and advocate for the importance of fossil research and preservation.

ABSTRACTS

An Example of a Co-operative Venture …Tate and BLM

Jean-Pierre Cavigelli, Tate Geological Museum

The Tate Geological Museum opened on the Casper College campus in 1980 thanks to a gift from Marion and Inez Tate. In the 1990s, the museum started collecting on BLM lands using the University of Wyoming as a repository. In 2000, Casper College hired Dave Brown to be the museum's director. One of his goals was to get everything organized and in professional condition aiming to become a BLM repository. In 2005, with encouragement from BLM paleontologist Dale Hansen, Brown applied for BLM Repository status for the Tate. Repository status was granted in 2006 after a site visit with BLM staff, making the Tate Geological Museum one of two BLM approved repositories in this fossil-rich state. The museum has a statewide surface collecting permit and has successfully applied for several excavation permits.

The Tate is part of Casper College which is a state-run community college. As a community college, Casper College is more education-based than research, so the Tate's collections are also more education-based than research-based. This is true of fossils collected on private as well as federal land. This being said, one of the goals of our collections is to make them available to researchers from outside the Tate.

There are 85 separate localities on BLM lands in the Tate database. These are in 12 counties and from 18 different rock units ranging from the Jurassic to the Pleistocene. They include sites reported to the museum by citizens and BLM staff, sites collected during paleontology surveys, sites discovered during Tate or Casper College outings, sites found by other institutions using the Tate as BLM repository, and a few previously known sites. Fossil localities are primarily vertebrate sites, but a few are invertebrate localities, including a significant ichnology site in the Mowry Shale.

Sites reported by citizens include the "McKinney Mammoth" site, where a local man found some mammoth bones south of Casper; "Kara and Logan's Bones," a Mesa Verde bone site north of Casper reported by a UW graduate student. Included in this group is also the "Cody Ichthyosaur" site. An ichthyosaur skeleton was collected here in 1974 and donated to the Buffalo Bill Museum in Cody. Recently the Buffalo Bill Museum decided that this specimen should not be in their museum since they are not a BLM repository. Working with BLM staff in Cheyenne, the specimen came to the Tate Museum after decades of being mostly in off-site storage (with a small piece on display).

Localities collected that were reported to us by BLM staff include the "Hamilton Lance Looter" site where unknown person had started an illegal dinosaur dig on a BLM section; "Mayoworth Ichthyosaurs" where three partial ichthyosaurs were collected in 2018; "This Side of Hell" where Marilyn Wegweiser (then with the MOR) collected parts of a hadrosaur in 2002, and where Tate staff and volunteers collected the remainder of the animal in 2014 and 2015, as invited to do so by Brent Breithaupt, BLM paleontologist.

The majority of the museum's BLM sites are results of surveys done by contract paleontologists who use the museum as a repository. These include localities in the White River Formation, Bridger, Wasatch, and Washakie formations. The contract paleontologists generally collect a few specimens, but also occasionally suggest a more focused excavation, as happened with "Ben's Big Turtle," a very large, articulated soft-shelled turtle now on display at the Tate, and a partial *Coryphodon* skeleton found in the Powder River Basin, perhaps the most complete Wasatchian mammal fossil from that basin. Some of these reports have inspired not only collecting reported specimens but also additional local collecting, as was done in the Eocene Haystack Mountains where Tate crews collected a reported *Patriofelis* jaw and explored the immediate area as well.

A few rather productive localities have been found on BLM lands during Casper College geology class outings. Some of the more interesting of these are a somewhat articulated large ichthyosaur skeleton, and a group of *Barosaurus* bones all found in the Alcova area southwest of Casper. Before the Tate had repository status, pterosaur tracks were discovered at Alcova. Many were collected and reposited with the University of Wyoming, but additional tracks have been found on BLM lands during Casper College geology field trips that have since been accessioned at the Tate.

Every few years, a group from the Tate goes to the Fence Line Locality in the Shirley Basin to surface collect Eocene vertebrate fossils. This site was discovered by a UW graduate student doing stratigraphic work but has never been exploited. The museum is slowly building a good collection of mammals from this site, as well as other vertebrates.

The Tate has been able to build up its collections of Wyoming fossils due to its work with the BLM, and the BLM has reciprocated by inviting the Tate to work on certain specimens. The BLM has also sponsored some of the Tate Geological Museum's collections storage facilities.

Figure 1. Diplodocus *foot from BLM lands at Alcova, Wyoming, collected and prepared by the Tate Geological Museum.*

Figure 2. Large Eocene soft-shelled turtle reported on a paleo survey for a uranium mine. Collected and prepared by Tate Geological Museum crews, where it is now on display.

Figure 3. Tate Geological Museum crew cleaning up a hadrosaur site on BLM land in Park County, Wyoming.

Let Us Try: Monitoring and Salvage Paleontology With the US Army Corps of Engineers

Darrin Pagnac, South Dakota School of Mines and Technology
Georgia Knauss, SWCA Environmental Consultants

The U.S. Army Corps of Engineers (USACE) is the branch of the U.S. Army (Department of Defense) tasked with management of the navigable inland waterways for commercial, recreational, and environmental purposes. As one of the world's largest public engineering management operations, they operate and maintain over 12,000 miles of inland shoreline; 926 coastlines, Great Lakes, and inland harbors; 383 major lakes and reservoirs; and operate 609 dams and spillways. This translates to thousands of linear miles of exposed outcrop with paleontological potential along major waterways within the United States.

The USACE is not generally regarded as a chief steward of paleontological resources management. However, the USACE does have a modest history of supporting resource management, thereby exemplifying their motto of Essayons, or "Let us try." Notable fossils from USACE held lands include two *Tyrannosaurus rex* specimens from Fort Peck Reservoir (Montana), the Devonian Fossil Gorge Site (Iowa), and Silurian fossils within the dam spillway at Caesar Lake (Ohio). Additional paleontological resource work on USACE lands has have been undertaken by SWCA Environmental Consultants and the South Dakota School of Mines and Technology (SDSMT). SWCA assisted the USACE by completing paleontological resource surveys and providing recommendations for potential recreation development around the Fort Peck Reservoir in northeastern Montana and has provided similar support on other projects in areas with paleontological potential. SDSMT has conducted annual survey and salvage work with the USACE along Lake Francis Case in central South Dakota for over 25 years, documenting and salvaging hundreds of specimens from the upper Cretaceous, Niobrara, and Pierre formations.

Collaborative work has been overwhelmingly beneficial for both the USACE and the paleontological resources they have authority over, with many advantages for their paleontological resource partners. The USACE is generally "low maintenance," with minimal micromanagement of monitoring operations and surprisingly little bureaucracy. As a division of the Department of Defense, the USACE is not subject to government shutdowns. Available budgets can be generous, although allocation of USACE funds for paleontology projects can be overshadowed by the need for mandatory cultural surveys. As stated above, the USACE manages thousands of miles of shoreline covered with vast exposures of fossil-rich formations, ensuring productive results to survey endeavors.

Working with the USACE does pose a few notable, but minimal challenges. As a division of the Department of Defense, collaborators may encounter some unique issues regarding background checks for field paleontologists, adherence to specific security measures, and restricted release of fossil locality data. Fossil resource management is generally not priority, and USACE personnel may not be aware of its need without prior experience. USACE surveys can be some of the most effort-intensive to undertake. Access to interesting geologic outcrops along waterways can be challenging and may necessitate transport across water bodies. Secondarily, adequate water levels for entry are paramount for the paleontological crews to efficiently access shorelines and outcrops. Since the USACE maintains water levels and adjusts dam releases constantly for recreational and flood management purposes, detailed review of USACE water management plans and pre-field scheduling is critical. Finally, the sheer volume of accessible and productive outcrop can be daunting.

Despite the challenges, working with the USACE can be a rewarding and fruitful collaboration, bearing in mind a few key considerations. As with any project, keep lines of communication as open as possible and keep USACE contacts apprised of all activity and results. Managers will need to be ever diligent in their adherence to regulations and deliverables as security and transparency are paramount. Field crews need to be informed of land ownership adjacent to USACE lands, as these boundaries can be shared with federal, state, private, or tribal lands. Detailed knowledge of the precise location of these boundaries is key. Finally, the USACE can suffer from a poor public image as they are often blamed for floods and other natural disasters. Discovery and promotion of exciting and valuable fossil resources can go a long way toward helping the USACE improve their public face, something their personnel will appreciate a great deal.

Bureau of Reclamation Lower Colorado Region is on Board With PRPA

Aubrey Bonde, Great Basin Institute
Mark Slaughter, US Bureau of Reclamation
Mark Sappington, National Park Service

With the passage of the Paleontological Resources Preservation Act (PRPA) in 2009, the Department of Interior (DOI) has coordinated policy and pending final regulations on the protection of fossil resources; bureaus, and even jurisdictions within the bureaus, have been staggered in implementing the mandates of PRPA. The U.S. Bureau of Reclamation Lower Colorado Region (LCR) is proactively supporting a new project which includes efforts to integrate the mandates of PRPA into their resource management practices.

The Bureau of Reclamation LCR lands are located primarily along the Colorado River and other major water rights-of-way in Nevada, Arizona, and California. A significant portion of Reclamation lands in the LCR coincide with other DOI agencies, such as the National Park Service at Lake Mead National Recreation Area (LMNRA) (Figure 1). In areas such as this, Reclamation works in close partnership with LMNRA, which is the administering agency for the management of paleontological resources found on Reclamation lands. Starting in 2015, LMNRA revitalized its paleontological resources management protocols to incorporate the goals of PRPA. In partnership with Reclamation, LMNRA reviews and issues paleontological resources use permits for jointly managed lands, they may house fossil specimens and data, they track the location of specimens held in outside repositories, and they report information to Reclamation. Reclamation LCR is now working toward updating their own paleontological resources program to match the LMNRA standards and comply with the regulations of PRPA.

This project places focus on several main tasks: 1) establish a paleontological resources use authorization system and database for the LCR; 2) identify the location of paleontological legacy collections and transfer contextual data into a centralized database; 3) create a comprehensive paleontological resources inventory and monitoring report for public lands managed by Reclamation in the Lower Colorado Region.

While progress on all tasks is ongoing, one facet that was prioritized for completion was the paleontological resources use authorization system and database. Even though Reclamation LCR works cooperatively with LMNRA, LMNRA utilizes the Research Permit and Reporting System (RPRS) that is internal to NPS. Therefore, it was determined that it would be beneficial for Reclamation LCR to capture similar information as RPRS, yet record paleontological resources use permits using its own authorization system. The database Reclamation LCR is now using is modified from a system developed by the Bureau of Land Management (BLM). The BLM system is being expanded by them into a planned online application processing and reporting system known as Recreation and Permit Tracking Online Reporting, or RAPTOR. This approach allows for Reclamation to be coordinated with NPS on the fields of data recorded as well as the BLM on the fields of data captured and on how the permitting data is housed. In so doing, Reclamation LCR's efforts have begun to unify their paleontological resources use authorization system with those of other Department of Interior bureaus, meeting one of the central goals outlined by PRPA.

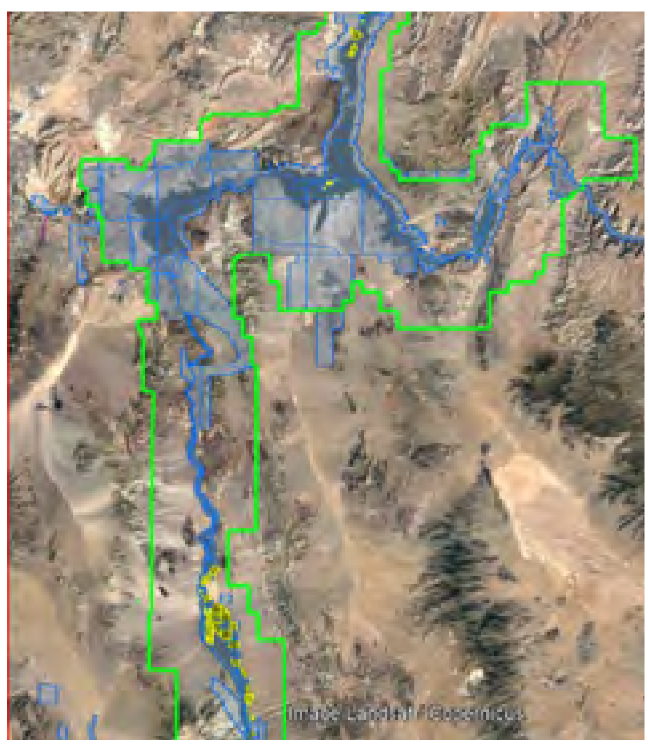


Figure 1. Location map of Lake Mead National Recreation Area (LMNRA) with the recreation area boundary out lined in green. U.S. Bureau of Reclamation Lower Colorado Region (LCR) managed lands overlap National Park Service lands at LMNRA. Reclamation LCR lands are marked by blue shading (withdrawn lands) and yellow shading (fee lands). Reclamationand NPS work in partnership to manage paleontological resources on these lands.

Paleontological Resource Inventory of the Paragon Geophysical Services, Inc. Snowy 3D Seismic Project on the Fall River Ranger District, Buffalo Gap National Grassland, Fall River County, South Dakota

Barbara A. Beasley, USDA Forest Service, Minerals and Geology Management

The Snowy 3D Seismic Project was located on National Forest System lands in southwest South Dakota. Forest Service (FS) regional office staff awarded the contract, without contacting the subject matter program managers at the local office. This company has been contracted by the Nebraska National Forests and Grasslands on past projects.

A USDA Forest Service paleontological permit was issued to the principal investigator (PI), and the paleontological resources are reposited at the James E. Martin Paleontological Research Laboratory in Rapid City, South Dakota. April 22 through May 22, 2017, the PI, a paleontologist, led the paleontological pedestrian inventory on three Late Cretaceous marine and two Quaternary geologic units in the Buffalo Gap National Grassland in Fall River County, South Dakota.

Consisting of 392 miles of 100-foot-wide transects, the Snowy 3D project was located approximately 9 miles southwest of Edgemont, South Dakota. Forty-three fossil sites were located during the survey with a total of 141 specimens recorded between April 22 to May 22. Carlile, Niobrara, and Pierre Shale formations were inventoried with paleontological resources documented in these units. Plants such as fossilized tree logs with clam borings; invertebrates, including mollusks and traces; and vertebrate fossils including fish, sharks, and marine reptiles, were recorded and excavated.

During the June project tour, the PI led the FS paleontologist through the project area. The PI and FS paleontologist determined that 25 sites were to be either collected or protected from ground disturbing activities of the project. Pierre Shale paleontological resources proved to be very prolific to the extent that entire fossil localities had to be collected because avoidance would create such a wide area causing the seismic tracts to be too far apart; negatively affecting the seismic process.

Collection of fossils was conducted July 5 through August 4, 2017. Two of the Late Cretaceous marine geologic units present as a fissile shale, causing the exposed fossils to literally sit on the surface. Between the pedestrian inventory and collection, livestock were released into the FS pastures and heavy precipitation events took place; both causing major ground disturbance which obliterated or degraded six sites containing mosasaur vertebra, turtle, *Squalicorax* (i) tooth and jaw, *Baculites* (i), and an unidentified marine reptile partial skeleton. Five sites were not collected; therefore, motor vehicle travel over these sites was prohibited during the project; six sites were identified to be monitored by the FS. Areas with bedrock of the Niobrara Formation in the project area commonly were littered with baculite casts, and *Inoceramus* and *Pseudoperna congesta* fragments, but were not offered protection due to the abundance, and the outcrop's vertical nature protected many of these fossils.

The FS paleontologist is well pleased with the professional and detailed paleontological work of the paleontological PI and field crew presented in the final report. By the end of the contract; three issues were identified: proposal did not account for costs of immediate collecting of at-risk specimens; the proposal underestimated the paleontological resource productivity of the geologic units; and, the major underestimation of conservation costs.

This project achieved the goals of documenting and protecting paleontological resources on public lands. The collection will provide the public with the opportunity to work in a scientific institution, with their paleontological resources, while learning about public land management and museum functions and goals.

Figure 1. An Enchodus *mandible weathering out of the Pierre Shale.*

Figure 2. Possible Platecarpus *bone scatter.*

Figure 3. Cattle track narrowly missing specimen.

Prehistoric Trackways National Monument, New Mexico: Photogrammetric Ichnology of a Permian Trace-Fossil Lagerstätte

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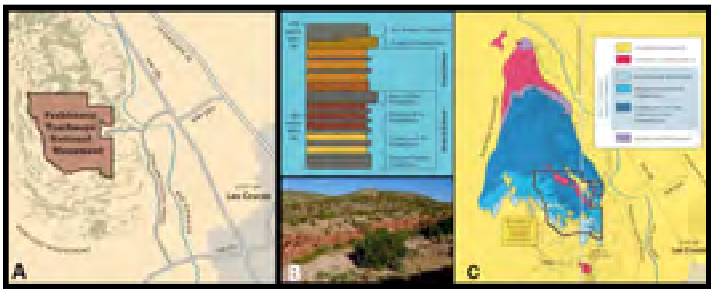
The nation's 100th national monument, Prehistoric Trackways National Monument (PTNM) was founded in 2009 to conserve, protect, and enhance the unique and important paleontological, scientific, educational, scenic, and recreational resources found in the Robledo Mountains north of Las Cruces in Doña Ana County, New Mexico. PTNM is part of the Bureau of Land Management's (BLM) National Landscape Conservation System (National Conservation Lands) and consists of approximately 5,280 acres (21.37 sq. km). Although the presence of tracks in the Permian red beds of the Robledo Mountains was known since the 1960s, it was not until the 1980s that prolific sites and fossil assemblages were discovered (Hunt et al., 1993; MacDonald, 1994).

Some of the world's most important footprint localities are located within the PTNM. The monument contains some of the most diverse and well-preserved Paleozoic tracks in North America and some of the most scientifically significant early Permian track sites known. Fossilized traces of vertebrates (fish, amphibians, and reptiles) and invertebrates (arthropods), as well as fossilized plant impressions and petrified wood are preserved in the lower Permian red beds of the Robledo Mountains Formation of the Hueco Group (Lucas and Heckert, 1995; Lucas et al., 1998; Lucas, 2011). Deposition of this unit occurred on the northwestern shore of a marine embayment, approximately 286 million years ago (Leonardian/Middle Artinskian). Due to the high occurrence, ichnotaxonomic diversity, and morphological preservational variants, these tracks provide an unprecedented glimpse into the paleoecology of the Permian period.

These ichnites provide valuable information for the understanding of Paleozoic ichnotaxa worldwide and have served a "Rosetta Stone" for rewriting global Permian tetrapod ichnotaxonomy (Minter and Braddy, 2009; Lucas et al., 2011). As such, this unique biotic assemblage allows an opportunity to use state-of-the-art, 3D digital documentation technology to conserve, protect, and visualize exceptionally preserved paleontological resources. Over the last decade, specimens selected from over 2,500 track-bearing slabs curated at the New Mexico Museum of Natural History and Science in Albuquerque were documented using close-range photogrammetric techniques (Matthews et al., 2016). Representative examples of tracks and trackways of the ichnotaxa *Batrachichnus*, *Dimetropus*, *Dromopus*, (representing temnospondyl amphibians, pelycosaurs, and early diapsids, respectively), and others were chosen for study. Three-dimensional image datasets created from this documentation provide a permanent digital record of the tracks for in-depth evaluation and assessment. These studies allow trackway block to be realigned, analyzed, and compared with neoichnologic information, providing a "snapshot" of the activities and kinetics of movement of organisms as they traversed the ancient Hueco Sea coastal plain. These data also provide valuable insights into the ichnotaxonomy, trackmaker identity, and paleoecology preserved in PTNM. In addition, the enhanced 3D visualization of these novel ichnites can be used to effectively present information on this unique area to the general public and land managers, thereby increasing the awareness and concern for such natural treasures. Nearly three decades of research by scientists from all over the world have identified the Robledo Mountains Formation trace fossils as one of the most scientifically significant ichnofossil records known, a true trace-fossil Lagerstätte (i.e., Ichnolagerstätte).



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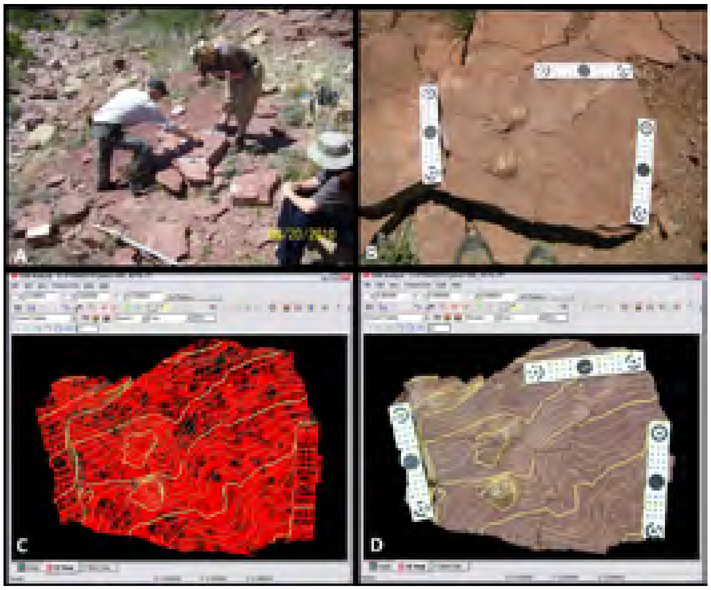

Figure 2. (above) A. Hand-held, close-range photogrammetric documentation was conducted at the Discovery Site in Prehistoric Trackways National Monument in 2010. B., Footprints of Dimetropus *at the Discovery Site with coded targets for photogrammetry (distance between circular computer codes is 25 cm). C., Photogrammetrically processed image of track block in Figure 2.B, showing 3D mesh and contour lines. D., Orthophoto image of* Dimetropus *track block with topographic contour lines. Contour interval 5 mm.*

Figure 3. A. Hand-held, close-range photogrammetric documentation of selected specimens in the research collections at the New Mexico Museum of Natural History and Science (NMNHS) from PTNM was conducted in 2010 and 2018. B., Footprints of Dimetropus *in the research collections at the NMNHS with coded targets for photogrammetry. C., Photogrammetrically processed image of* Dimetropus *track in Figure 3.B, showing orthophoto image with topographic contour lines (upper) and color depth map (lower). Contour interval 0.1 mm. Improvements in computer processing and photogrammetric software can be visualized when comparing the output products (Figure 2, C.D. and Figure3C), as images taken in 2010 can be reprocessed with improved results over time.*

Figure 1. (left) A, Location of Prehistoric Trackways National Monument (PTNM) in Doña Ana County, New Mexico. B., Generalized stratigraphic section of the Permian rocks in southern New Mexico (upper) and view of the track-bearing red beds of the Robledo Mountains Formation in PTNM (below). C., Geologic map of the Robledo Mountains with the boundaries of the PTNM shown. From Lucas, 2011.

Methods and Initial Results of In-situ Monitoring Efforts at Prehistoric Trackways National Monument, Southern New Mexico

Colin R. Dunn, Bureau of Land Management

Established 10 years ago in 2009, Prehistoric Trackways National Monument (PTNM) is managed by the Bureau of Land Management. At 5,280 acres (8.25 square miles), PTNM covers less than half of the Robledo Mountains northwest of Las Cruces, New Mexico. Nevertheless, PTNM contains scores of fossiliferous redbed outcrops of an Early Permian (Leonardian) ichnofossil lagerstätte.

Finalized in late 2015, the PTNM Resource Management Plan called for the development of a paleontological monitoring plan to “establish baseline conditions of fossil resources, and track changes to those resources based on management, research, and other factors,” specifically calling out impacts from dispersed camping, livestock, soil erosion, and actions from vegetation, fire, and trail and transportation management. Other evaluated impacts include erosion from water and wind, wildlife activities, temperature changes, intentional anthropogenic threats (littering, defacing, vandalism, and theft), and other land uses (i.e., grazing infrastructure). This effort was kicked off in late 2016 and is intended to produce a standardized monitoring methodology that can be utilized by land managers, interns, and volunteers.

At each locality, a threat impact assessment is completed by rating each impact threat as low, medium, or high. As these ratings could be subjective based on each individual assessor, a standardized list of impact threat level definitions was developed, although further refinement is still underway. When assessing impacts to a locality from gravity erosion, for example, the level of lithification (poor, moderate, or well), the amount of fracturing (many, moderate, or few), the thickness of bedding (thin/loose, moderate, or massive), and the degree of slope (steep [90°-70°], moderate [70°-30°], or low [30°-0°]) are all taken into account. A locality with well-lithified, massive bedding and many fractures and joints on a steep slope would rate a high threat, and a rationale is also provided on the assessment for each impact to justify the rating.

Once all impacts are identified and rated, an overall impact threat score is calculated. Some of the impacts are weighted higher than others, such as water erosion compared to wind erosion, or theft compared to littering. The overall score influences the cyclical rate of repeat monitoring. A locality with a high impact score could be monitored quarterly, whereas a low score locality only yearly. Limitations here are largely based on manpower availability. Also determined is the style of monitoring: repeat photography, trail camera, erosion stakes, and photogrammetry.

Monitoring stations are established after completion of the impact assessment, with a minimum of one repeat photography station per locality. The GPS coordinates of each station are recorded and physically marked with an 8-inch galvanized steel stake. Photographs of the stake location are taken to aid in relocation. Multiple photographs may be taken from a single station, with the facing direction recorded for each. A standardized naming convention utilizing the station name and date will be used back in the office to organize the many photos taken. Ideally repeat photo stations will be close enough that the subject is completely in the frame, although these conditions are not always possible due to terrain and vegetation constraints. Zooming should be avoided as it is difficult to properly replicate.

These photos are used to create a locality monitoring datasheet, containing a small map of the locality and the nearby monitoring stations, and all baseline photos with facing directions that all subsequent monitoring photos should match. These are invaluable tools for users who have not been to the localities to easily and quickly find the stations while on a monitoring run. A simple form is used on monitoring runs to document any obvious changes or impacts to localities (such as graffiti, evidence of slab flipping, or cairns).

To evaluate the condition trend of a locality from multiple repeat photography sessions, a computer program is used to realign photos to the original baseline photo. This realignment greatly aids in determining changes to the locality over time. Management and mitigation measures may then be taken if needed.

Photogrammetry via drone flight has been used at two localities, “Discovery Site” and “Brachiopod Sidewalk,” which are featured on guided hikes and are well known to the public.

This notoriety, in combination with high impact threats from potential theft and erosion, give these localities a high impact threat score. The drone flights are piloted by licensed BLM GIS specialists, and as such are contingent on the availability and workload of the in-house GIS staff. The methodology of this technique is still under development, and results are mixed but promising. Comparing these flights to future flights of these localities will allow for evaluation of more minute changes to the locality.

Future plans include utilizing small-scale photogrammetry to capture additional outcrops, as well as to create a “save point” for individual in-situ fossils to measure natural erosion rates as well as damage or destruction to the specimens.

Figure 1. Discovery site.

Figure 2. Brachiopod sidewalk.

Preservation of Ephemeral Ice Age Mammal Trackways at White Sands National Monument

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David Bustos, White Sands National Monument
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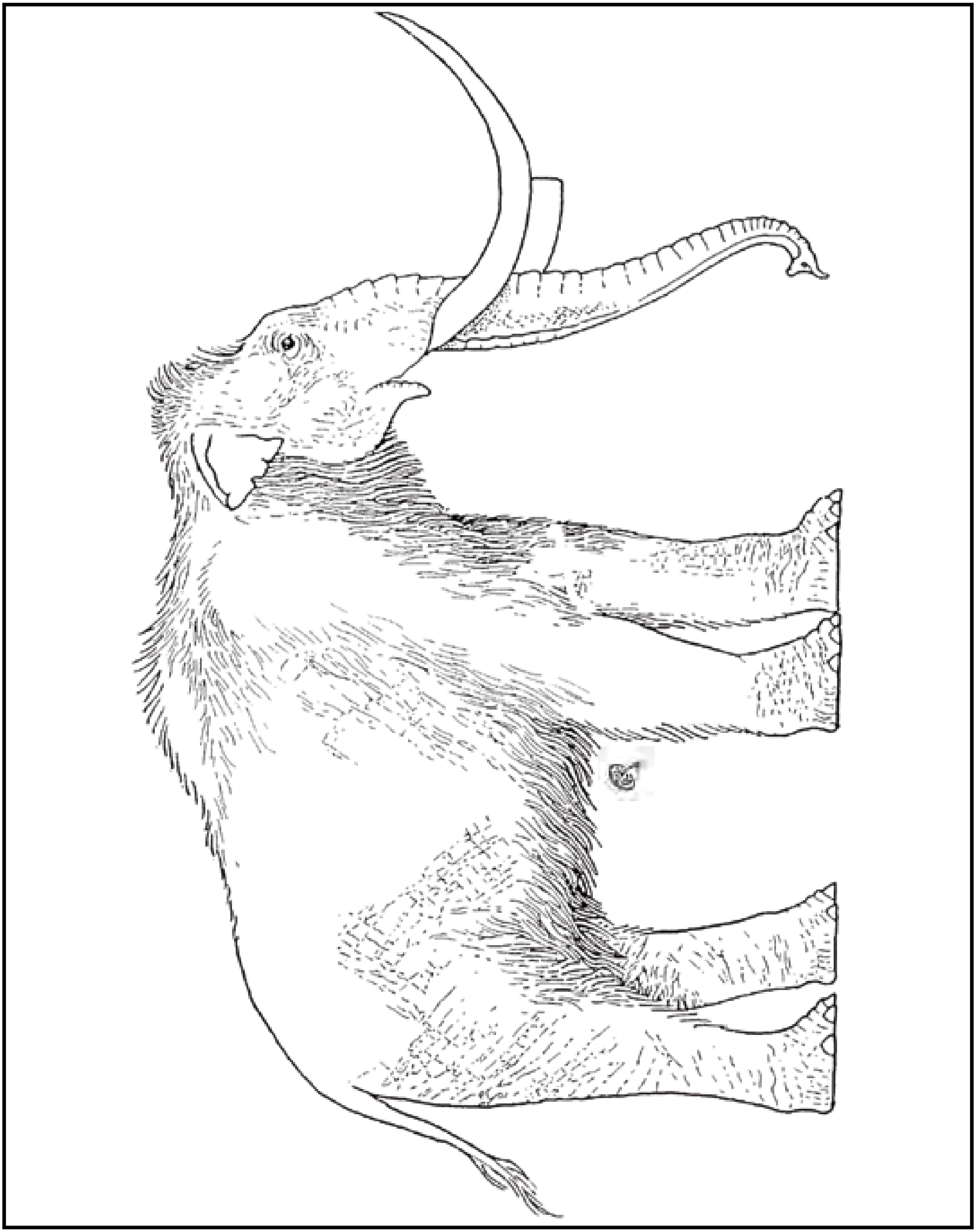
White Sands National Monument (WHSA) is well known as the world's largest gypsum dune field created from gypsum sediments eroded from an ancient lake bed. The lake bed also preserves a large number of Pleistocene ichnofossils. In recent years, thousands of prints of extinct Rancholabrean fauna have been found, including prints of Proboscidea (mammoth), Xenarthra (ground sloth), Carnivora (canid and felid), Artiodactyla (bovid and camelid), and most recently fossil prints of humans. Individual prints of both animals and humans can be tracked over kilometers. Overstepping prints show contemporaneous animal and human interaction, making WHSA an important part of the human story in North America. The sheer density of tracks (>10 per square meter) and their spatial extent makes the site unique in the Americas if not the world. These footprints are preserved in soft sediment and are visible at the surface only under specific moisture conditions, for this reason, they have been referred colloquially as 'ghost tracks.' The prints are ephemeral and, in some areas, where the top layer of sediment has been lost the tracks are quickly destroyed by erosion in just a few years. The tracks are most numerous in the areas of the monument under co-use with the White Sands Missile Range, and the assemblage extends into these areas. This acts to protect them, but also makes them vulnerable to occasional damage during missile tests. Recent droughts in the Tularosa Basin have also led to a loss in soil moisture and may accelerate future erosion rates, increasing track loss.

In light of this and the confirmation of human footprints in 2016, WHSA has been working with Bournemouth University, Cornell University, Arizona State, USGS, and many others to document, monitor, and preserve this incredible story. A number of tools are being used at WHSA to preserve and record this important ichnological resource. Key amongst these is the application of field-based photogrammetry which not only allows excavated 3D traces to be captured and subsequently analyzed, archived, and 3D printed, but also produces ortho-rectified mosaics which allow detailed mapping of excavated and unexcavated tracks. We have also been developing geophysical methods both as an aid to prospection and potentially as a way of imaging unexcavated tracks in high resolution. This ongoing work shows real potential. With these tools, WHSA can now begin to preserve the data associated with the thousands of footprints present at this site before they are lost. Moreover, this work sets an example of how tracks can be studied at other playa sites both in the Americas and elsewhere in the world.



Structure From Motion Photogrammetry Enhances Paleontological Resource Documentation, Research, Preservation, and Education Efforts From National Park Service Areas

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Vincent L. Santucci, National Park Service
Andrew R.C. Milner, St George Dinosaur Discovery Site at Johnson Farm
Jeff Wolin, NPS Florissant Fossil Beds National Monument
Vince Rossi, Smithsonian Institution, Digitization Program Office

Structure-from-motion (SfM) photogrammetry methods are an increasingly common component of paleontological research and resource management. The 3D data and derived products allow for novel and exciting avenues to engage with a range of stakeholders (Lewis, 2019). The National Park Service (NPS) is striving to develop a robust SfM program to support park units with resource documentation efforts, training for staff, and building capacity for 3D data processing. We report on ways that SfM techniques have been applied to in situ fossil discoveries, monitoring of paleontological localities, and digitization of fossil specimens in museum collections (Figure 1). The capacity within the NPS for photogrammetry to support paleontological research is also enhancing collaborative efforts with new fossil discoveries in NPS areas. A recently discovered float block found in Glen Canyon National Recreation Area shows abundant theropod tracks displaying a variety of behaviors and an "*Anomoepus*"-like trackway. These fossil tracks appear on a bedding surface exposed when a slab of Wingate Sandstone detached from the canyon wall, fell and cleaved in two, leaving one half as a near vertical ~8m high slab. The counterpart came to rest farther downslope, creating a small talus cave beneath the slab, with numerous tracks revealed on the ceiling. Photogrammetry has enabled detailed mapping and surface topology analysis of the slab, which would otherwise have been inaccessible (cf. Belvedere et al., 2018). The derived 3D data has broad research utility including comparative morphology and remote analysis for ichnospecies identification and description. Photogrammetry also facilitates interagency collaboration. For National Fossil Day 2018, a years-long collaboration between the NPS and the Smithsonian's National Museum of Natural History (SI) culminated with the release of numerous 3D fossil models online for the public. This project employed SfM to digitize over two dozen rare specimens, including several holotypes, originally obtained from within NPS managed lands and which are housed in the collections of the SI. Over a dozen of these models are now online and available to members of the public to promote distance learning. Photogrammetry data are also easily adapted for 3D replica making (Wood and Santucci, 2015). Use of such models allows outreach to current and new park audiences, as well as those with visual impairments and others that benefit from interaction with tactile elements. Rapid prototyping (e.g., 3D printing) technology employs newer materials and comes with lower costs when compared to traditional fossil replication methods. A test case utilized one of the models from the SI as part of a new display that employs braille and "hands-on" elements at Florissant Fossil Beds National Monument, Colorado (Figure 2). New applications for 3D data and SfM photogrammetry methods will continue to expand within fossil research. The NPS continues to make positive strides forward to be at the forefront of developing SfM methods for paleontology.

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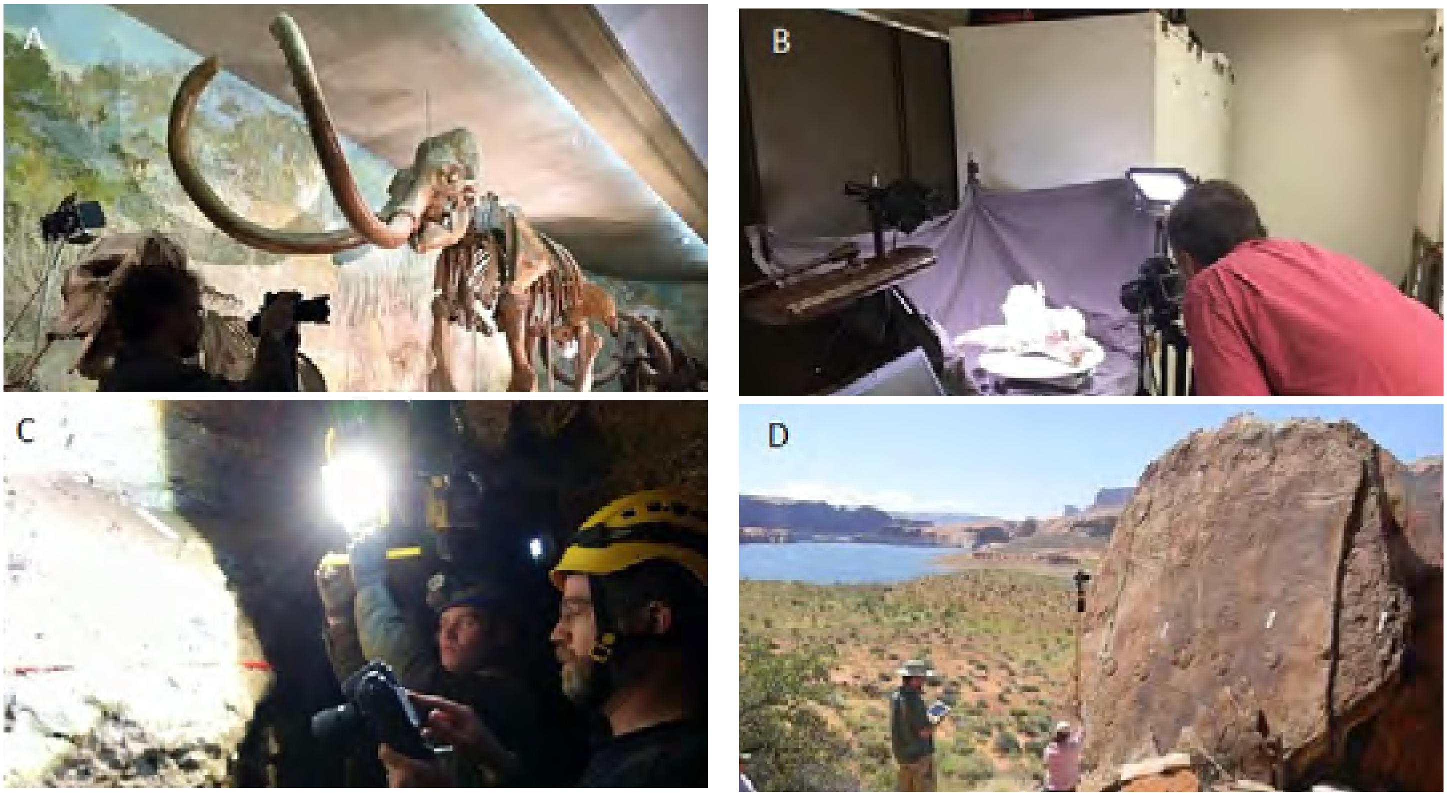

Figure 1. – A) Gathering images of a mounted specimen at the University of Nebraska; B) Obtaining images for a full wrap-around 3D model as part of the collaboration with the Smithsonian; C) Photographing Pleistocene carnivore tracks in soft sediment within the cave at Oregon Cave National Monument and Preserve, Oregon; D) A large near vertical track block with numerous tracks and trackways on the surface of the bedding plane at Glen Canyon National Recreation Area, Utah (re. Milner et al, 2016).

Figure 2. – A) Specimen of Nanodelphys *from the collection of the National Museum of Natural History (The Smithsonian); B) colorized surface map derived from the 3D data; C) New kiosk at Florissant Fossil Bed National Monument that uses a 3D print of the* Nanodelphys *fossil and braille text to better engage visually-impaired visitors.*

Paleopedology of the Piedra Chamana Fossil Forest, Peru

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Introduction: The Piedra Chamana fossil forest of northwest Peru preserves a combination of detrital woods and distinct in situ fossil forest assemblages dating from 39 million years ago that were preserved by various types of volcaniclastic flows and primary ash falls (Woodcock et al., 2009; Navarro et al., 2012). Since 2009, researchers from U.S. institutions and staff from Florissant Fossil Beds National Monument have worked in partnership with local and federal agencies and citizens of the nearby town of Sexi to promote and protect these fossils (Figure 1). Their cooperative efforts have resulted in the construction of an on-site museum in Sexi, development of interpretive literature and proposed trails, creation of a cyclic survey and inventory assessment of fossil sites, and establishment of a support infrastructure for visiting scientists.

Previous research at Piedra Chamana focused on the taxonomy of the abundant fossil trees, in addition to fossil leaves preserved as impressions and carbonized films in volcanic ash layers (Woodcock et al., 2009, 2017, 2019), and suggest that the Piedra Chamana represents a coastal environment composed of both seasonally flooded lowland forests and dry tropical forests. To further characterize the paleoenvironments of the Piedra Chamana, part of the 2018 expedition to the Piedra Chamana was dedicated to interpreting the paleopedology and depositional environments of these late middle Eocene landscapes.

Paleopedology: Paleosols were recognized by their association with in situ fossil trees. Two trenches were excavated along the same paleo-landscape to document roots, soil structures, colors and mottling, and mineralogy (Figures 2, 3). Samples were collected for mineralogical, geochemical, and petrographic analysis. A third trench was excavated at a different stratigraphic level to characterize potential variability in paleoenvironments and soil types.

All three soil profiles developed on fining upward sequences of volcaniclastic materials characterized by white euhedral plagioclase grains within a light olive matrix that changed upward into salmon pink and orange altered plagioclase grains within a pinkish-orange matrix (Figures 2, 3). Other than silicified horizontal tree roots associated with in situ stumps, most roots are several millimeters in diameter and preserved as a combination of downward branching and horizontal clay infills and drab haloed traces, some of which are associated with intense reddish-orange staining. Zones of reddish-orange mottling occur at different levels in each profile.

Comparisons of two profiles along the same paleo-landscape (Site 1 and 2) suggest slight differences in geomorphic position over ca. 200 meters (Figure 2). Both sites preserve the same thickness of individual fining upward packages, but mottling is more pronounced in Site 1, suggesting a greater amount of hydromorphy. This paleo-landscape at both sites is overlain by a uniformly thick fining upward package of volcaniclastic sediments which also has rare in situ trees and is in turn capped by a volcanic ash that contains accretionary lapilli and fossil leaves (Figures 2, 3). As with the underlying profile, this thinner, overlying volcaniclastic interval displays greater hydromorphic influence at Site 1 and suggests that these two profiles formed on different parts of the same landscape.

Site 3 is located 10s of meters below Site 1 and 2 and also represents pedogenic modification of a fining upward volcaniclastic sequence (Figure 2). No trees were found in association with this profile, but the same reddish-orange hydromorphic mottling is present toward the top of the profile. This profile is in most respects identical to the paleo-landscape of Site 1 and 2, with the exception of greater amounts of coalified/charcoal plant remains disseminated throughout, and within a smaller overlying volcaniclastic interval with concentrations of carbonized plant remains at its base.

Previous research on the paleobotany of the fossil woods at Piedra Chamana suggest that during the late middle Eocene this site was in a tropical coastal zone with mean annual temperatures of 26-35oC and precipitation of ca. 1278 + 0.4 mm (Woodcock et al., 2009, 2017, 2019). This interpretation is consistent with the paleogeographic reconstruction of Lauterbach et al. (2014) and would suggest that this region has experienced extreme tectonic uplift. Although only three separate locations have been studied to date for their paleopedological characteristics, their soils are consistent with previous paleofloral interpretations of both seasonally flooded and dry forest settings (Woodcock and Meyer, 2019). Preliminary observations of geologically older exposures near the Piedra Chamana suggest a combination of fluvial and lacustrine environments with paleosols that formed along both low-lying and extremely well-drained geomorphic positions. These older deposits also preserve abundant fossil wood and, when taken as a whole with the Piedra Chamana, argue for their importance as an extremely valuable site for understanding the dynamics of Eocene tropical conditions of South America.

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Figure 1: Map showing the location of the Piedra Chamana fossil forest. Modified from Woodcock et al. (2017).

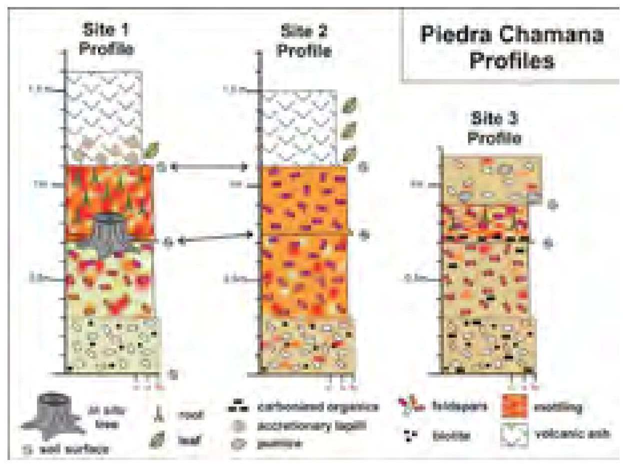

Figure 2: Measured sections of three paleosol profiles within the Piedra Chamana fossil forest.

Figure 3: Excavated paleosols of Site 1.

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Development of New Geologic Trail Exhibits and an Associated Mobile Application for Multi-level Interpretation of Geology at Florissant Fossil Beds National Monument

Herbert W. Meyer, Florissant Fossil Beds National Monument
Conni J. O'Connor, Florissant Fossil Beds National Monument
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Florissant Fossil Beds National Monument established a new geologic trail route in 2015 to expand the scope of visitor interpretation beyond the famous Florissant Formation. Paleontology interns and staff developed new content for nine new trail exhibits in 2015 and 2017 on topics including geologic time, Cenozoic climate change, mineralization, Pikes Peak Granite, geomorphology, Wall Mountain Tuff, and an overview of changes throughout time in the valley. The input from interns and staff academically trained in geology resulted in more robust scientific content than conventional NPS exhibits, including scripts, graphics, and reconstructions. Traditional content for such exhibits is typically targeted for a 12-year-old audience, but the new exhibits aimed for higher levels of understanding. In order to serve a broader audience, the monument is currently enhancing a newly developed mobile application that will provide content to serve three levels of user backgrounds: 1) advanced science students, 2) inquisitive tourists, and 3) elementary school children and "Junior Rangers." Our research objective is to explore visitor reactions to "in the moment" free choice learning through visitor interaction with a multi-level smart device application, Florissant Explorer, which is a tool to facilitate broader learning. This is an innovative prototype that is hoped to provide an example for other sites that seek to provide broad-based learning at all education levels.

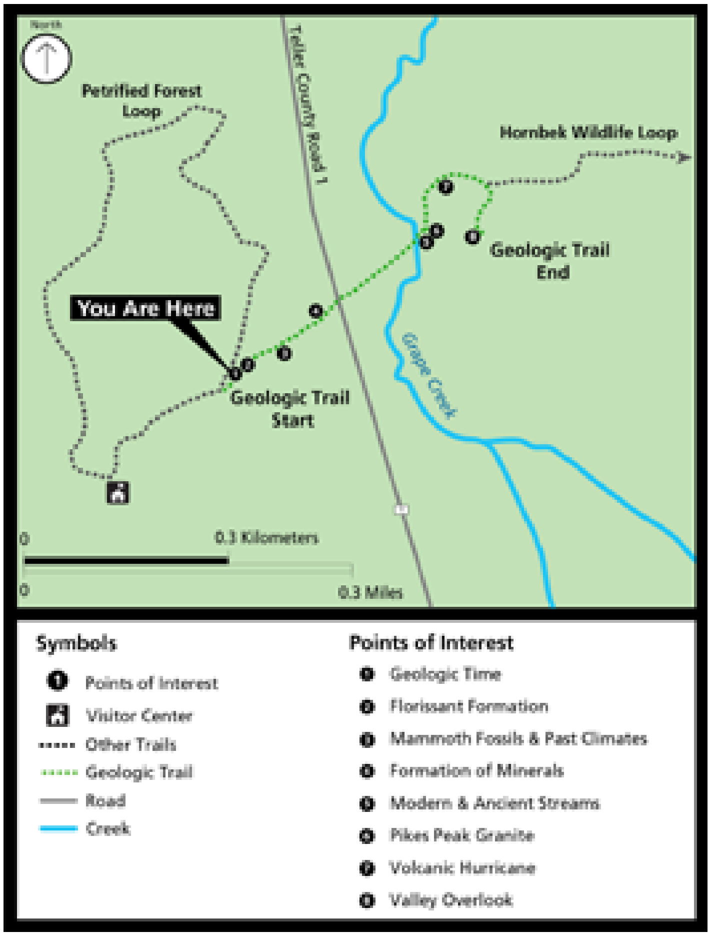

Figure 1. Example of one of the navigational map pages on the new app.

Canadian Fossil Legislation and the Alberta Historical Resources Act

Daniel N. Spivak, Royal Tyrrell Museum of Palaeontology
Allison R. Vitkus, Royal Tyrrell Museum of Palaeontology

Unlike countries with highly-centralized governments, such as China and Mongolia, and countries with vast ranges of federally managed lands, such as the United States, Canada does not have a national fossil law. Except in specific cases, such as national parks (Canada National Parks Act) or international import/export (Cultural Property Export and Import Act), fossil resources in Canada are managed under provincial legislation. Most provinces and territories, except Ontario and Quebec, have some type of fossil protection legislation.

The Alberta Historical Resources Act (HRA) was the first legislation in Canada to include fossil resources and is the foundation of a well-established fossil resource management program. The HRA applies to all lands in Alberta, including both public and private property and provides the Government of Alberta (GOA) with the authority to manage all fossils in the province.

The main tenet of the HRA is that all palaeontological resources (defined as a work of nature consisting of or containing evidence of extinct multicellular beings and includes those works of nature or classes of works of nature designated by the regulations as palaeontological resources) in the province belong to the Crown in right of Alberta. Essentially, all palaeontological resources in Alberta are government-owned resources, managed by the GOA on behalf of the people of Alberta.

Palaeontological resources collected in Alberta cannot be sold, altered, marked, damaged, or removed from the province unless the holder of the fossil has received written permission or a Disposition certificate from the Minister of Alberta Culture and Tourism (ACT). Private ownership, or Disposition, of certain fossils (ammonite shell, petrified wood, plant leaf impressions, and oyster shell) collected after July 5, 1978, is permitted under the Dispositions (Ministerial) Regulation. The Disposition application and approval process is outlined by Spivak (2014).

Excavation of palaeontological resources requires a permit, issued by ACT via the Royal Tyrrell Museum of Palaeontology. To be eligible to hold a Palaeontological Research Permit, the applicant must have a post-graduate degree (thesis based) in palaeontology, 24 weeks of supervised fieldwork experience, six weeks of curatorial and laboratory training and must be able to demonstrate that they have planned and executed a study similar to the one proposed in the application. Student permits are available to any student registered in a university program who is required to conduct fieldwork to obtain their degree. Once the application is approved and the fieldwork is complete, the permit holder must deposit all collected fossils at the repository listed on the application and submit a report detailing the results ofthe fieldwork.

In instances where a proposed excavation activity (e.g., pipeline, mine, road, subdivision, etc.) will or is likely to impact palaeontological resources, the Minister of ACT can order the project proponent to complete a pre-project impact assessment, a construction monitoring program and/or a salvage program. This work must be done by a palaeontologist who is qualified to hold a Palaeontological Research Permit and a report detailing the results of the investigation must be submitted to ACT for review prior to the issuance of clearance or further requirements.

Maximum penalties under the HRA are a $50,000 fine and/or one year in jail.

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Alberta's Listing of Historic Resources: A Resource Management Tool for Identifying Areas of Known or Potential Paleontological Significance

Allison R. Vitkus, Royal Tyrrell Museum of Palaeontology
Daniel N. Spivak, Royal Tyrrell Museum of Palaeontology

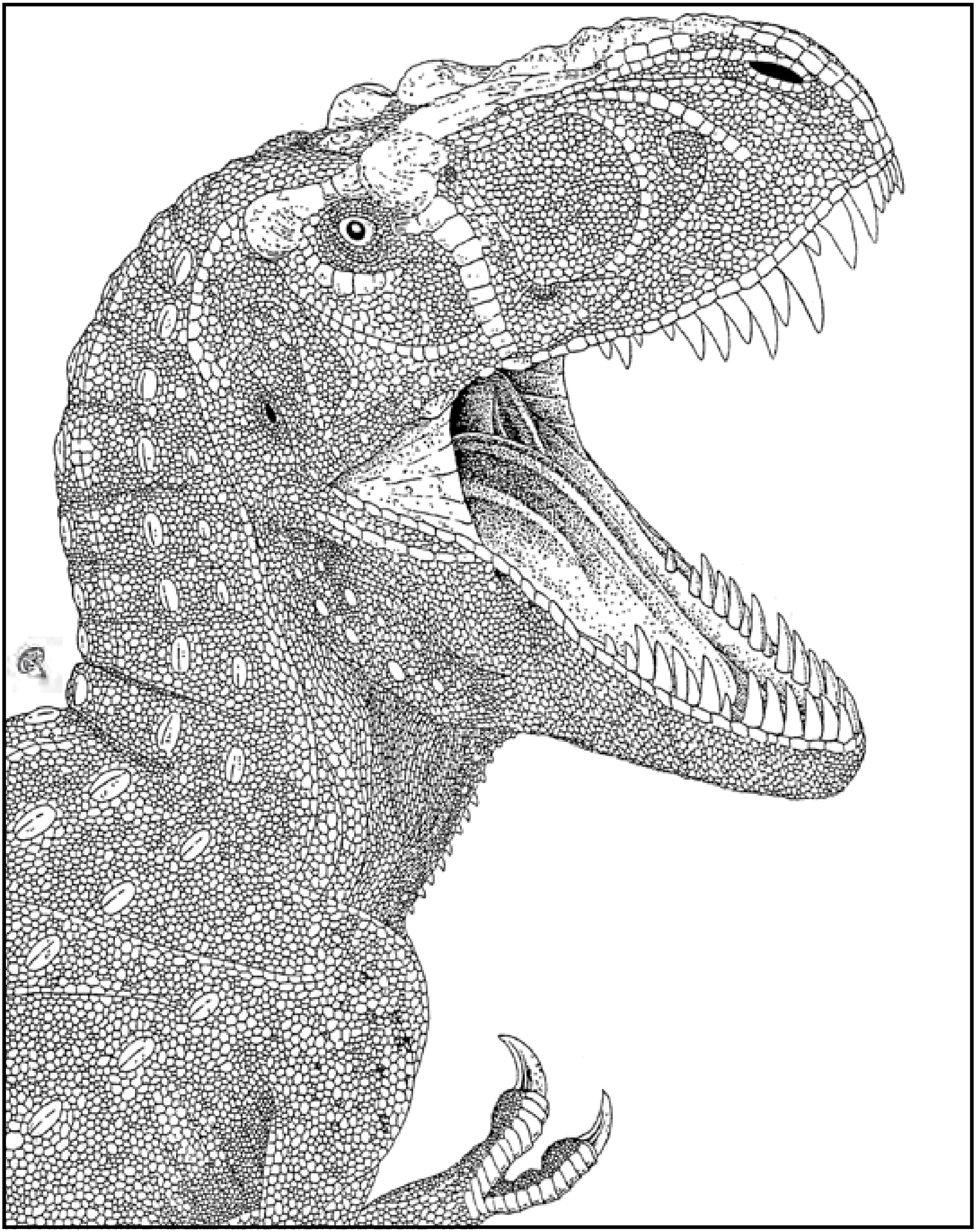
Alberta has a rich fossil history and, consequently, one of the most comprehensive fossil laws in the world. The Government of Alberta (GOA) is responsible for managing Alberta's historic resources, including paleontological resources, under the authority of the "Historical Resources Act" (HRA). The Listing of Historic Resources, also known simply as the Listing, is the system used to identify areas that are known to contain historic resources or are likely to contain historic resources.

Within the Listing, areas are assigned a Historic Resource Value (HRV) ranging from 1 to 5, with 1 containing the most significant resources. HRV 1 is reserved for areas officially designated as Provincial Historic Resources, a status that confers additional protections for a specific area. Currently, there are only a few paleontological Provincial Historic Resources, including the Devil's Coulee Dinosaur Egg Site. HRV 2 is for Registered Historic Resources, a designation that is not used for paleontology but is used for built heritage resources. HRV 3 is for sites containing significant historic resources, and HRV 4 is for previously recorded sites. HRV 5 is for areas with high potential to contain historic resources, but where specific sites have not been recorded. For example, many of Alberta's major river valleys are listed as HRV 5 for paleontology, as fossiliferous bedrock exposures and Quaternary deposits are common in these areas.

Development projects that have the potential to disturb historic resources must obtain government approval under the HRA prior to the start of project activities. Developers and mitigation paleontologists use the Listing to determine whether individual development projects may require approval. Projects that do need HRA approval are reviewed by GOA paleontologists. Some reviews of development projects lead to requirements for Historical Resources Impact Assessments and/or Monitoring Programs, which are conducted by mitigation paleontologists through paleontology permits with the GOA.

Originally, the Listing existed only as a table of sites with HRVs and legal land descriptions. Today, the Listing is managed using Geographic Information Systems (GIS), allowing regulators, developers, and mitigation paleontologists to visually compare potential developments to HRV areas. Regulators add or remove areas on the Listing based on the recording of new fossil sites, the observations of researchers and mitigation paleontologists, and local geology information. Updates to the Listing are published publicly online twice per year as both a table and a GIS shapefile, both of which can be searched for specific locations.

Many fossils, including significant and well-preserved specimens, have been found during industry activity in Alberta. The Listing of Historic Resources helps the Government of Albert identify which development projects are likely to impact fossil resources across a geographically large and paleontologically rich province.



ArcGIS Online and the Future of Paleontology Data Collection

Gregory A. Liggett, Bureau of Land Management

The Bureau of Land Management continues to develop an online solution for paleontology permit authorizations and online report submission. The system is intended to centralize and standardize the permit application process across the nation, and allow permittees to submit their required reports directly into BLM's system.

Locality reporting is critical. Knowing where resources are being observed or collected is vital information for the BLM to conduct its resource and land management mandate. And locality reporting is a time-consuming part of the report preparation process for permittees. As a reminder, BLM wants you to report every locality visited during your field season, even if you have reported the locality in the past. We want to document every visit, and all fossils observed or collected should be noted, including non-vertebrates and plants. BLM manages all fossil resources, not just vertebrates.

Presently, the Montana State Office of the BLM enters every locality reported into a standardized database. This requires careful review of every locality form submitted, quality control checking of the information provided against submitted maps, and confirming how the coordinates plot in ArcMap; the process is very time-consuming. However, years of experience in this exercise reveals that reported data can be quite unreliable.

Certainly, some permittees provide careful and highly accurate information about localities and the taxa involved. However, issues such as a heavy reliance on volunteers or inexperienced students to record data, or mistakes in transposition of coordinates from field notes to locality forms, or not recording the datum that coordinates values relate to, or dare we say errors in BLM data entry, all contribute to error. The manual examination of the reported data not infrequently turns up discrepancies in locality coordinates reported year after year or coordinates that do not plot consistent with the locality map provided. For a science that is highly dependent on accurate spatial and stratigraphic data, this situation is untenable.

The BLM hopes that the system currently under development will be a welcome fix for both permittees and the bureau. For narrative portions of the reports, permittees can fill in standardized fields and upload documents. For the critical locality reporting, we hope to make that available in at least two ways, making use of ESRI ArcGIS Online (AGOL) and other emerging technologies (Figure 1).

The first method of locality reporting will be an online mapping interface to AGOL that users could work on from any computer. They could plot localities onto a base map, and then using a form-based interface supply the attribute data such as site name, geological unit, and so on. This workflow could be done after the field season by entering data collected in traditional field notes. However, that still has potential for error in the double entry process.

The second way users can interface with the locality data system will be by utilizing mobile devices. Users can preload GIS map data onto a device for off-line data collection using the ESRI Collector app (Figure 2). That would allow a user to collect crucial locality data while in the field, use the native Geographical Positioning System (GPS) within the device, or upgrade to a higher quality GPS receiver that can communicate with the device, as with Bluetooth technology. The forms, developed in ESRI Survey123 (Figure 3), can also be preloaded, so that all the data can be collected on the spot, and saved to the local device.

When a user later has either cellular or Wi-Fi service, the data collected can be synced with the ESRI system immediately. Thus, the bulk of reporting and the part of the reporting that can be so prone to error is done when leaving at the end of the field season.

Of course, security of the data is a top concern, both to the BLM and to researchers. Data will only be visible to the users that collected it, so individual research teams are not inadvertently sharing their data with others. Also, ESRI servers are maintained to keep data secure, but the plan is to go further in securing the data by pulling the data from ESRI servers into the BLM's systems. This will use ESRI servers as a "pass-through" into secure BLM systems behind our firewalls.

Whereas it has always been true that locality reports to the BLM served as a backup of locality information for researchers and museum repositories, having the data in an accessible digital system further enhances BLM's role as a backup source for that information. Should a catastrophic loss of data occur at a research institution, as in the recent tragic example of the September 3, 2018, fire that destroyed Brazil's National Museum in Rio de Janeiro, BLM can serve as an off-site data repository.

BLM is excited to share with the paleontology community our plans for the online permit and reporting system. The intent is to make the application and reporting process more accurate, and easier for everyone involved.

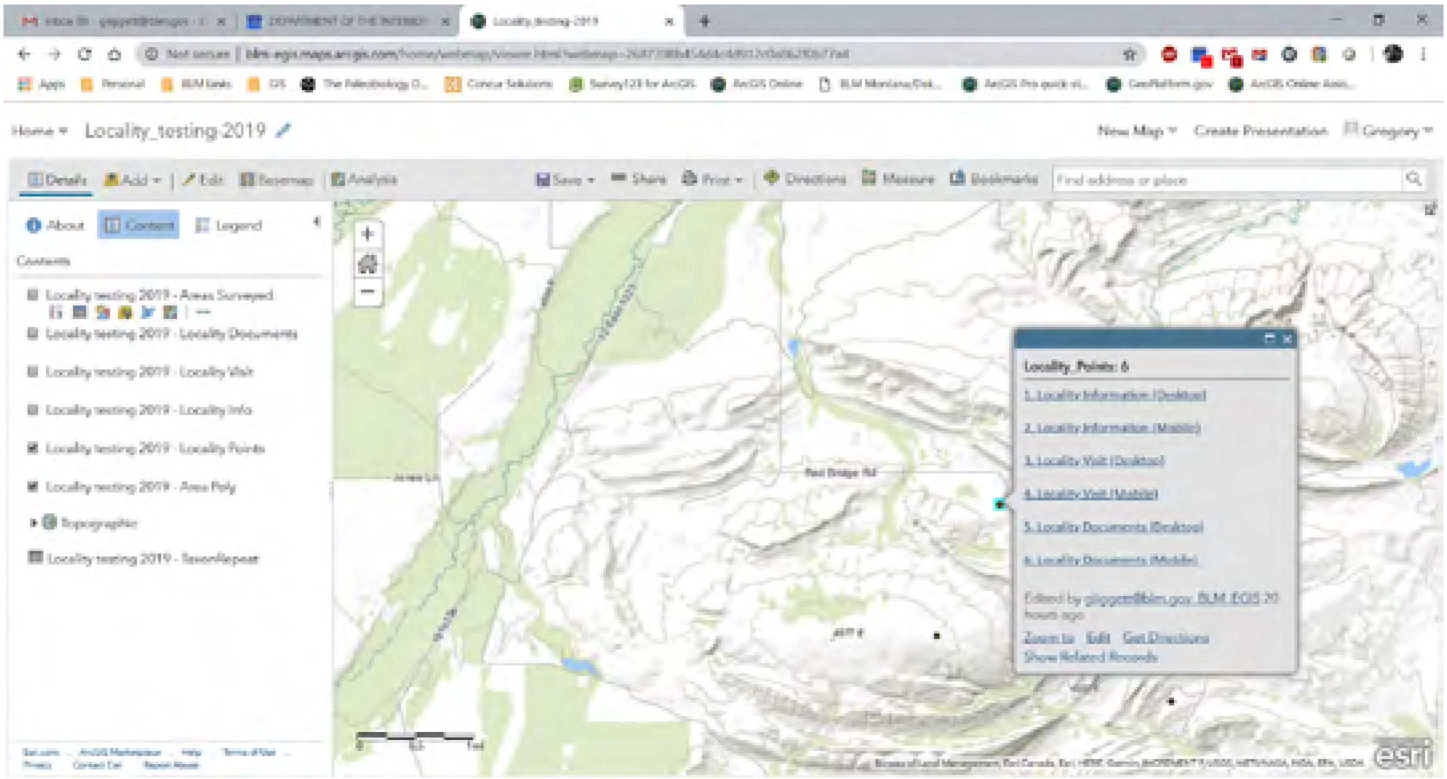


Figure 1. View of a typical ESRI ArcGIS Online Web Map on a computer, showing the pop-up menu that appears when a locality point is selected. The links allow the user to add data.

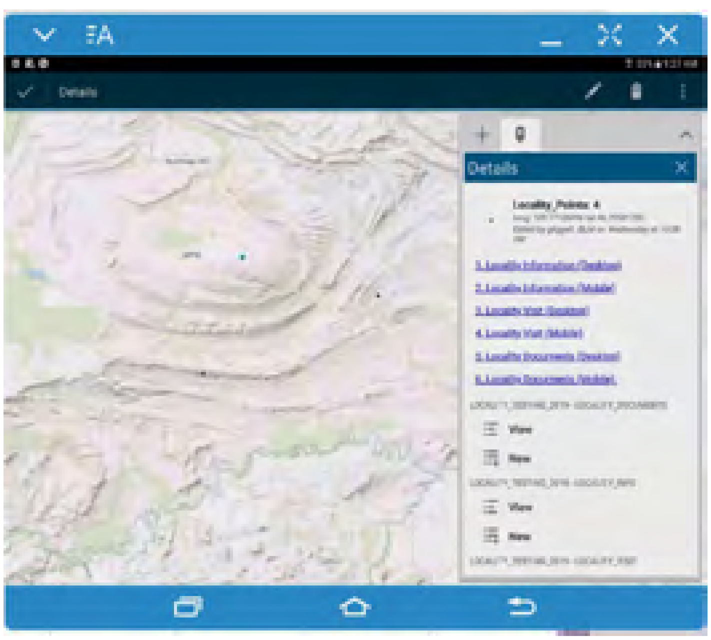


Figure 2. Snapshot of the ESRI Collector App on an android mobile device. Note that the same pop-up menu is accessible as in the computer version.

Figure 3. An ESRI Survey123 form opened on an android mobile device. Forms allow for standardized data collection and a reduction in entry mistakes through the use of domain values preprogrammed into the survey.

Confidentiality and Open Science: A Best Practice for Sharing Paleontological Locality Information

Scott E. Foss, Bureau of Land Management
Kathy Hollis, Smithsonian National Museum of Natural History

In 2002 the President of the Society of Vertebrate Paleontology, Richard Stucky, testified before Congress about the need for a law to protect paleontological resources on public lands, citing multiple cases of fossil theft and fossil locality vandalism throughout the U.S. (Protection of Paleontological Resources, 2002). Any law to preserve paleontology would need to provide criminal penalties for theft and vandalism of paleontological resources and also provide provisions for the confidentiality of field location data. The Paleontological Resources Preservation Act of 2009 (PRPA) provides for the confidentiality of scientific data, but allows bureaus to release locality information to the public when disclosure would: 1) further the purpose of the Act, 2) not create risk or harm to or theft or destruction of the resource, and 3) be in accordance with other laws.

The scientific and social landscape has changed since PRPA was passed in 2009. Today, we live in a society that values sharing information quickly and easily. The scientific community expects open data that facilitates transparency and collaboration (OSTP, 2012). For datasets of biologic and paleontological occurrences, locality data is essential for understanding how and where plants and animals changed through time. Many paleontological resources are at risk of theft or damage when their localities are made publicly available. How can we protect at-risk fossils in an environment where open data is valued?

One of the major online platforms for biologic and fossil occurrence data is the Global Biodiversity Information Facility (GBIF). GBIF is “an international network and research infrastructure funded by the world’s governments and aimed at providing anyone, anywhere, open access to data about all types of life on Earth” (What is GBIF? at gbif.org/what-is-gbif). Data providers such as museums and herbaria make their occurrence data accessible through GBIF. Geospatial data (i.e., locality data) is a basic data element anyone can access through GBIF. Recognizing that locality data of rare, endangered, or commercially valuable biological specimens should not be shared, GBIF published best practice guidelines for protecting species occurrence data in the wild (Chapman & Grafton, 2008). The GBIF guidelines recommend data providers assess how sensitive or “at risk” an organism or specimen would be if its locality was publicly available. The level of sensitivity or risk is translated to five defined categories ranging from 1 (extreme sensitivity) to nonsensitive (see table 1). Each category provides guidance on how much precision should be truncated from the locality data when it is shared with the public.

We propose adopting a professional best practice for publicly sharing paleontology locality data that is consistent with the GBIF guidelines and meets the confidentiality requirements of PRPA. Specifically, high sensitivity (GBIF category 2) would be applied as a default to all vertebrate fossil localities, and low sensitivity (GBIF category “nonsensitive”) would be applied as a default to all nonvertebrate localities. Nonvertebrate fossils (invertebrate and plant fossils) are generally more abundant than vertebrate fossils, and paleontologists often want localities to be publicly accessible so that amateur and avocational groups may discover fossils and share them with the scientific community. Vertebrate fossils are less abundant and generally require more time and care to extract from the ground, so there is a need to leave them undisturbed until adequately equipped and permitted paleontologists can assess how to safely remove them. The default application of high sensitivity for fossil vertebrates and low sensitivity for nonvertebrates covers most of the practical risk to these paleontological resources. In certain circumstances, a vertebrate fossil locality might be assigned to low sensitivity if releasing the information would not result in harm to the resource. Conversely, certain nonvertebrate localities may be elevated to a high sensitivity when releasing the information might result in harm to that resource.

The proposed high sensitivity (GBIF category 2) would have the accuracy of locality data truncated to 0.1 decimal degrees latitude/longitude, which is approximately 6 miles in diameter, more or less depending on actual latitude (see table 2). The proposed high sensitivity would easily correlate to other coordinate systems such as Universal Transverse Mercator (UTM) as 10,000 meters x 10,000 meters or the Public Land Survey System (PLSS) as one township (or 6 x 6 sections). Under the application of high sensitivity locating a precise paleontological locality would be difficult or impossible, but it would be possible to understand the geographic distribution of fossil taxa, especially when conducting a basin, state, or continent-scale analysis. When a researcher or land manager needs to know the precise locality for a high sensitivity locality the information may be shared by the data steward on a case-by-case basis.

Data stewards implementing these recommendations within their data management systems include museums, universities, researchers, and government offices. Each data steward should make these assignments by following this best practice and their own internal policy. When two or more data stewards manage the same data, decisions should be guided by institutional mission. Data aggregators and portals generally release any data that is available, so it is the responsibility of the data steward to apply these best practices prior to releasing locality data to the public.

Responsible care of fossil resources will always require keeping certain field location information confidential, but advancing science and education is contingent on data accessibility. A balance can be found by assessing the practical risk to fossil resources. The differing needs of various fossil resources require different approaches for sharing paleontological locality data. Rather than invent a new system we propose that the GBIF best practices (specifically GBIF category 2 for high sensitivity) be adopted as a professional standard for paleontological locality data.

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GBIF		Proposed Best Practice		
CATEGORY	SENSITIVITY	CATEGORY	SENSITIVITY	DATA TRUNCATION
1	Extreme			Not released
2	High	Vertebrate	High	Rounded to 0.1 degree
3	Medium			Rounded to 0.01 degree
4	Low			Rounded to 0.001 degree
Not Sensitive	Not Sensitive	Non-vertebrate	Low	Unrestricted

Proposed High Sensitivity		
Latitude/ Longitude (Lat/Long)	0.1 degree latitude 0.1 degree longitude	6.9 miles 6.0 -4.5 miles (at 30º-50º N latitude)
Universal Transverse Mercator (UTM)	10,000 meters (10 kilometers)	6.2 x 6.2 miles
Public Land Survey System (PLSS)	1 township/range (36 sections)	6 x 6 miles
Descriptive	County + closest city or geographic feature	

The Good, the Bad and the Ugly – Using Federal Planning Documents as a Measure of Paleontological Resource Management

Andrew Stanton, Utah Valley University

The National Environmental Policy Act (1969) requires all federal agencies to consider environmental impacts when undertaking any major action that could affect the environment. Among the resources that should be considered during the planning process includes any paleontological resources (Foss 2014). The Paleontological Resources Preservation Act (PRPA) specifies that federal land agencies "shall develop appropriate plans for inventory, monitoring, and the scientific and educational use of paleontological resources." One measure of how PRPA is being implemented is to examine planning documents such as Environmental Impact Statements to see if and how fossil resources were included in the planning process.

I measured each agency and unit's compliance with PRPA and paleo resources regulations by examining 614 planning documents from the USFS and each of the land management agencies from the Department of the Interior. Documents were selected from those publicly available on the planning web pages for each agency, or from the websites of the local management unit. I used a simple text search to find keywords, such as "fossil" and "paleontological," and determine the context in which they were used. Results such as "fossil fuels" were omitted.

I conducted over 1600 logistic regressions for the entire data set and multiple subsets and combinations of the data by time, agency, and geographic area. Time subsets included before and after PRPA, and before and after USFS regulations that took effect May 18, 2015. I also did logistic regressions for latitude and longitude. These steps were repeated for 14 factors related to managing paleo resources on public lands. My efforts found over 140 trends that were statistically significant.

My hypothesis was that the passage of the PRPA would cause an increase in planning documents that addressed paleontological resources. It turns out, however, that a decline in planning documents that addressed these resources began in the early 2000s and continued after the passage of the PRPA in 2009.

While this trend is troubling, it appears it is more strongly influenced by an increase in planning documents from land units that did not have a history of including paleo in planning efforts. While progress does appear to be slow, there are some units and regions that do show an increase in the number of planning documents that include paleontological resources. Although observable trends were found for most logistic regression analyses, only a small portion was statistically significant enough (p-value <0.05) to rule out the null hypothesis that the observed trend is due to sampling or experimental error.

Leaving out any discussion of paleo resources in planning documents raises questions as to whether it was done because of the absence of those resources or if it was due to negligence. While the absence of any mention of paleontological resources could be simply due to the lack of any known resources within the management area, such absence should be noted in these planning documents. This is the same standard used for other types of resources, such as cultural and archaeological resources, and endangered or sensitive species. The standard I used for this analysis is a statement such as "no paleontological resources are known to exist in the project area." If similar language was used, I scored the planning document as having addressed paleontological resources. I also recorded which documents mentioned basic protections for paleontological resources, including how newly discovered resources should be reported, if field surveys and inventories should be conducted, and any mention of permit requirements, etc.

I found more variation across the Department of the Interior than for any individual agency within the department. The Department of the Interior had similar results to the trends for the entire data set. Nineteen trends were deemed to be statistically significant with p-values below 0.05. For all logistic regressions across the Department of the Interior by latitude show a higher proportion of the more northerly and westerly units having a higher probability of addressing issues related to paleo resources in their planning documents. These trends were often skewed by a number of more detailed planning documents from Alaska. Alaska was the only state in this study that mentioned the abandonment of a project to be an option if paleontological resources would be impacted, and it was one of only five states to have planning documents that mentioned redesigning a project to be an option if paleontological resources would be impacted. Documents from California also had an affect on trends, however excluding California typically made trends more defined.

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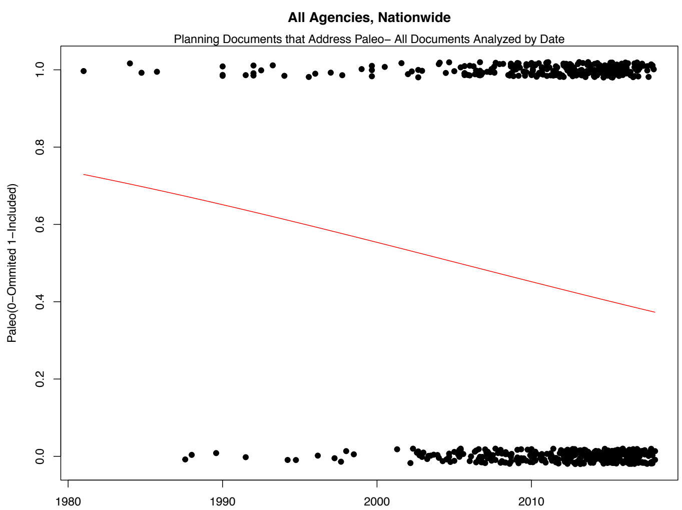
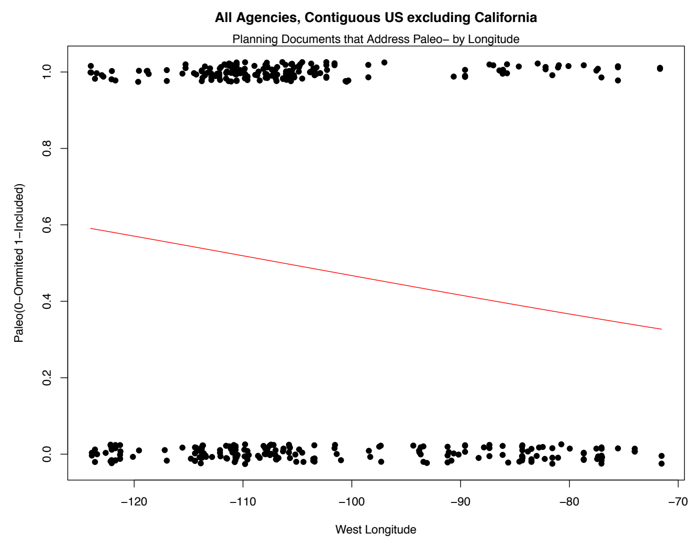
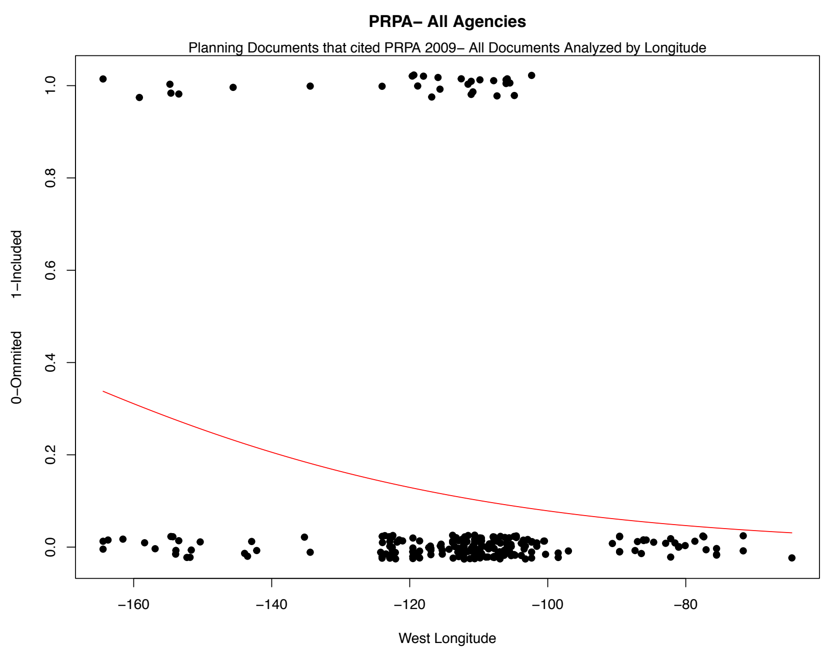






A MAP to Manage Paleontology

Scott E. Foss, Bureau of Land Management

Those of us who manage fossil resources are bureaucrats, not politicians. The politicians who make laws are generally people who do not know what paleontology is. In many countries existing legislation that would provide for the preservation or protection of fossils is nested in laws that are directed at antiquities, but not fossils. To the public, and politicians, the word paleontology is often synonymous with the word archaeology, and archaeologists are often asked to manage paleontological resources. Unfortunately, archaeological laws and practice are often inappropriate when applied to problems of paleontology, which is a completely different discipline and associated with a completely different science. This is not to pick on archaeologists, who feel the converse of the paleontologist's pain when the subject of archaeology is construed to include dinosaurs. Archaeology is a fine profession, but asking an archaeologist to manage paleontology is akin to asking a podiatrist to care for your toothache.

THE MAP

Managing paleontology requires the development of a program that fits the needs of science and society. Here, I present a road map, or MAP, to manage paleontology that should fit any bureaucracy or governing structure. This involves a mission **(M)** that articulates the purpose for managing paleontological resources. The mission might be simple or complex, but must be consistent and attainable. The mission must also be framed in a legal context of authorities **(A)**. Authorities include statutes, laws, written rules, and policy. The primary statute that authorizes the BLM paleontology program is the Paleontological Resources Preservation Act of 2009 (PRPA), but there are many other statues and policy that also authorize and guide the program. Finally, managing paleontology requires a detailed structure or program **(P)**. A paleontology program must have a mission that is consistent with applicable authorities (and not in violation of other authorities) in order to be successful, and should also consist of the following program components: inventory and monitoring; planning and mitigation; collection and curation; and education and protection. The MAP provides a rational structure for developing a paleontological management program that can be transposed to any governing structure.

MISSION

The mission articulates the purpose for managing paleontological resources and is based on value, which is not the same in every country or state. What is needed; fossil protection, management, science, collecting, commercial enterprise, etc.? One value or collective need must find its way to the top and be articulated as the mission. The mission must also be attainable and rational. Is it to do science? Then what are the overarching scientific questions? And the mission must establish why you would manage paleontology and have a clear understanding of the goal. Implementation of the mission is wholly dependent upon laws and policy.

AUTHORITY

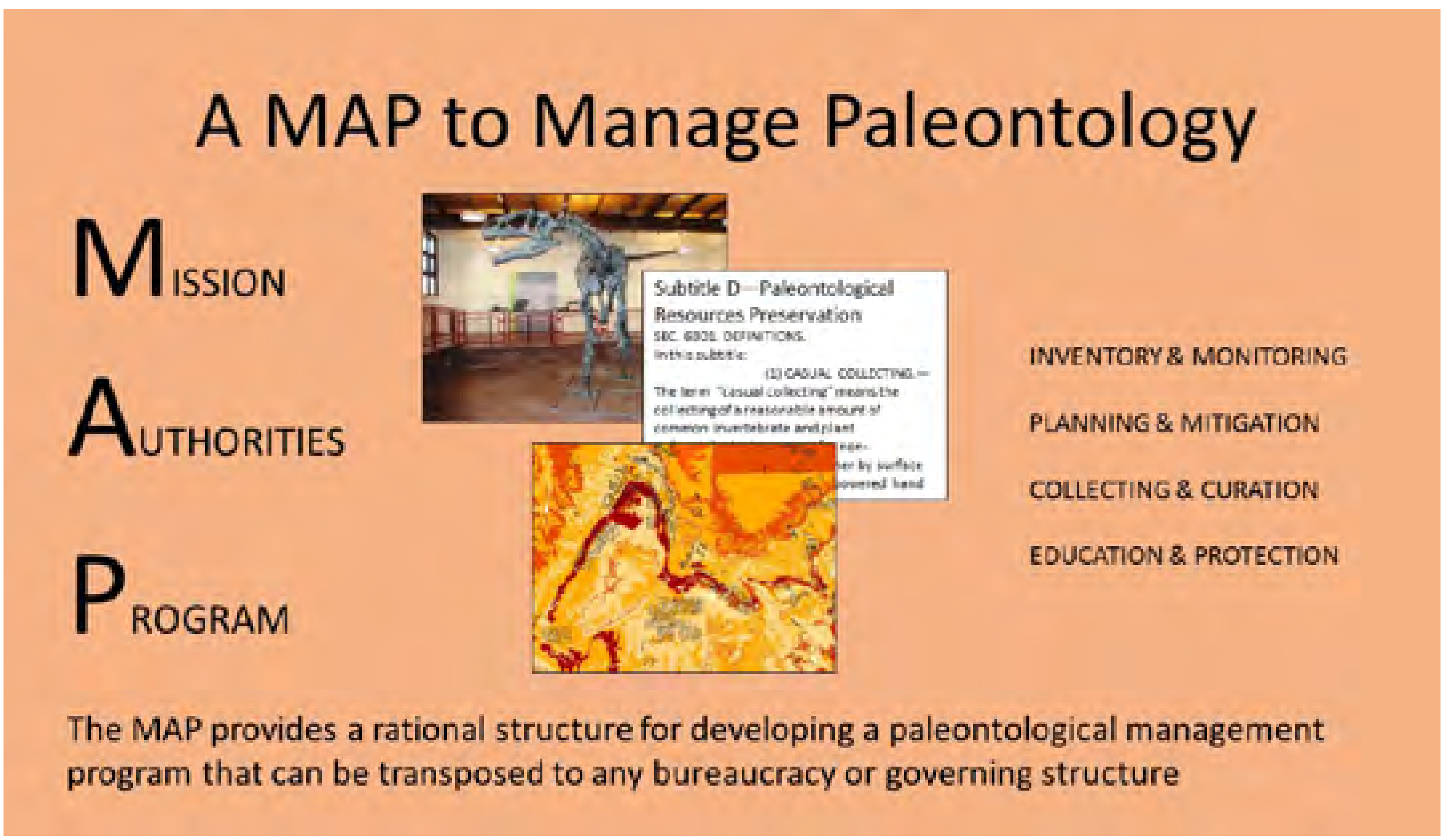
Authorities are statutes, laws, written rules, and policy that allow for the mission to be realized. It is best when the laws are written to address the needs of fossil resources, though this rarely happens. In the best of circumstances, the laws will articulate a mission by which to manage paleontological resources. More often a paleontology program must be based on a patchwork of laws that incidentally apply to fossils. In all cases, it is necessary to know the broad range of laws that apply to the land. We take these laws and knit them into a fabric that is the program that we enact.

PROGRAM

If authorities are the what, then the program is the how. First and foremost, the program must be an outgrowth of both the mission and the authorities. For example, the BLM and the NPS are both part of the U.S. Department of the Interior but have important differences. The BLM is mandated by PRPA to allow the casual collection of reasonable amounts of common nonvertebrate fossils to the public without a permit. Such collecting is an anathema to the NPS, which not only forbids the casual collection of fossils but does not allow collecting of any kind without a permit. This difference is not only present in the law that authorizes the management of paleontology (PRPA), but is also inherent in the enabling legislation, and thus the primary mission of each bureau. The BLM is established to manage the public lands and their various resource values so that they are utilized in the combination that will best meet the present and future needs of the American people (Federal Land Policy and Management Act of 1976). This is generally referred to as the bureau's "multiple use" mandate. The NPS, on the other hand, was established with a single mission to "conserve the scenery and the natural and historic objects and the wildlife therein and to provide for their enjoyment in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS Organic Act of 1916).

The result of different enabling legislation and separate bureau mandates is that the program for each bureau will be unique, though PRPA does provide for the land management bureaus to coordinate to the extent practical.

Any program must address inventory and monitoring, planning and mitigation, collecting and curation, and education and protection. It would, therefore, be most constructive for any legislation for the preservation or management of paleontological resources to provide appropriate authority for these eight program areas, with special emphasis on its specific need. “The Paleontology MAP,” consisting of Mission, Authority, and Program, provides a rational paleontological management structure that can and should apply to any paleontological legislation and subsequent bureaucracy in any country or state.



The Potential Fossil Yield Classification (PFYC), Present Status Within BLM

Gregory A. Liggett, Montana State Office, Bureau of Land Management
Philip A. Gensler, New Mexico State Office, Bureau of Land Management

The Potential Fossil Yield Classification (PFYC) system is a predictive model of where scientifically important paleontological resources (fossils) of all taxonomic groups may occur. It is based upon the assumption that geologic formations that have produced scientifically significant fossils in the past are more likely to produce them in the future, compared to geologic units that have not been shown to produce scientifically important fossils. The ranks potential fossil yield are assigned to geologic units by qualified BLM paleontologists, and the six ranks of the PFYC are: 1) very low potential; 2) low potential; 3) moderate potential; 4) high potential; 5) very high potential; and 6) unknown potential. Additional mapping ranks include water and ice.

After extensive experience working with the PFYC, the BLM has settled on a formal national standard for the completed PFYC package. The standard includes two parts: documentation and a geodatabase. Documentation includes 1) a document outlining the geologic units of a state; 2) an extensive literature review of each unit; and 3) a brief justification for the PFYC ranks assigned. The geodatabase has two features, both comprising standardized attribute data. One of the features contains index information about the source map data such as map name, when it was published, and so on. The other feature holds the geologic polygons and detailed information about the mapped units. Where appropriate, domain values for fields were established to promote consistency in the data, and standard formats were applied to the rest.

Geologic maps vary in scale and in the skill and subject expertise of the mapper. An assumption of the predictive model is that the highest scale maps made by competent geologists are the best data to work from. The BLM has been engaged in an active campaign to compile the highest scale digital geologic maps for each of the western states and to merge those maps into a mosaic by state. Generally speaking, the lowest scale map is a state-wide geology map, often at 1:500,000 scale. That is used as the base map. Higher scale maps are “cut into” the base map, replacing the lower scale data. Information from the source maps are retained in the index feature layer, and geologic data populate the attribute table of the geology polygon feature. A representation is built into the geodatabase to apply standard color-coding to the maps based on the PFYC values.

What is the current status of finalized BLM PFYC maps?

Alaska: GIS data is in the data standard, document being compiled

Arizona: working GIS version, document being compiled

California: southern part of state GIS is close to standard, document is finished

Colorado: GIS data is close to standard, document being compiled

Idaho: GIS partially done not to standard, document being compiled

Montana, North Dakota, South Dakota: working GIS version compiled not in the standard format, and document is finished (Liggett and Silsbee, 2014)

Nevada: GIS data is close to standard, document being compiled

New Mexico, Oklahoma: working or partial GIS versions, document being compiled

Oregon and Washington: GIS data is close to standard, document being compiled

Utah: GIS data is close to standard, document being compiled

Wyoming: GIS data is in the data standard, document being compiled

The intent of the BLM is to freely share the completed data sets to anyone interested, including other agencies, consultants, and the general public. As new maps become available digitally, the data sets will need to be updated periodically.

The data is used internally for assessing mitigation efforts for ground-disturbing activities, finding potential areas to promote the casual collection of fossils as required by the Paleontological Resources Preservation Act (PRPA), and identifying areas that hold high potential for scientific research that have not been visited by researchers. Thus, these data sets are invaluable for the management of fossils on public lands.

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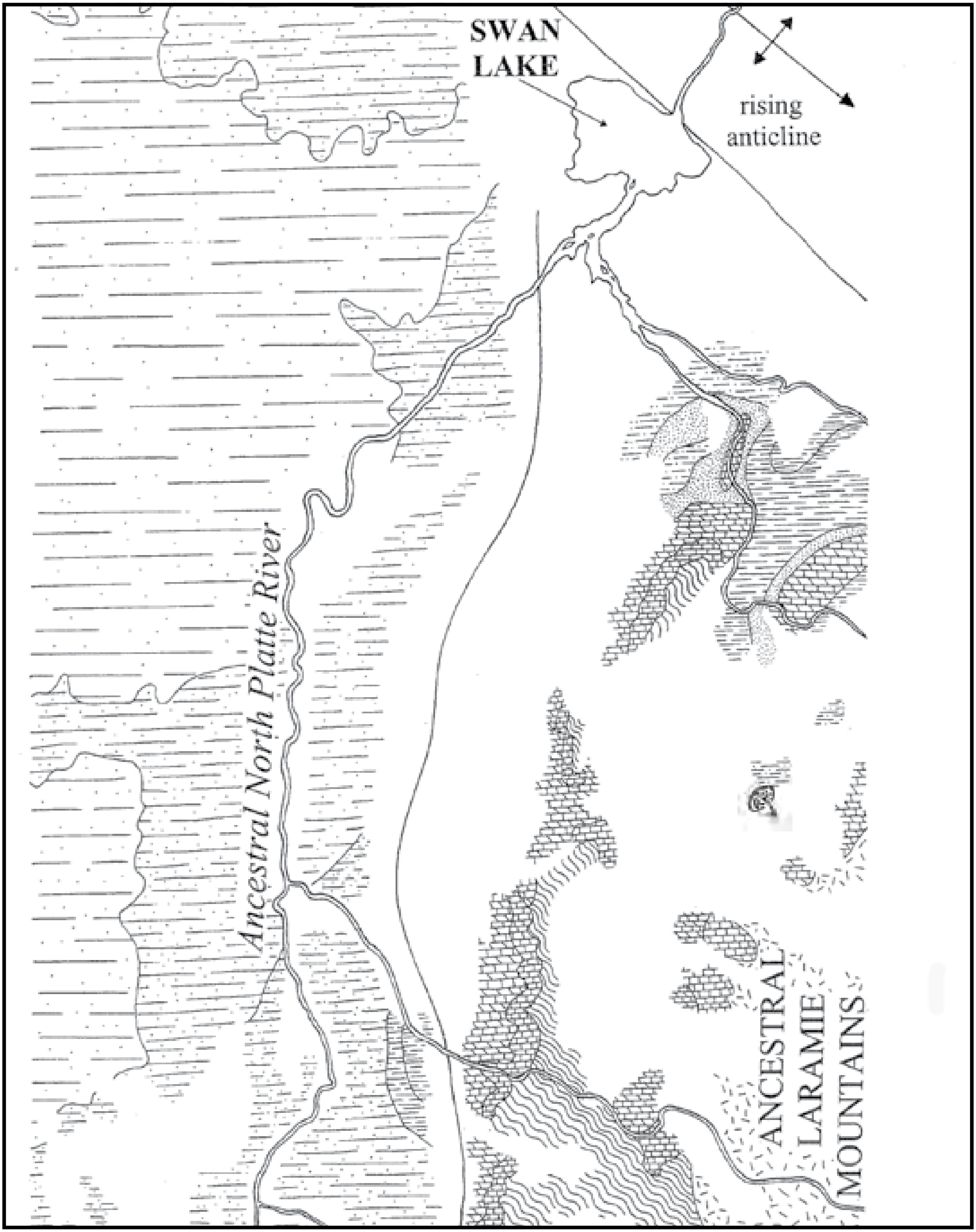

SWAN LAKE
rising anticline
Ancestral North Platte River
ANCESTRAL LARAMIE MOUNTAINS

Minding the Neighborhood: Insights From Two Decades of Paleontological Research on Public Lands

Douglas G. Wolfe, Zuni Dinosaur Institute for Geosciences (ZDIG)

Fossils resources on public lands are a critical resource for STEAM education, citizen participation, and community development. In the Four-Corners region of the southwestern U.S., public lands managed by U.S. BLM commonly provide unique windows to geologic outcrops that otherwise extend to less-accessible lands owned by private, Native American or corporate interests, or managed by more restrictive federal or state agencies (Department of Defense, National Parks, Wilderness Areas, etc.).

Successful fossil collection leading to scientific publication requires interdependent steps beginning with identification of property ownership, access, and permit requirements. Federal collection permits require designation of a repository, that principals have requisite experience and ability to collect specimens in geologic context; and preparation/curation of specimens to acceptable standards. Repositories must provide sufficient feedback and documentation for annual permit reports, and to meet scientific publication standards.

Meeting these conditions may challenge smaller museums, colleges, schools, and avocational institutions. Many institutions have limited preparation and storage capacity, and some have initiated curation storage fees. Many open-access journals provide a cost-free service to the public but require a fee from the author(s). The 2009 PRPA mandate to survey and mitigate fossil resources on federal lands benefits identification and salvage of fossil resources, but also adds a commercial imperative and additional demand for curation space. Fossils recovered from paleo-mitigation projects may not receive the same level of discovery-to-publication interest as those from problem-directed research.

Smaller institutions, students, citizen scientists, and volunteers can meet these requirements through collaboration. Over 20 years of permitted research, collaborative efforts in the Moreno Hill Formation in western New Mexico (The Zuni Basin Paleontological Project) have described four new dinosaur genera including the horned dinosaur *Zuniceratops*, the Therizinosaur *Nothronychus*, and a soon-to-be-published tyrannosaur. Collaborators have included volunteers from the Southwest Paleontological Society, Mesa, Arizona; graduate and high-school student volunteers; citizen scientists and teachers; geologic professionals; and researchers from universities and institutions from around the world.

In addition to basic permit requirements, experience indicates that consideration of the following factors may be warranted:

These are not your fossils; although some may attach an outsize or inappropriate sense of ownership to fossil discoveries. From discovery to curation, the individuals and institutions responsible for fossils from public lands are stewards of resources owned by the citizens of the U.S. This should be clearly expressed to volunteers, students, and institutional partners who may be less familiar with rules governing fossils from public lands. Permits confer no proprietary benefits to researchers from fossil resources which remain accessible to other researchers and future generations.

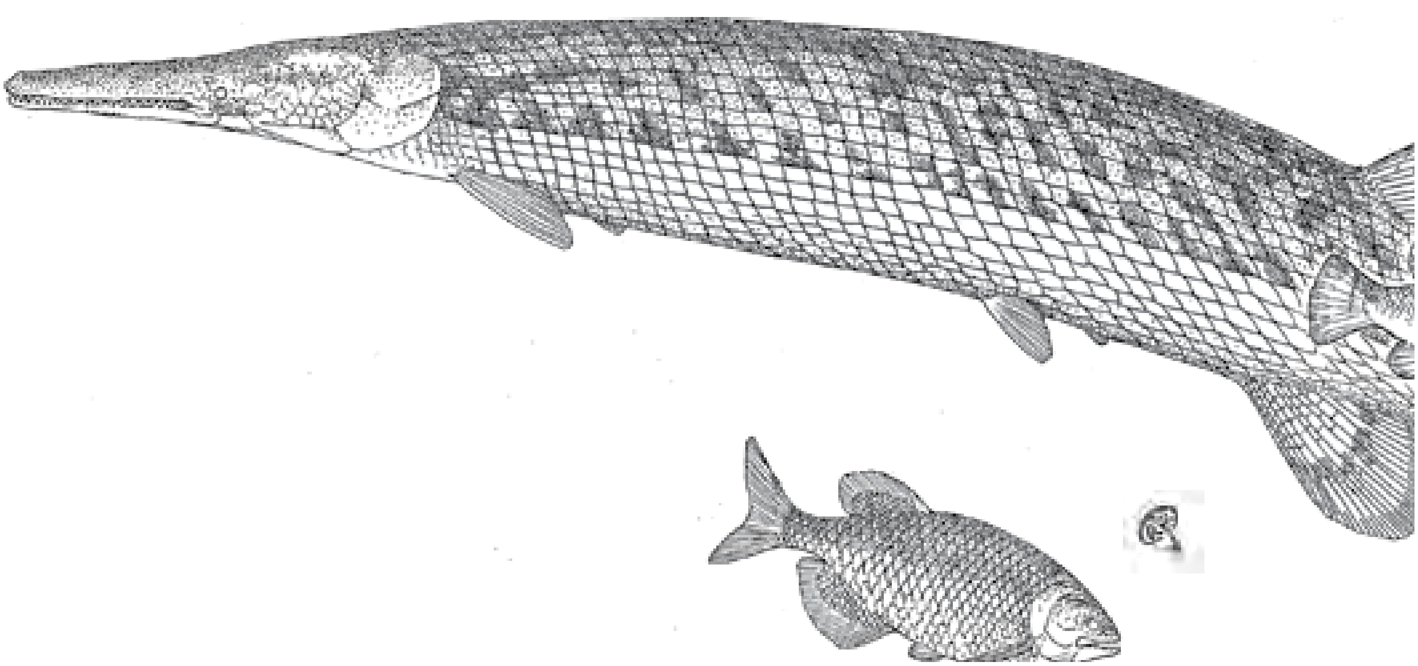
The paleontological resource "value" will not be immediately apparent. A dinosaur skeleton (from private land) may sell for millions of dollars at auction, and energy companies may spend millions drilling to find diagnostic biostratigraphic index fossils, commonly tiny plankton such as foraminifera, to establish regional correlations leading to major hydrocarbon discoveries. Recalibration of Cretaceous stratigraphy in the Zuni Basin based on microfossils and invertebrate index fossils led to discoveries of the "middle-Cretaceous" Zuni Basin dinosaur assemblage, new fossil tree species, trackways, insights into climate, continental connections, and the early evolution of well-known dinosaur taxa. In all cases, collection of data beyond recovery of "trophy" specimens provides added value, important context, and data leading to insights years later.

We are not archeologists; though we will be taken as such by the neighbors. Many Native lands and ranch lands have suffered a legacy of "pot-hunting," the often unlawful removal of cultural artifacts, and fairly or not, the permittee should prepare to understand the basic cultural context of the permitted area and to answer questions from some who may assume the worst. A community suspicious of geologists, archeologists, or government officials based on past experience, may harbor concerns about nearby paleontological collecting. Permitted collecting on public lands should seek to improve community appreciation of local fossil resources, their scientific importance, and leave a positive impression of scientists as careful stewards in general.

This is not your back yard; In the open spaces of the southwest, many ranchers/landowners lease the same lands for grazing and other purposes. Leaving open gates, transgressing property boundaries, damaging roads, or making new roads are especially offensive to these citizens. Native Americans are acutely aware of activities in and around their lands; and often maintain deep and complex feelings and history about landforms, the Earth, fossils, and cultural remains; much that is rarely expressed outside the local community, and differing between cultures. Many examples of fossil-bearing strata on federal land, including Chaco Culture Historical Park in northwest New Mexico, also intersect irreplaceable cultural resources. Future access to fossil resources on some public lands will depend in part on consultation and collaboration with neighboring interests and disciplines.

Institutional vision, priorities, leadership, and staff will change over time. Fossils may survive millions of years; people and institutions do not. Holotype specimens have been lost, stolen, or damaged in museums worldwide; the September 2018 fire at the national museum in Brazil is a tragic example. With time, institutional and human memories become disconnected from original insights gained during discovery, excavation, and study.

By maintaining continuity of geologic context, curation standards, documentation, and results of study over time, the maximum value of fossil resources can be preserved. Additional support is required to meet basic requirements for fossil resource protection and study more broadly. Decentralized curation of local reference collections, duplicate casts, and supporting publications can help promote stakeholder support while creating additional curation capacity, preservation of data, and historical context. Smaller institutions, volunteer organizations, students, and citizen scientists can contribute to these goals. Policy considerations should include wider distribution of access and resources for study and curation of fossil resources to the local STEAM-related organizations and communities neighboring public lands.



Locating Fossil Localities in the White River Badlands Using Historic Journals, Sketches, and Photographs of Past Paleontologists

Emmett Evanoff, University of Northern Colorado

The first vertebrate fossils collected from the western United States came from the White River Badlands now in Badlands National Park and Buffalo Gap National Grasslands, South Dakota. The first fossils were gathered in the 1840s by trappers and traders of the American Fur Company along the wagon road between Fort Pierre on the Missouri River and Fort Laramie on the North Platte River. These fossils were sent to St. Louis and eventually made it to Yale University and the Philadelphia Academy of Natural Sciences. The provenance is not known for these first specimens beyond the Mauvaises Terres, the French name for the Badlands. The first scientific expedition of the area was by John Evans in 1849 as part of the geologic survey of Wisconsin, Minnesota, and Iowa led by David Dale Owens. Though Evans had an artist on the expedition (Eugene De Girardin) and made a report and crude map of the area (Evans, 1852) no detailed locality information can be determined beyond the east and south sides of Sheep Mountain Table.

The first fossil locality in the Badlands that can be determined in detail comes from the journal of Thaddeus Culbertson who traveled to the area in May 1850 (published by McDermott, 1952). Culbertson was a student from Princeton University who traveled west along the Missouri River to study the animals and Native Americans but was asked by Spencer Baird of the Smithsonian to make a collection of vertebrate fossils from the Badlands. Culbertson's journal gives a detailed description of the route and specifically states that he collected fossils along the base of the buttes currently located just south of the town of Scenic, South Dakota. Spending only one day at the locality (May 13) he and his companions collected the type specimens of *Hyracodon*, *Agriochoerus*, and *Mesohippus* (Leidy, 1850; Emry and Purdy, 1984).

Fielding B. Meek traveled to the Badlands and worked with a young Ferdinand V. Hayden in June and July of 1853. Sent west by James Hall of New York to collect fossils in the Badlands, Meek kept a detailed journal and made sketches of the area. The journal has been published (Fryxell, 2010) but the mostly unpublished sketches are in the James Hall Archives in the State Library of New York in Albany (see Figure 1). Meek's sketches show only two areas with fossils (Figure 1) and are difficult to find because they show multiple, nonadjacent landforms and are not a photo-realistic rendering of individual sites. However, from the sketches and the descriptions in his travel journal, they collected fossils on the east side of Sheep Mountain Table, along and just north of the modern access road to the Table. Unfortunately, the specimens they collected were largely dispersed as Hall sold them to collectors to raise money for his studies in New York.

Harold Rollin Wanless was a graduate student at Princeton University working with William J. Sinclair in the White River Badlands between 1920 and 1922. Wanless took many photographs of the topography, roads, camps, and fossil localities in the area. Wanless' son, Hal Wanless, has provided over a hundred photographs taken by his father during this time (not all taken in the Badlands) and provided a copy of a detailed journal Wanless made in 1920 when he worked for Sinclair. Three of these photographs have paleontological significance: 1) the type locality of *Archaeotherium wanlessi*, 2) the type locality of *Archaeotherium clavus clavus*, and 3) a view of the Bear Creek pocket, a site east of Sheep Mountain Table which was the most productive fossil locality that Sinclair and Wanless found in 1920. This site was also collected by Meek and Hayden in 1853, but the locality is now being buried under sediment eroded from the adjacent badlands walls. These photographs allow for detailed descriptions of the locations (including GPS UTM and Lat/Long data) and stratigraphic positions of specimens that were collected almost a century ago. These data also provide a historical perspective for land managers to understand and protect the fossil resources in Badlands National Park and the adjacent Buffalo Gap National Grasslands.

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Figure 1. F.B. Meek's sketch of the fossil beds in the Mauvaises Terres, made on July 9, 1853. The buttes in the sketch are combined from various places near the headwaters of Bear Creek just east of Sheep Mountain Table and do not represent the view of a single location. The density of fossil tortoises and skulls shown in this sketch may have reflected the actual abundance of fossils in the early 1850s. This sketch is one of several in a notebook in the James Hall Collection of the New York State Library in Albany. It has been published as Figure 71 by Hanson, 1976, and has been incorrectly attributed to F. V. Hayden.

Characterization of a new Eocene Lagerstätte along the Wild and Scenic Flathead River

Dale E. Greenwalt, National Museum of Natural History

The Kishenehn Formation consists of 45-million-year-old riverine and deltaic sediments and is exposed along the western boundary of Glacier National Park. The first fossils in the formation were found over a hundred years ago by F.C. Daly of the Geological Survey of Canada. Fossils include fully articulated fish, described by Mark Wilson in 1994 and 2016, and isolated individual mammalian jaws and teeth. The first of the mammalian fossils were described from the Kishenehn Formation in 1954. In 1990, Malcolm McKenna described the jaw of an arboreal primate related to extant insectivorous members of the family Tarsiidae that today are restricted to islands of Southeast Asia. A 2018 study by Mary Dawson and Kurt Constenius described 26 mammalian taxa. Invertebrate and plant fossils are also present. Fossil gastropods, described by Harold Pierce and Kurt Constenius in 2001 and 2014, are present at a number of sites including a “Gastropod Zone” in the middle sequence of the Coal Creek Member of the Formation. Leaves are rare but can be found in deposits of very coarse sandstone; the large grain size of this matrix, unfortunately, has limited preservation of much morphological detail. Amber is also present although it is very fissile and has not been shown to contain inclusions. Chemical analysis of the amber may provide information about the species of tree that produced the original resin.

Of potentially greater significance are the insects. The first insect fossil collected in the formation, a caddisfly case, was collected by the U. S. Geological Survey in 1953. In the 1980s, Kurt Constenius discovered large numbers of insect fossils in a 45-m thick layer of lacustrine oil shale exposed along the Middle Fork of the Flathead River; this discovery went largely unnoticed – only a single new species, a crane fly (*Helius constenius*) described by Wieslaw Krzeminski in 1991, was named during the following two decades. Starting in 2009, the author has established a collection of approximately 10,000 specimens of fossil insects for the National Museum of Natural History in Washington, D.C. The insects are almost always small – specimens over 1 cm in length are extremely rare – but the preservation of anatomical detail is unprecedented. Characterization of these specimens has documented insect diversity that rivals that of the several better-known North American insect localities. For example, there are 31 families of flies (Diptera) documented in the Kishenehn Formation as compared to 37 in the Florissant Formation, 28 in the Green River and 15 in the Okanagan; seven of the Kishenehn dipteran families have not been reported from other North American localities. Nearly 20 scientific papers have been published and over 50 new insect species, several new genera and a new family have been described. The presence of this new insect Lagerstätte is particularly important given the absence of Eocene amber deposits in North America.

Also unique to the formation is the preservation of original biomolecular components (e.g., remnants of host blood in an engorged mosquito), a characteristic that has generated substantial publicity. The four fossils of blood-engorged mosquitos from the Kishenehn Formation are the only such specimens known to science. Other examples of preservation of original biomolecules include a jaw-hardening metal complex in a rove beetle. The outstanding preservation of the insects has provided an opportunity to study the taphonomic processes by which the fossils were preserved. The depositional environment appears to involve a lake surface covered by a cyanobacterial mat. It is hypothesized that the mucin-rich mat trapped tiny insects and enveloped them as the mat grew, entombing and protecting the insects from predation and degradation. Actualistic experiments with cyanobacterial mats collected from the Everglades have demonstrated an insect fauna similar to that found in the thin lacustrine shale of the Kishenehn Formation.

The notion of deep time fossils as reservoirs of an organism’s original molecular components is a relatively new one and a concept that has piqued the interest of the lay public. For example, one of the blood-engorged mosquitos is the subject of an exhibit at the National Museum of Natural History. In addition, the Exploration Station network’s program “Awesome Planet,” broadcast by Fox television, aired an episode based on the collection of insect fossils along the Middle Fork of the Flathead River in 2017. In contrast to this publicity, the fossil locality itself is isolated and essentially unknown to the public. Accessible only by raft, the collecting sites are on federal lands on both sides of the river between Glacier National Park and the United States Forest Service property to the west. Recreational rafters and guided fishing parties are unaware of the paleontological resources exposed along the river. The scientific community, however, is becoming more aware of this unique resource. Scientists from Simon Fraser University in Vancouver, Canada, have collected at the locality as has the staff of the Flathead Valley Community College. For several years, the Montana State University Undergraduate Research program sponsored summer interns who collected insect specimens and studied the geological and paleobiological features of the formation. As new discoveries from the Lagerstätte are described in the press, the public's knowledge of the presence and importance of the formation's unique fossils will become more widely known.

Figure 1. Exceptional preservation of a rove beetle (Colecoptera: Staphylinidae) in Kishenehn Formation oil shale. Scale bar = 1 mm.

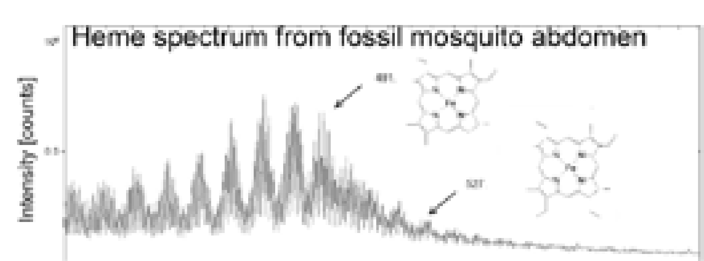


Figure 2. Mass spectrometric identification of the porphyrin heme in the abdomen of a Kishenehn Formation blood-engorged mosquito.

Figure 3. Fording the Middle Fork of the Flathead River to reach the Park Site exposures of the Kishenehn Formation.

Summary and Lessons Learned regarding US Forest Service Program Administration and Law Enforcement and Investigations for Paleontological Resources

Barbara A. Beasley, USDA Forest Service, Minerals and Geology Management

Prior to 1986, the USFS required a permit for collecting any paleontological resource from National Forest System Lands (NFSL), 36 261.1a "Prohibit the excavation and removal of any paleontological object from NFSL without first obtaining a special use authorization." In 1986, 36 CFR 261.9(i) Prohibitions Property section was published in the Federal Register Vol. 51 No 165; as "Excavating, damaging, or removing any vertebrate fossil, or removing any paleontological resource for commercial purposes without a special use authorization." This verbiage was added during the final Office of Management and Budget review of the 36 CFR Prohibitions; Property section.

As published, 36 CFR 261.9(i) was not based upon any statute or policy, as stated in the summary of the Federal Register, "In keeping with the language of the Archaeological Resources Protection Act of 1979 and in response to informal comments from the scientific and academic communities, the FS is clarifying its regulations concerning fossil collection on NFSL." For almost 30 years, this paleontological regulation caused confusion. Until the publication of Federal Register, Vol. 80 No.74, April 7, 2015, 36 CFR 261.9(i) was removed because it was inconsistent with the Paleontological Resources Preservation Act 2009, 16 U.S.C. 470aaa-5 and 291.27(a)(b) of the final regulations, which would prohibit the sale or purchase of paleontological resources from NFSL.

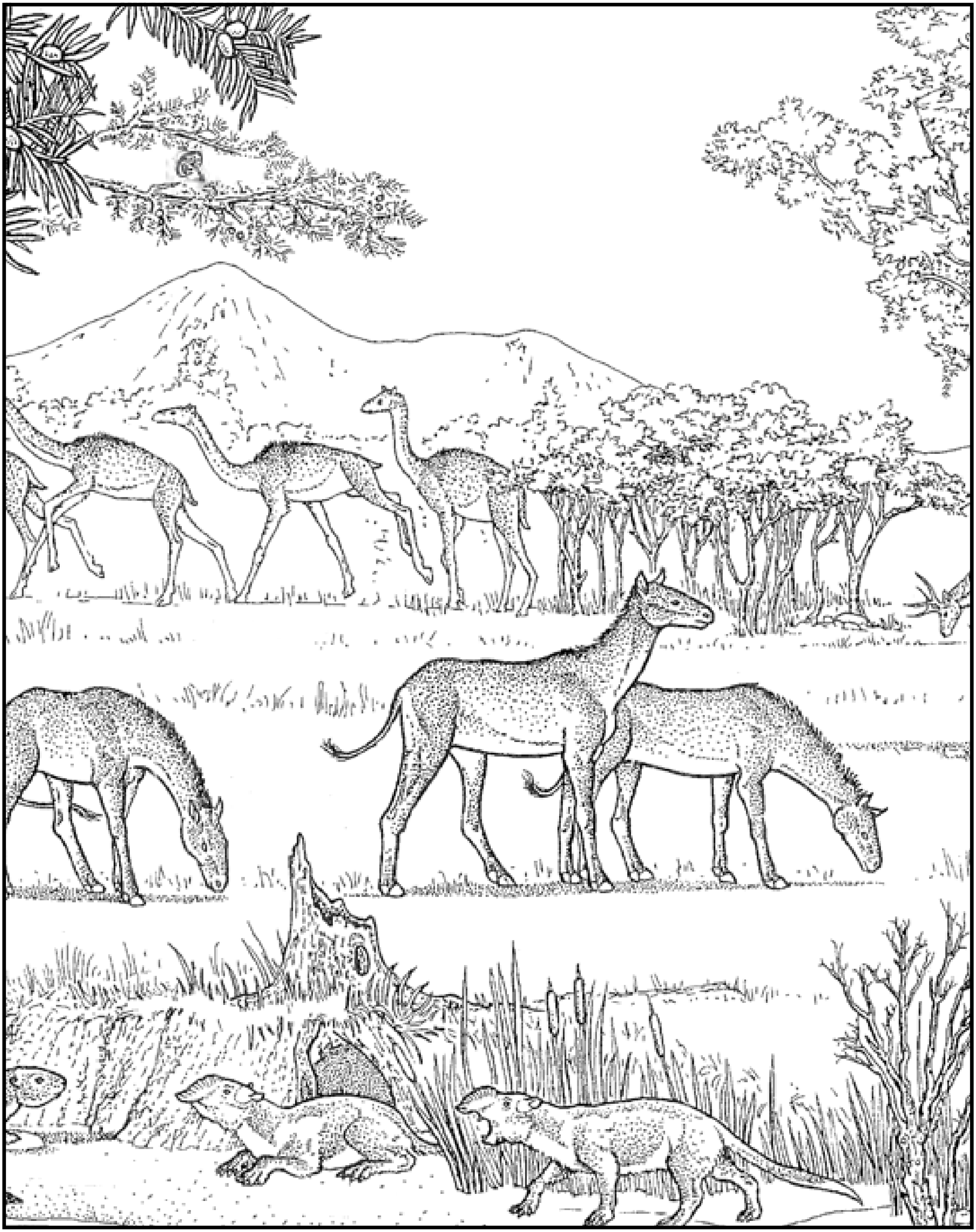
The US Forest Service Law Enforcement and Investigations (LEI) has a history of paleontological resource theft and vandalism, dating back to1985 with the Frank Watson Case. The "Sue" case, US vs. Black Hills Institute of Geological Research (BHI) was a civil case in 1992. The most comprehensive paleontological resource thefts were presented in the criminal case; US vs. BHI, in 1996. Resulting from this case, LE&I in South Dakota and Nebraska has a keen focus on paleontological resources with several cases actually making it to sentencing or pleas. Quoting former Pine Ridge District Ranger, Pat Irwin, "Fossils are Nebraska's (National Forest) timber program."

I credit 1991 Nebraska National Forest Heritage Resource Manager, Terri Liestman, for recognizing the theft of paleontological resources on NFSL by initiating Challenge Cost Share Agreements to conduct paleontological resource inventories and she hired the first paleontologist in the FS, thus providing the foundation for a new program. The developing USFS Paleontology Program continued with these inventories through 1996 and, these remain the only forest and grassland wide (border to border) inventories in the FS. The results of these inventories were presented to Congress supporting the need for a national paleontological resource preservation law.

After the passage of Paleontological Resources Preservation Act, 2009, an interagency coordinating team (ICT) consisting of representatives of Bureau of Land Management, USFS, NPS, and US Fish and Wildlife making up about 23 members, (no LEI) to develop the unified regulations. Once finalized, each agency was to use these agreed upon definitions and proposed regulations for their agency. Thanks to Mike Fracasso's leadership, USFS published 36 CFR 291 Paleontological Regulations in 2015.

My experience is that crucial errors are not always discovered in the review process. Since 36 CFR 261.9(i) was removed from FS prohibitions in 2015 and not replaced with another paleontological regulation in the Prohibition of Property section, there is no longer a misdemeanor relating directly to paleontological resources. A temporary fix is to cite 36 CFR 261.9(a) "Damaging any natural feature or other property of the US" and/or (b) "Removing any natural feature or other property of the US." Paleontological resource theft would only be known and counted when the citation uses fossiliferous keywords when entered into LEIMARS or another database.

Another issue discovered is the felony limit is $500; this lower felony limit is not the misdemeanor; it is a lower felony limit. All fossil thefts are felonies, with the exception of citing 36 CFR 261.9(a) or (b), inconsequential to the dollar amount; exactly opposite of the intentions of the federal agencies, Congress, and ICT.



Establishing a Baseline of the Elemental Composition of Fossil Bone From the Morrison Formation Using a Portable X-ray Fluorescence Spectrometer (XRF): Possible Use in Paleoforensics

Robin L. Hansen, Bureau of Land Management
H. Gregory McDonald, Bureau of Land Management

The preservation of bone through permineralization is dependent on the mineral content of the surrounding sediments and the chemistry of the groundwater that transports the minerals from the sediments into the bone. Depending on the minerals present this will result in different elements in different proportions being deposited resulting in a "chemical fingerprint." How consistently the chemical fingerprint is present in bones from different localities within a single formation has not been documented. While it is expected that fossil bones from different members within a formation would be different in their chemical composition, how consistent is this signature in bones from the same facies but from widely separated localities? Our project has been investigating the chemical signatures of bones from multiple formations of different ages to determine the types of differences in their elemental composition. For the purposes of this presentation, we will focus on bone from the Jurassic Morrison Formation, primarily from the Brushy Basin Member, since it has the highest concentrations of dinosaur bone localities, and the Salt Wash Member, which also has bone although it is not as common. The Morrison Formation has a wide geographic distribution so provides an opportunity to examine whether bone from different locations has different elemental compositions, and to determine if it is possible to determine where a bone originated based on its chemistry. We collected our data from multiple museum collections as well as bones in situ in the ground. Our current sample consists of readings from 20 from the Morrison Formation.

When the elements in a fossil bone are exposed to short-wavelength X-rays or gamma rays, their component atoms become ionized. This will result from the ejection of one or more electrons from the atom when the energy is greater than its ionization energy and the tightly held electrons from the inner orbitals of the atom are expelled. The removal of an electron(s) makes the electronic structure of the atom unstable, so electrons in higher orbitals move into the lower orbital to fill the hole left behind. During this relocation, energy is released in the form of a photon, whose energy is equal to the energy difference of the two orbitals involved. The emitted radiation is energy characteristic of the types of atoms present. Fluorescence is the term applied to phenomena in which the absorption of radiation of a specific energy results in the re-emission of radiation of a different energy (generally lower).

To determine the elemental composition of the bone we used a handheld Niton XRF made by Thermo Fisher Scientific Portable Analytical Instruments* (Figure 1). When possible, we measured up to 30 bones from each locality. For some of the very large bones, we took multiple measurements. We set a maximum measurement time of two minutes so the instrument could fully utilize its four filters to reduce the background noise and enhance the detection of up to 33 elements. During the study, we noticed that part of the variation within a single bone depended whether the reading was on external or internal bone (Figure 2). Heavier elements were present in higher concentrations in the cortical bone while lighter elements were more common in the internal bone, so it is important to note on what part of the bone you take a reading. We also took readings of matrix on bone when it was available, and this can provide a secondary source of information of the bone's provenance.

We found that there was variation in the elemental composition of fossil bones from different localities. The most useful was a simple presence or absence of some of the more uncommon elements, but in other cases, the primary differences were in the relative abundance of some elements. Some elements such as iron, manganese, and strontium are common and in high abundance in all localities so are not useful to distinguish localities while other elements such as arsenic, copper, nickel, zinc, uranium, and thorium are not as consistently present and will vary by locality. Some elements such as molybdenum are more sporadic in their occurrence even within a single locality so may not be a useful indicator for a specific locality (Figure 3).

A preliminary test of this database as a forensic tool was provided by a law enforcement investigation by the Bureau of Land Management on the theft of dinosaur bone from BLM land. We were able to measure bone confiscated by law enforcement and based on their investigation we surveyed the area from where the bone was thought to have been illegally collected. The bone was removed from two separate locations, which we were able to find. Bone was still in place in both places, and we collected data on the bone still in situ. While the bones recovered by law enforcement from the two separate localities were mixed together by the collector, we found two distinct signatures within the sample of poached bones, and each matched the elemental signature of bones that were in situ in the locations suspected of being the source for the illegally collected bones.

While we have a good start on a comparative database, more data is needed, and a wider range of localities from the Morrison as well as expanding that for other formations is needed. This can be accomplished by visiting museum collections to obtain the needed baseline data. It would also be useful to establish a centralized database so other researchers can contribute data. Fortunately, the portable XRF is noninvasive and does not negatively affect the specimens examined so facilitates obtaining the permission of the curator to examine specimens in their care.

*The use of the name of the equipment used is strictly for documentation purposes and should not be considered as an endorsement of the product by the federal government or the Bureau of Land Management.

Figure 1. XRF on sauropod femur showing readout on screen. Photo courtesy of Dan Chure, Dinosaur National Monument.

Figure 2. Cross sections of dinosaur bones showing difference in density of outer cortical bone and inner trabecular bone filled with matrix, which will have different elemental compositions.

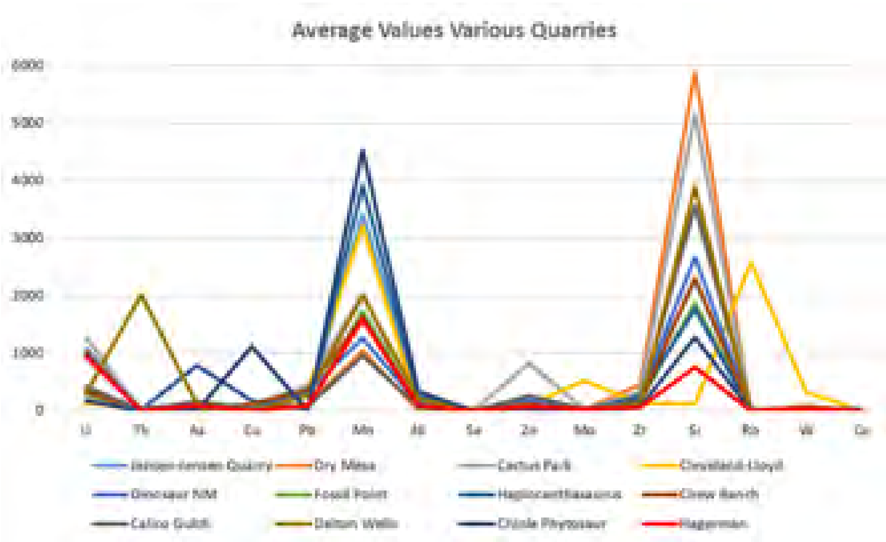


Figure 3. Graph showing differences in elemental composition of fossils from different localities. Values for elements in parts per million.

Big Buffalo I: Deterring Degradation of a Scientifically Significant Fossil Locality at Badlands National Park

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Badlands National Park preserves one of the most significant vertebrate fossil resources within the U.S. public lands system. Some of the world's richest and most diverse records of ancient mammals are contained within the many buttes, spires, and ridges that punctuate the western South Dakota prairie. The rapidly-eroding mudstones and siltstones that dominate the White River Group give the park its rugged beauty but present a unique challenge to resource managers because the rocks and fossils are continuously exposed and lost to erosion.

The Paleontology Department at Badlands National Park is tasked with documenting and preserving fossil resources over the ark's 244,000 acres. Under Park Paleontologist Dr. Rachel Benton, the park began documenting significant fossil sites in 1998 and currently maintains a database of over 300 paleontologic and geologic localities. Due to staffing constraints, very few of these localities have been revisited since their initial discovery. Even fewer localities have been subject to the monitoring and mitigation actions needed to collect and preserve fossil material at the sites. With erosion rates averaging 1 cm per year over much of the Park (Stetler, 2014), fossil resource loss at hundreds of unmonitored localities remains unknown.

In June of 2014, project staff developed a policy for the monitoring and mitigation of known fossil localities. One of the park's most significant localities, Big Buffalo I (BADL-LOC-0035), was chosen for mitigation in 2018. Unlike many of the park's paleontologic localities, which typically consist of abundant but contextually isolated specimens, Big Buffalo I is scientifically important because of the presence of a "bone bed," a densely-packed accumulation of fossil bones exposed at the site (Figure 1). Although only 50 m^2 in size, to date it has produced higher quality specimens due to the lack of heavily weathered fossil material at its surface. The vast majority of bone material at the site is in situ, with most still buried and protected from weathering. The faunal assemblage is dominated by the remains of the small, three-toed horse *Mesohippus* and the sheep-like *Merycoidodon*, a distant relative of modern camels. The large number of closely associated specimens in this bone bed provides a snapshot in time of a very temporally and geographically constrained population of animals.

The site is a former pediment surface eroded into a south-facing, rounded point, and the fossiliferous layers are exposed on the top surface and three vertical sides. The bone bed is at the base of a calcareous, reddish brown, clayey mudstone bed capped by scattered light tan to very light gray globular calcareous nodules. The fossiliferous mudstone bed overlies alternating very light gray sandstone and light brownish gray muddy sandstone beds containing very fine sand. Above the discontinuous nodules of the fossiliferous mudstone bed is a widespread marker bed, the Saddle Pass marker. The Saddle Pass marker includes a lower noncalcareous light brown-gray mudstone bed and an upper calcareous, reddish brown, clayey mudstone bed, totaling 3.4 m thick. The site's fossiliferous mudstone bed is 1.0 m thick, but to the east, the mudstone bed fills a scour cut into the underlying sandstone beds. Eastward, the mudstone bed thickens to 1.6 m thick and then thins to 1.2 m. The bone bed is on the western margin of this mud-filled scour and may have been the periphery of a water hole. This might explain the extremely dense layer of bone material present at the site.

Erosional degradation was of concern since the locality's discovery in 1999, but funds were not available to mitigate the erosion until 2018. The White River Group is composed of highly dispersive soils which present exceptional challenges when attempting to deter erosion. The bone bed was exposed in steep topography, further complicating mitigation. The area directly below these exposures was littered with bone scatter or "float," fossil bones that had become dissociated from the in situ bone layer (Figure 1). Other factors, i.e., potential impacts from visitors or wildlife, were also considered when devising a plan to intervene at the site.

The primary goal was to stabilize the locality and prevent further fossil loss as a result of exposure and erosion. Initially, the site was covered with fossil float, and mitigation could not begin until this issue was addressed. As a first step, a meter-square grid was established on the horizontal surface. The float specimens from this surface were collected and recorded according to the grid in which they were located.

Fossils eroding from the exposed vertical sides were collected and assigned a designation based on their proximity to an area of the bone bed exposure. The fragmented bone elements were collected because many had the potential to be reassembled in the fossil preparation lab. After the surface fossils were collected, the exposed areas of the bone bed were consolidated with Paraloid B-72. When dry, these consolidated surfaces were covered in tissue and mud-packed. Quilt batting was soaked in plaster and applied to the prepared surfaces (Figure 2). The site was covered in landscape fabric to deter plant growth but allow water to pass through the barrier. As a final step, poultry fencing was laid down to discourage wildlife from disturbing the site during the off-season.

Data collection and site work will be ongoing in the coming seasons. A previous, superficial survey revealed 32 vertebrate specimens representing eight distinct genera. Presently it is unknown if other genera are present or to what extent the skeletons may be articulated. Therefore, to preserve the context of the site, quarrying will continue as the preferred method of excavation. As the bone bed continues to be uncovered in 2019, a wealth of taphonomic and taxonomic data will be obtained through the large-scale excavation of this rare fossil accumulation.

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Figure 1. Big Buffalo I. Note the white fossil bone eroding from the hillside.

Figure 2. Big Buffalo I. View after stabilizing and protecting exposed bone bed layer.

Tule Springs Fossil Beds National Monument's Vanishing Treasures: An Historic Preservation Approach to Preserving Historic Fossil Sites

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On December 19, 2014, the Tule Springs Fossil Beds National Monument became the 405th unit of the National Park Service to "conserve, protect, interpret, and enhance for the benefit of present and future generations the unique and nationally important paleontological, scientific, educational, and recreational resources and values of the land" (P.L. 113-291, sec. 3092). Located in the upper Las Vegas Wash, the monument now protects 22,650 acres of land rich with paleontological and archaeological resources. The monument preserves the largest open-site vertebrate fossil assemblage dating to the Rancholabrean Age in both the southern Great Basin and the Mojave Desert (Scott et al. 2017).

Tule Springs Fossil Beds National Monument is situated on the north edge of Las Vegas and North Las Vegas, bounded by the Clark County Shooting Complex, Ice Age Fossils Park (Nevada State Parks), Bureau of Land Management, Desert National Wildlife Refuge (U.S. Fish and Wildlife Service), the settlement of Corn Creek, Las Vegas Paiute Tribe, and Nellis Air Force Base. As a new urban park with no facilities and limited staff, the monument is prone to disturbances such as illegal fossil and artifact collection, trash dumping, target shooting, fence destruction, and off-road activity. The close proximity to the cities and various access points make it difficult to prevent human disturbances that negatively affect the monument's fossil localities.

Besides visitor disturbances, park staff have begun to identify and document natural threats and disturbances to fossil resources. Due to the elevation and topography of the monument, rainfall and floodwaters flow down the badlands towards the upper Las Vegas Wash that bisects the monument. A total of 10 north-south trending excavated trenches, created during the 1960s Tule Springs Expedition, funnel water towards the wash. In turn, causing undercutting and mass wasting of the trench walls within the historic Tule Springs Archaeological Site (Figure 1). As mass wasting occurs, the shape of the trenches widen, and newly deposited sediment changes the once well-defined appearance of the stratigraphic cuts. Trying to recover partially buried fossils from the eroded areas and identifying which unit the displaced fossils came from proves to be difficult.

VANISHING TREASURES

Tule Springs Fossil Beds National Monument is best known for the historic site of the interdisciplinary Tule Springs Expedition from 1962-1963. The site has been listed on the National Register of Historic Places as the Tule Springs Archaeological Site for its national significance as a well-documented and studied early man site, its central role in the discussion of man's first introduction to the New World and possible association with extinct Late Pleistocene megafauna, the magnitude of the interdisciplinary project (the largest at the time), and the first use of radiocarbon dating on a large-scale project. The National Register boundary includes the excavated trenches, fossil localities, and archaeological sites which also preserve in situ fossils and cultural artifacts.

Little guidance or standards exist for the management of historic fossil sites with in situ archaeological resources. Although they share similarities in field techniques, the two disciplines have conflicting prioritization for excavation, collection, and preservation of sites. The on-going human-made and natural disturbances at Tule Springs Archaeological Site calls for a standardized protocol for mitigating newly exposed fossils and artifacts. A historic preservation approach is being taken to address immediate management concerns of this site and to identify techniques and protocols that will be compatible with both archaeological and paleontological resources.

HISTORIC PRESERVATION FOR FOSSIL SITES

Since the Tule Springs Archaeological Site is listed on the National Register of Historic Places, preservation of the site is dictated by archaeological laws and regulations. Through the National Historic Preservation Act (NHPA), the secretary of the interior (SOI) is tasked with establishing professional standards and provides preservation advice for cultural resource sites that are listed or eligible for listing on the National Register of Historic Places. These standards and techniques can be followed as guidance and best practices for managing sites that contain both archaeological and paleontological remains whether they are listed or not.

According to SOI standards, “Preservation is defined as the act or process of applying measures necessary to sustain the existing form, integrity, and materials of a historic property. Preservation work implies identifying preliminary measures to protect and stabilize the historic property (NPS 2017).” Historic preservation standards provide a compatible framework for both paleontological and archaeological resources. The application of these techniques will assist park staff in responding appropriately to both human-made and natural disturbances at historic fossil sites without compromising one resource over the other. The Tule Springs Expedition was a unique interdisciplinary project where scientists shared methodologies and ideas to better understand the context of the site. Currently, park staff are repeating history by utilizing an integrated resources management process for planning and decision making to preserve the historic fossil sites of the monument.

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Figure 1. Modern view of an excavated trench from the 1960s Tule Springs Expedition.

Paleontology of St. Croix National Scenic Riverway, Minnesota–Wisconsin

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St. Croix National Scenic Riverway (SACN) follows the St. Croix River and its tributary, the Namekagon River, for more than 400 km (250 miles) from northwestern Wisconsin to the St. Croix-Mississippi confluence. It includes a narrow strip of land on both sides of the river system in eastern Minnesota and western Wisconsin. Where today pine forests and towns overlook the St. Croix River, a shallow tropical sea populated by shelled animals, trilobites, burrowing worms, and colonies of graptolites once existed. The Cambrian rocks of SACN have long been a source of fossils, which are among the most diverse and historically significant Cambrian fossils in the National Park Service. We documented these rocks and fossils throughout 2017. Some of the highlights include a history of discoveries back to the 1840s; a graptolite bed; abundant trace fossils; and the recognition that at least 19 and as many as 55 fossil species are based on fossils from sites within SACN.

The St. Croix drainage traverses a region that is mostly buried by Quaternary drift, but bedrock outcrops are found near and along the rivers. Fossiliferous rocks are exposed from near the Dalles of the St. Croix to the confluence with the Mississippi. Beyond this, above the Dalles, outcrops of any kind are rare, and unfossiliferous Precambrian rocks predominate. The St. Croix Valley is centered on the 1.1 Ga Midcontinent Rift, and the rift and its associated faults are the primary structures of the valley, which has otherwise been tectonically quiet. During the Cambrian, the Sauk II transgression entered what is now the St. Croix Valley approximately 500 Ma. Shallow marine deposition is known to have occurred through the rest of Sauk time and during the Tippecanoe sequence, but rocks more recent than approximately 455 Ma are not preserved in SACN or the rest of the valley. Fourteen formations and unusual facies were deposited in the SACN corridor during this time, most of which are fossiliferous in the park (Table 1; Figure 1). The great majority of the Paleozoic sedimentary rocks within SACN were deposited during the late Cambrian or Early Ordovician. The Cambrian rocks are mostly sandstones with finer-grained intervals, while the Lower Ordovician rocks are predominantly dolomite. Small outliers of Middle and Upper Ordovician rocks have been preserved by faulting, and represent the northwestern-most and most shoreward outcrops of these marine rocks. The Cambrian and Lower Ordovician rocks of SACN lead into the Middle and Upper Ordovician rocks of adjoining Mississippi National River and Recreation Area, together providing a detailed view of lower Paleozoic shallow marine deposition and life.

The geology of the St. Croix region was first documented by surveying expeditions led by David Dale Owen during the late 1840s, producing the first reports of fossils from the St. Croix Valley, which were recognized as perhaps the oldest fossils then known. James Hall followed and described a number of trilobite species from the valley. Hall's assistants and protégés continued to collect and describe fossils from the valley for decades. One of his protégés, Charles Walcott, amassed a significant collection from sites now within and near SACN. He used these fossils to designate the upper Cambrian of North America the "Croixan."

The Cambrian fossils of SACN include brachiopods, mollusks, trilobites, graptolites, and the burrows and trails of unknown soft-bodied animals, among others. Brachiopods occasionally are abundant enough to make coquinoid beds. Mollusks are generally rare and represented by steinkerns, molds, and casts of gastropods, monoplacophorans, and helcionelloids. Outcrops of the Mill Street Conglomerate facies just outside of SACN are famous for fossils of monoplacophorans and other animals that lived among boulders surrounding ancient basaltic islands. Trilobites are easily the most diverse group in the SACN rocks, and several biostratigraphic zones have been identified. Graptolites were once found in abundance at a locality now lost to road work. Invertebrate trace fossils are the most abundant fossils in SACN; some kind of trace can be found at almost any outcrop. Few Quaternary fossils have been found in the corridor, although a bison bonebed was found just outside of SACN in Interstate State Park-Wisconsin in the 1930s.

Formation	Age	Fossils Within SACN
Quaternary sediments	late Pleistocene–Holocene	Holocene: palynomorphs of mosses, lycopods, conifers, gnetophytes, and angiosperms
Decorah Shale	Late Ordovician	Conodonts and coquinoid limestone
Platteville Formation	Late Ordovician	Brachiopods and conodonts
Glenwood Formation	Late Ordovician	None to date
St. Peter Sandstone	Middle–Late Ordovician	None to date
Prairie du Chien Group: Shakopee Formation	Early Ordovician	Stromatolites
Prairie du Chien Group: Oneota Dolomite	Early Ordovician	Gastropods and conodonts, possibly also ?stromatoporoids, brachiopods, nautiloids, trilobites, and echinoderms
Jordan Sandstone	late Cambrian	Brachiopods, gastropods, trilobites, conodonts, and invertebrate trace fossils
St. Lawrence Formation	late Cambrian	Brachiopods, hyoliths, helcionelloids, monoplacophorans, gastropods, trilobites, aglaspidids, archaeostracans, graptolites, conodonts, enigmatic invertebrates, and invertebrate trace fossils
Tunnel City Group undivided	late Cambrian	Brachiopods, trilobites, and invertebrate trace fossils, possibly also gastropods, aglaspidids, and echinoderms
Tunnel City Group: Mazomanie Formation	late Cambrian	Brachiopods, helcionelloids, trilobites, and invertebrate trace fossils
Tunnel City Group: Lone Rock Formation	late Cambrian	Brachiopods, trilobites, graptolites, and invertebrate trace fossils, possibly echinoderms and microbial traces
Mill Street Conglomerate facies	late Cambrian	Unspecified fossils; a significant assemblage of brachiopods, monoplacophorans, gastropods, and trilobites has been found just outside of SACN in Interstate State Park
Wonewoc Formation	late Cambrian	Brachiopods and invertebrate trace fossils, possibly trilobites
Eau Claire Formation	middle–late Cambrian	Brachiopods, trilobites, and archaeostracans, possibly hyoliths
Mount Simon Sandstone	middle Cambrian	None to date

Table 1. Phanerozoic stratigraphy and paleontology of SACN.

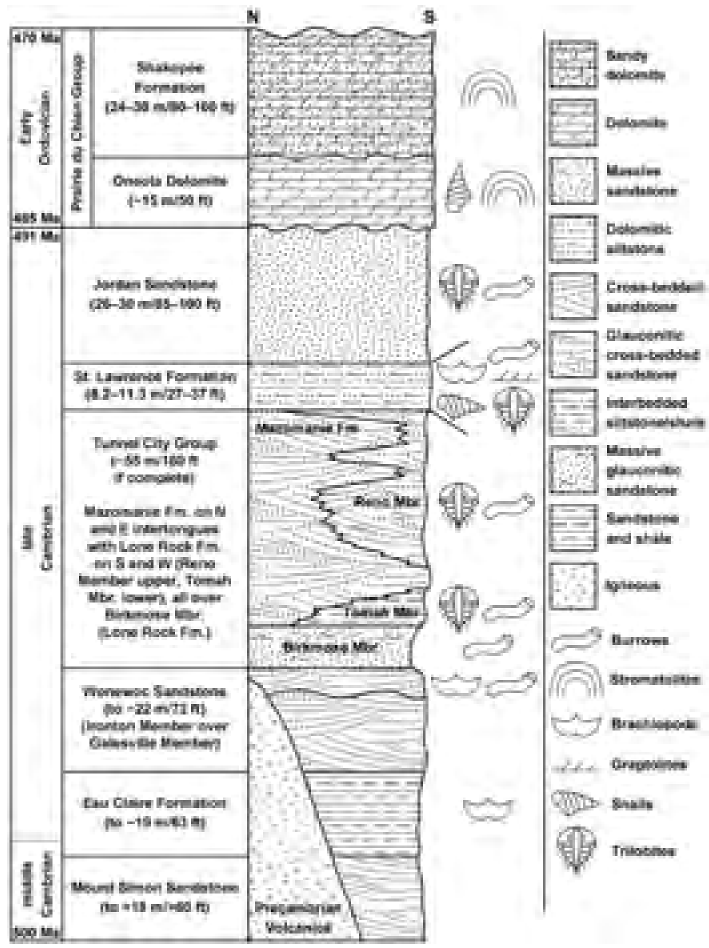

Figure 1. Schematic stratigraphic column of St. Croix Valley lower Paleozoic rocks, with common fossils. Dates are for the approximate ages of the rocks. Vertical and horizontal variations in the Tunnel City Group and volcanic rocks approximate the stratigraphic changes found in these rocks north (left) to south (right). The middle-late Cambrian boundary is approximated by a dotted line. Lithologic patterns and symbols are taken from the Federal Geographic Data Committee standards: pubs.usgs.gov/tm/2006/11A02.

Soft Tissue Preservation in Late Eocene-Early Oligocene Vertebrate Fossils of the White River Group

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Introduction: For the past two decades, Temple University has worked with staff from Badlands National Park, Oglala National Grassland, and the Wyoming office of the Bureau of Land Management to understand the controls on fossilization of Cenozoic vertebrate remains, and to use these findings to help with developing methods to mitigate fossil poaching on federal lands (Metzger et al., 2004; Grandstaff and Terry, 2009, Terry et al., 2014). As an offshoot of this research, we have recently started to investigate the preservation potential of cellular and soft tissue structures within these same fossils, with the goal of relating our previous results to understanding the taphonomic conditions required for such detailed preservation. Multiple studies have identified soft tissue and cellular structures, such as osteocytes, blood vessels, and fibrous/proteinaceous matrix, preserved within vertebrate fossils which closely resemble those of extant vertebrates (Schweitzer et al., 2005, 2007; Bertazzo et al., 2015; Wiemann et al., 2018; Ullmann et al., in press). However, controls on soft tissue preservation in vertebrate fossils remain poorly understood. Interestingly, one recent study has suggested that soft tissues may be more likely to preserve in bones which fossilized in oxidizing environments (Wiemann et al. 2018). The strata of the Eocene-Oligocene White River Group (WRG) provide a perfect setting for testing this hypothesis.

During the Eocene-Oligocene transition (EOT), global temperatures cooled, and terrestrial landscapes became drier, with the extensive forests of the Paleocene and Eocene giving way to grasslands and shrub prairies in the Oligocene (Zanazzi et al. 2007). The Eocene-Oligocene transition is captured within the strata of the WRG (Figure 1), which spans multiple states across the Great Plains and records deposition over several million years (~ 37-30 mya). Depositional environments within these strata include fluvial, aggradational eolian, stable eolian, and lacustrine settings (Benton et al., 2015). We herein present the results of initial demineralization assays on vertebrate fossils from the White River Group to explore the geologic and paleoenvironmental controls on soft tissue preservation in vertebrate fossils (Figure 2).

Methods: The four vertebrate fossils used in this preliminary study were collected from the WRG of northwest Nebraska and southwest South Dakota as part of earlier research efforts to understand the role of rare earth elements (REE) in fossilization (Figure 1), and their utility as a geochemical fingerprinting tool (Metzger et al., 2004; Grandstaff and Terry, 2009; Terry et al, 2014). These include postcranial fragments of a brontothere (late Eocene, channel sandstone), oreodont (late Eocene, floodplain mudstone), and two tortoise shells (late Eocene floodplain mudstone, and Oligocene eolian siltstone). Demineralization was conducted in 0.5 M ethylenediaminetetraacetic acid (EDTA) at pH 8.0 for four weeks, with exchanges of fresh EDTA performed every 48 hours. Resulting demineralization products were loaded onto standard glass slides, cover-slipped, and imaged by optical microscopy.

Results and Implications: The fossils exhibited varying demineralization rates, with the brontothere fossil fragment demineralizing the fastest, and the oreodont fragment and tortoise shell from floodplain mudstones taking about one week longer. The tortoise shell from the eolian siltstone exhibited a far slower demineralization rate, with most of the sample still intact after four weeks. Many potential endogenous microstructures were identified, including numerous osteocytes and vessel fragments (Figure 3). The reason for differences in demineralization times is unknown at present.

This is the first study to document cellular and soft tissue preservation in vertebrate fossils from the WRG. Our goal is to understand the controls behind their preservation, in particular, the influence(s) of depositional environments and paleopedology on the rate and degree of fossilization as recorded by REE uptake and apatite crystallinity (e.g., Metzger et al., 2004). As we expand our dataset with additional fossils, we will be able to address the influence of oxidizing environments on soft tissue preservation (as per Wiemann et al., 2018) during a period of paleoenvironmental change from humid, forested fluvial systems of the late Eocene to cooler and drier eolian conditions of the Oligocene within the WRG.

Acknowledgments: Previous research funded by grants to D. Terry from the National Park Service, U. S. Forest Service, and Bureau of Land Management.

Figure 1: Outcrops of the White River Group near Scenic, South Dakota, (S) and Toadstool Geologic Park, NE (T).

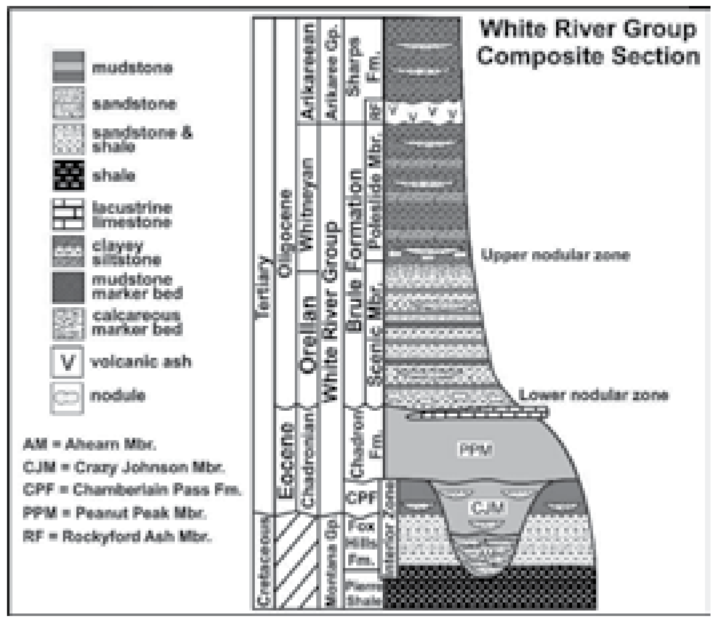

Figure 2: Measured section of the White River Group in Badlands National Park, South Dakota. Forested, fluvial conditions of the Eocene Chadron Formation change progressively up-section to open, eolian environments of the Oligocene Brule Formation.

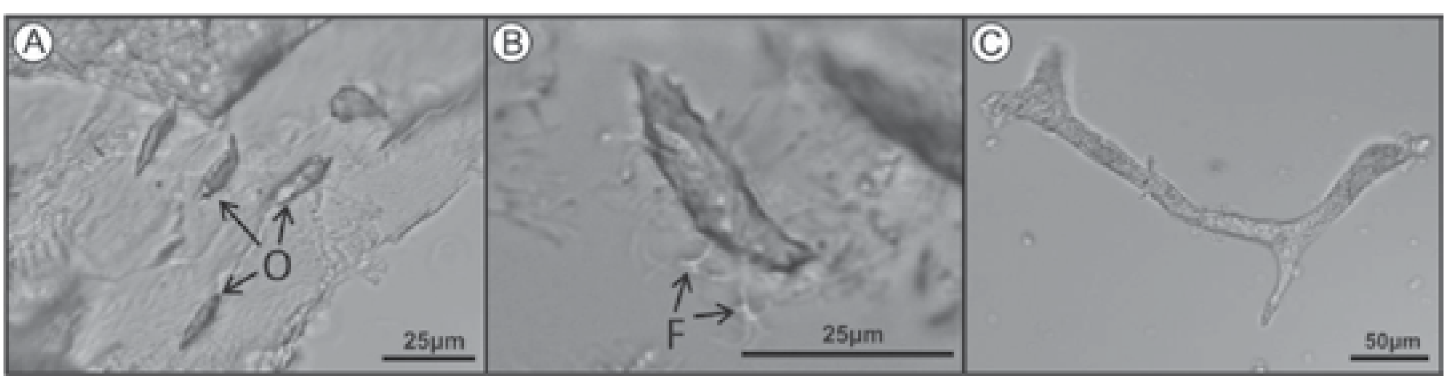

Figure 3: Cellular microstructures. A: Partially demineralized Eocene oreodont bone with osteocytes (O), B: Close-up of a free-floating osteocyte with filopodia (F) from a turtle scute preserved in Oligocene floodplain mudstone, C: Vessel fragment from an Eocene oreodont.

A Quick and Dirty Guide for the Application of Paleopedology to Vertebrate Taphonomy

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Introduction: Soils form in response to the five main factors of soil formation: **CL**imate, **O**rganisms, **R**elief, **P**arent material, and **T**ime (CLORPT; Jenny, 1941). The interaction of these five factors give rise to distinctive sets of physical, chemical, and biological traits that are used to classify modern soils into 12 distinct types (Soil Survey Staff, 1999). Ancient soils (paleosols) archive paleoclimatic and paleoenvironmental conditions, and when described in context with vertebrate fossils, can provide information on paleogeomorphic conditions (paleo-CLORPT) that influenced fossil preservation (e.g., Retallack, 1988). For federal agencies that manage fossil vertebrate resources, paleopedology is a useful tool for understanding the distribution of fossil remains, and once the relationship between paleopedology and sedimentary facies/stratigraphy is understood, for predicting the occurrence of other fossil concentrations (Benton et al., 2015).

Paleosol Features: Recognition and interpretation of paleosols spans the macroscopic to microscopic scale of observation (Figure 1). At the outcrop scale, paleosols commonly manifest as variegated striping that can be traced over large distances. Depending on the facies within which the paleosols have formed, differential erosion accentuates parts of a sequence which have experienced subaerial weathering. Upon closer examination, paleosols will display roots, hackly textures within mudstone (peds), and distinct mineralized accumulations (glaebules). The size, orientation, and preservation style of fossil roots are related to paleo-CLORPT, e.g., trees vs. grasslands, horizontal vs. vertical, and carbonized vs. clay infills. Peds are three-dimensional bodies of soil material formed by root action and wetting/drying of the soil. They are granular, blocky, angular, and columnar bodies that increase in size downward into the soil and eventually give way to relict depositional bedding. Glaebule mineralogy is a function of climate, with calcium carbonate representative of subhumid to arid conditions, and iron oxides representative of wetter, hydromorphic conditions.

In order to apply paleopedology to vertebrate taphonomy, the top and bottom of any paleosol must be defined in relationship to the fossil remains. Tops of individual profiles are marked by the truncation of roots and burrows, higher overall concentrations of roots, and in some cases, are marked by in situ fossil tree stumps. In fluvial systems, paleosols are capped by coarser deposits of the next flood, with grain size dependent on proximity to the former channel. Eolian systems can vary between aggradational soil profiles that result in evenly distributed pedogenic features throughout or stable landscapes that concentrate pedogenic features in distinct zones. Depending on the regional geology, ancient land surfaces are occasionally marked by the fallout of volcanic ash. The bottom of individual profiles in fluvial systems is marked by a change to original depositional textures (relict bedding) as the influence of pedogenesis weakens. Once the profile is defined, the position of the vertebrate fossil within/on the ancient soil can be used in combination with the taphonomy of the vertebrate remains (e.g., degree of weathering, processing, articulation) and the associated sedimentary facies in order to derive an interpretation of the paleo-geomorphic factors that influenced fossil preservation.

Application: For the past two decades, researchers from various U.S. academic institutions and staff at Badlands National Park in southwest South Dakota have combined observations from sedimentology, stratigraphy, paleopedology, and paleontology resource surveys to understand the controls on fossil preservation and distribution within the Eocene-Oligocene White River Group (WRG). Strata of the WRG are dominated by fluvial systems in the Eocene Chadron Formation and change progressively up section to eolian dominated strata of the Oligocene Brule Formation as climates cooled and dried (Retallack, 1983, Benton et al., 2015). This upward change in paleoenvironment and paleoclimate is coupled with a change in associated paleosols and modes of vertebrate fossil preservation.

In fluvial systems, vertebrate fossils are preserved as a combination of articulated to isolated remains within floodplain deposits to bone lags incorporated by lateral accretion of channels (Figure 2). Articulated remains are commonly found near the bottom or middle of individual, pedogenically modified overbank depositional events and likely represent catastrophic death assemblages. In some cases, these highly fossiliferous, individual depositional events can be traced over several square kilometers and can be correlated with areas within the park that experience higher rates of fossil poaching. Isolated elements with varying degrees of weathering are common at the top of individual pedogenically modified depositional packages and likely represent attritional accumulation and postmortem processing. In eolian systems, the concentration of vertebrate fossils is related to the rate of sediment aggradation (Figure 3). During periods of high accumulation, pedogenic features and fossil vertebrates are scattered throughout massive eolianites. During low periods of aggradation, pedogenic features and vertebrate fossils are concentrated together at or near the ancient land surface. These surfaces tend to manifest as distinct ledges or benches that can be traced over large areas. Regardless of the rate of eolian aggradation, vertebrate fossils occur most commonly as associated to isolated remains.

Conclusion: Paleopedology is a powerful tool for understanding the influence of paleo-geomorphic processes on the taphonomic history of vertebrate assemblages. Whether on the scale of an individual excavation site or a park-wide paleontological survey, the collection of paleopedological data enhances the overall understanding of paleoenvironmental and paleoclimatic conditions and can help to predict the relationships between depositional environments, stratigraphy, and fossil abundance.

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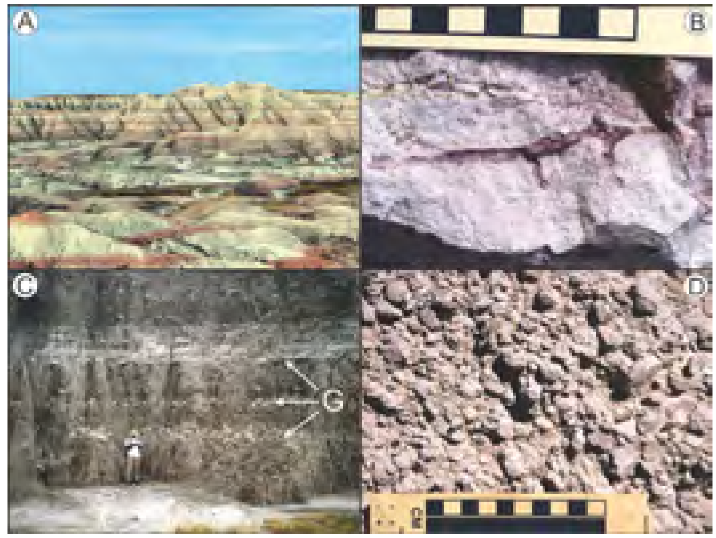


Figure 1. Macroscopic paleosol features: A. banding, B. roots, C. peds, D. glaebules, (G) in C.

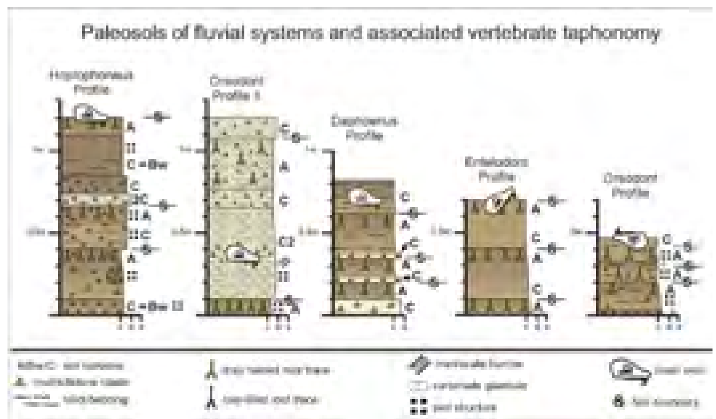


Figure 2. Vertebrate taphonomy of fluvial systems.

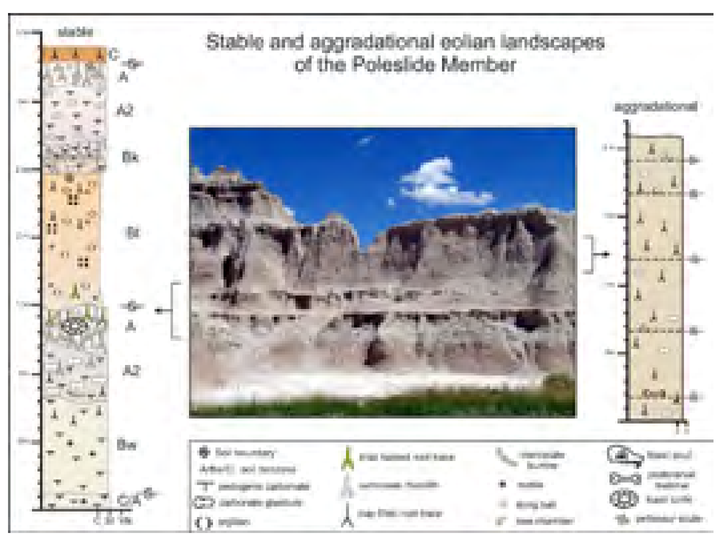


Figure 3. Vertebrate taphonomy of eolian systems.

Haringtonhippus francisci, a 'Stilt-legged' Late Pleistocene Horse From Gypsum Cave, Mojave Desert, Southern Nevada

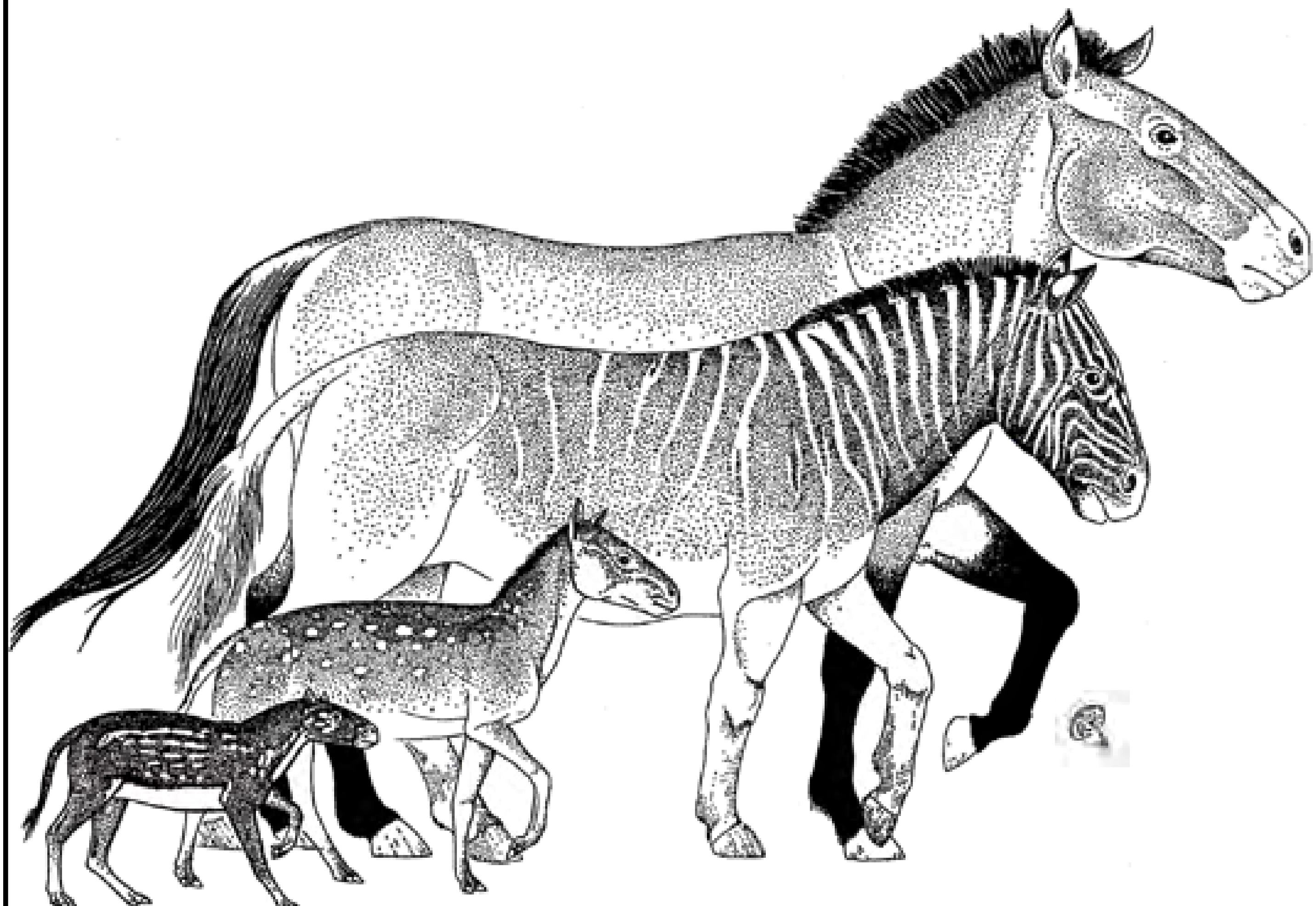
Eric Scott, Cogstone Resource Management, Inc.

Gypsum Cave is a late Pleistocene limestone cavern in the Frenchman Mountains of southern Nevada. Presently administered by the Bureau of Land Management, the cave was originally excavated in 1930-31 and yielded multiple well-preserved fossils of horses as well as another late Pleistocene megafauna. Preservation is exceptional, including soft tissues; fossils from the site have previously yielded both radiocarbon dates and genomic data. In 2017, horse fossils from Gypsum Cave dating to $\sim$13 ka were critical in establishing a new genus of Plio-Pleistocene horse, *Haringtonhippus*, for the sole species *H. francisci*. Based upon complete mitochondrial and partial nuclear genomes, *H. francisci* was interpreted to have a geographic range reaching from the Yukon Territory southwards to southern Nevada, and to have separated from the crown group *Equus* more than 4.5 Ma.

Remains of *Haringtonhippus* at Gypsum Cave are well represented in the overall large mammal assemblage from the locality. Multiple skeletal elements, both cranial and postcranial, are preserved, including a largely complete cranium. The sample preserves a minimum number of 10 individuals, including two adults, three subadults, and five juveniles. All of these fossils represent a small stilt-legged species, verified metrically and through previous genomic analysis, and so are assigned to *H. francisci*. Radiocarbon dates associated with these remains yielded ages of $\sim$13 ka. Additionally, a large species is also present, represented by a single terminal phalanx encased within an intact hoof, dated to $\sim$25 ka. Based upon these data, two species of horse are represented at Gypsum Cave: *H. francisci* and a large stout limbed species. Carnivoran damage on vertebral elements suggests predation and/or scavenging, offering indications of how the horses were introduced into the cave.

The small horse fossils from Gypsum Cave are the best-preserved remains of small stilt-legged late Pleistocene equids presently known from anywhere in southwestern North America. In conjunction with other Pleistocene localities in the Mojave Desert (e.g., Tule Springs, Lake Manix, Kokoweef Cave, Tecopa) and the Colorado Desert (e.g., Pinto Basin), it is evident that at least three species of horse inhabited this region in the late Pleistocene: the large *Equus scotti*, a smaller stout-limbed horse often assigned to the species *E.* "*conversidens*," and *H. francisci*. In contrast, more coastal assemblages (e.g., Rancho La Brea, Diamond Valley Lake) lack stilt-legged equids altogether, instead preserving remains of *E.* "*conversidens*" and the larger *E. occidentalis*.

The fossil record of horses from Gypsum Cave convincingly demonstrates the significance of this underutilized locality for advancing studies of late Pleistocene megafauna in southwestern North America. Continued investigation of fossils from the cave, potentially coupled with site-based education and outreach, offer a unique window into the end of the Ice Ages in southern Nevada.



POSTER

New Additions to the Miocene Vertebrate Fauna of the Tesuque Formation, Española Basin, New Mexico

Phil Gensler, Bureau of Land Management
Gary Morgan, New Mexico Museum of Natural History
Scott Aby, Muddy Spring Geology
Garrett R. Williamson, Private Consultant

For over 140 years, outcrops of the Tesuque Formation in the Española Basin of northern New Mexico have produced a diverse fauna of early to medial Miocene vertebrates from the Hemingfordian and Barstovian North American land mammal ages (NALMA). Edward Drinker Cope first collected Miocene vertebrates from the Española Basin in 1874, describing 32 new species of mammals, land tortoises, and a bird, many still recognized today. Paleontologists from the Frick Laboratory of the American Museum of Natural History, including Joe Rak, John Blick, and Ted Galusha, conducted a long-term survey of Miocene mammals in the Española Basin from 1924 to 1965, resulting in an unparalleled collection numbering in the thousands of specimens.

Beginning in 2008 and continuing to the present, the U.S. Bureau of Land Management (BLM) and New Mexico Museum of Natural History (NMMNH) have collaborated on a survey of Miocene vertebrates from BLM land in the Española Basin, focusing on the Sombrillo Area of Critical Environmental Concern (ACEC) in northern Santa Fe and southern Rio Arriba counties. Unlike the Cope and Frick surveys, BLM/NMMNH paleontologists have access to GPS technology and accurate geologic and topographic maps to precisely document fossil sites. Three superposed members of the Tesuque Formation in the Sombrillo ACEC have produced vertebrate faunas: Nambé Member (Nambé Fauna, late Hemingfordian, late early Miocene, 16-17 Ma); Skull Ridge Member (Skull Ridge Fauna, early Barstovian, early medial Miocene, 15-16 Ma); Pojoaque Member (Pojoaque Fauna, late Barstovian, medial Miocene, 12.5-15 Ma).

The BLM/NMMNH survey has recovered many new specimens of Miocene vertebrates from the Tesuque Formation; a sample is listed here. Late Barstovian Pojoaque Fauna: Carnivora-mandibles of the borophagine canid *Aelurodon*; mandible of the tiny felid *Pseudaelurus stouti*; maxilla of the large mustelid *Sthenictis*; mandibles of the large mustelid *Brachypsalis* and small mustelid *Martinogale*; Perissodactyla-skull, maxilla, and mandibles of the rhinoceros *Peraceras*; skulls, mandibles, and partial skeletons of the horses *Merychippus* and *Protohippus*; Artiodactyla–mandible of the oreodont *Merychyus*; mandibles of the camels *Aepycamelus*, *Procamelus*, and *Protolabis*; mandibles of the blastomerycine *Longirostromeryx*; numerous mandibles and horn cores of the antilocaprid *Meryceros*; Proboscidea–two skulls and mandibles of *Gomphotherium productum*; Small mammals–mandibles of shrews, humeri of moles, mandibles of the rodents *Copemys* and *Monosaulax* and the rabbit *Hypolagus*, and the first bat from the Española Basin. Early Barstovian Skull Ridge Fauna: skull of the oreodont *Brachycrus*; skull and partial skeleton of the camelid *Protolabis*; and mandible of the mylagaulid rodent *Notogaulus*. Ongoing field work on Miocene vertebrates in the Sombrillo ACEC will allow us to more fully document the faunas from the Tesuque Formation, with an emphasis on microvertebrates and biostratigraphy.

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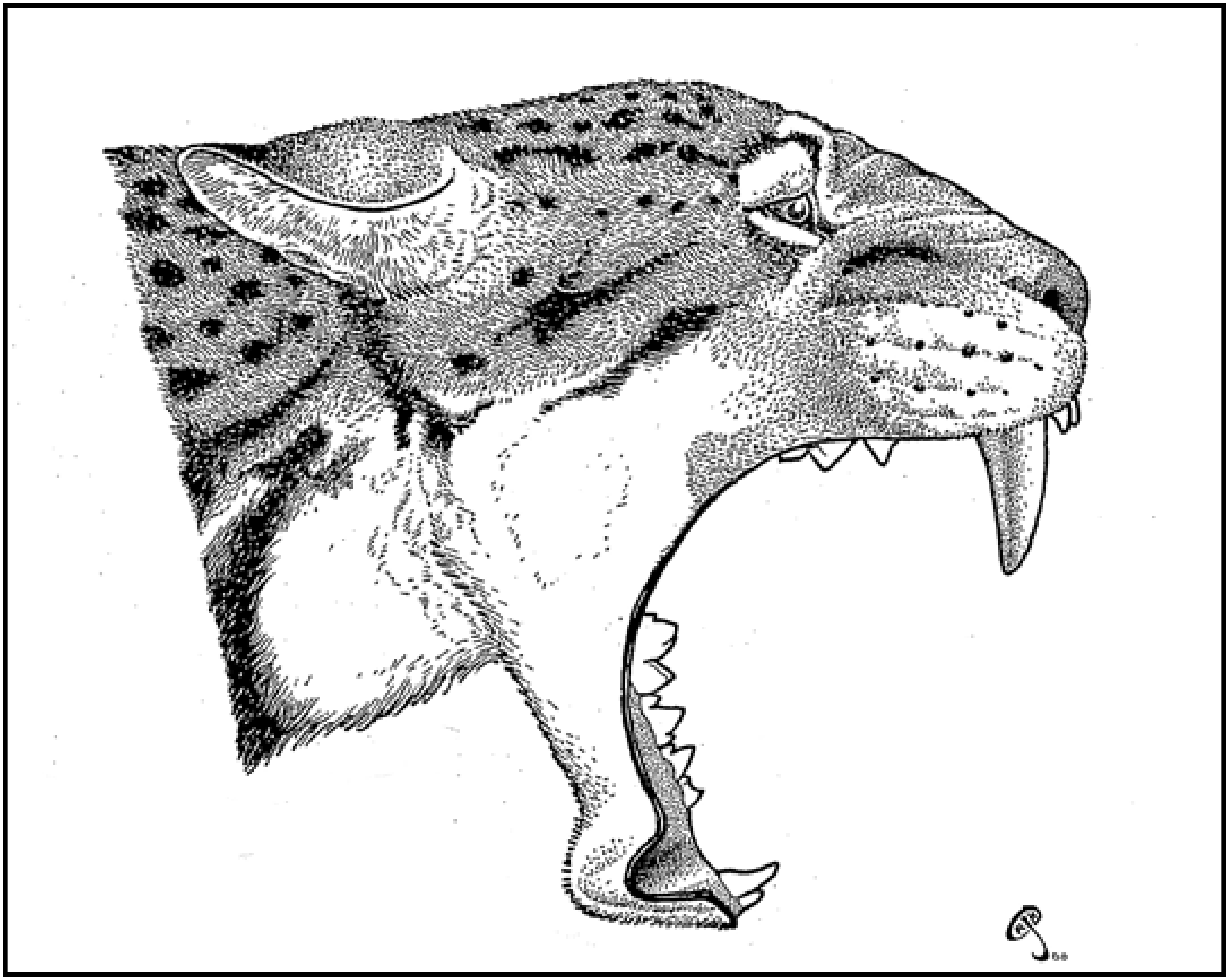


POSTER

The Tragedy of the Paleontological Common

Theodore Fremd, University of Oregon
Vincent Santucci, National Park Service

In 1968, the ecologist G. Hardin prepared an important article (Science 162, 1243) in which he observed that "Freedom in a commons brings ruin to all." This seminal contribution has been expanded and usurped by a variety of disciplines in the sciences as well as cultural memes. Largely illustrated by an imaginary pasture exploited by rational herdsmen, each looking to maximize their own gain, the concept is applicable to paleontological fieldwork on public lands as well.

Professional paleontologists are research-oriented, and many of us take access to fossils on public lands for granted (with cheerful grousing over permit and report hassles). There is a bewildering variety of relatively recent laws and regulations applied to fossils found on public lands ("the Commons") throughout the world, with no two countries having identical policies. Examination of existing specimen collections retrieved from public (largely federal) lands in many repositories reveals that the value of the specimens for additional multidisciplinary investigations is often minimal. Associated data of value to taphonomists, biostratigraphers, paleobotanists, and invertebrate workers, for example, are usually left in the field and/or undocumented simply because of limited time, assets, or knowledge. Those materials with the greatest utility for others are acquired by individuals willing and able to collect information peripheral to their direct area of interest.

Many scientists disregard the importance of effective land management to their work, despite the obvious need of a verifiable "laboratory" providing an opportunity for others to replicate and/or falsify research conclusions. Despite a few odd investigators clamoring for unregulated access to the fossil commons, a conservation ethic is a historical norm; indeed, vertebrate paleontologists have a proud tradition of supporting the preservation and wise stewardship of most natural resources, including fossils.

The scientific and public usefulness of materials exhumed from the commons appears to have much more to do with the collector's motivation, rather than the academic credentials of the workers. Providing for the appreciation and preservation of specimens for others to benefit in a myriad of ways (evidenced by appropriate research and curation) seems a more appropriate use of the commons than supporting individuals on "the Me Plan" (viewing fossils as marketable commodities, or merely satisfying one's personal hobby/research interest, etc.). This applies across all taxonomic biases. There is no valid reason why an unusual assemblage of fossil plants, soft-bodied invertebrates, or trace fossils should be regarded as less significant than any vertebrate fossils. For example, widespread occurrences of millions of fossil fish – so common as to be essentially worthless as research material – can scarcely compare to many fragile and/or unique invertebrate and botanical sites.

In the late 1980s, there was a general belief that public land management agencies would serve the general public and the scientific community well by cooperatively managing these "commons." For example, within the John Day Basin in Oregon, unique interagency agreements between the NPS, BLM, and others were forged to manage certain parcels for paleontological preservation. We established mechanisms to provide recognition and protection to an additional 15 parcels of land external to the National Monument within the John Day Basin, using a combination of administrative designations including National Natural Landmarks, ACEC's, and Research Natural Areas into a system of "Cooperative Areas for Management of Paleontology" (CAMP sites).

The tragedy of these kinds of noncongressionally sanctioned agreements is that they are doomed to failure without ongoing sustenance. Such supposedly long-term strategies (which in government can be quite brief), originally well-intended to provide resource protection and study, founder without knowledgeable and diligent government support. We have witnessed rapid staff turnover in several bureaus, resulting in a noticeable change from enthusiastic to anemic support amongst agency specialists in many natural resource disciplines affecting "the commons." An "institutional memory" is feeble at best.

Much of the issue comes down to motivation. Fossils can be viewed as marketable commodities, and on private lands in the United States (and some state lands, as we have seen) they may legally be treated as such. On public lands, even permitted professionals associated with reputable institutions may not be particularly motivated to collect the material and data useful to workers outside their particular discipline. This leads to collecting biases (disinterest in retrieving invertebrates or turtle shells, for example), ignoring taphonomic data that could be collected, sloppy section measurement, and so forth. We have observed that a few "amateurs" have kept more verifiable field maps than certain "professionals." Unfortunately, most avocational fossil enthusiasts lack the advanced education necessary to distinguish important scientific materials and are not willing or able to obtain the required knowledge in order to enhance their efforts. Conversely, a few academics simply don't have well-rounded field skills and aren't particularly inclined to improve them.

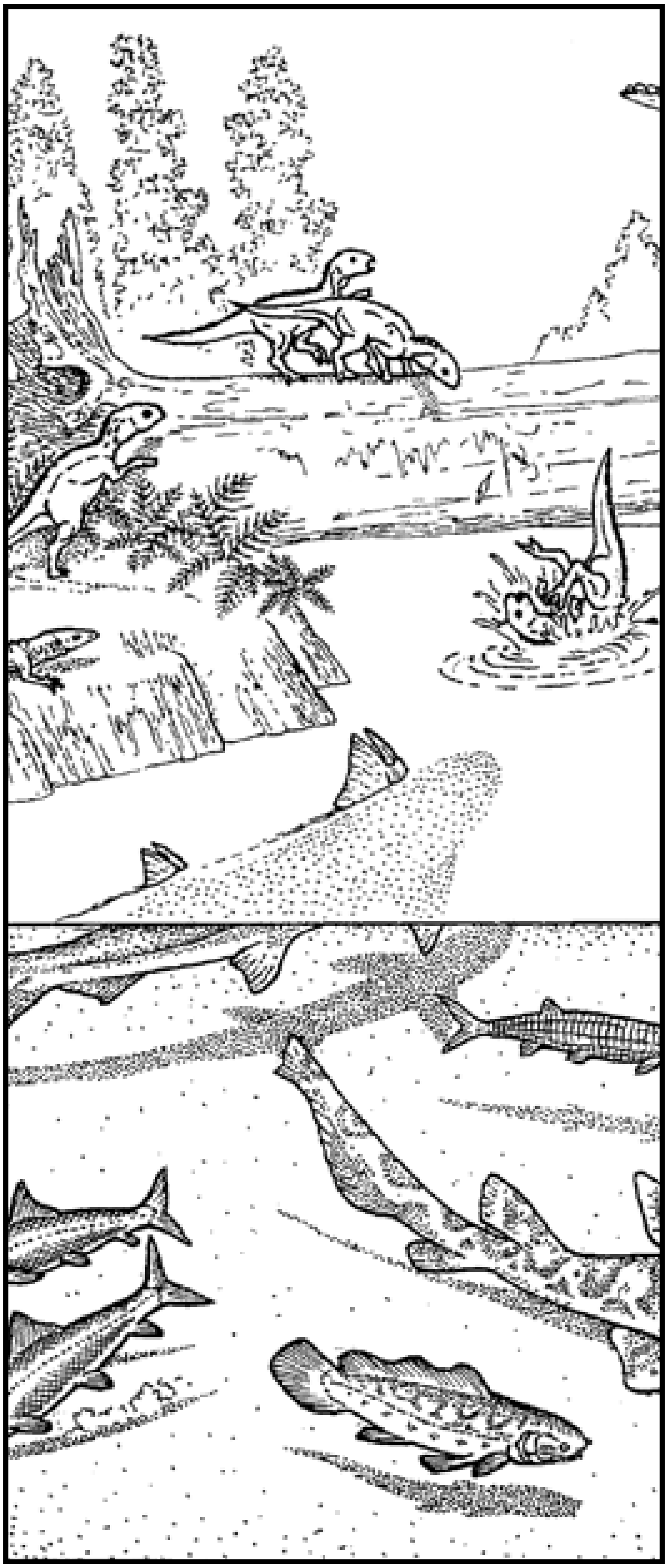
What would drive someone to forego their adherence to "the ME plan" while engaged in collecting within the fossil commons? After all, it can take vastly more time to record associated data than to simply excavate a specimen. Some public repositories have suffered from curators that thought of the material in their care as "their" collections, regardless of what lands they were obtained from, or who might use them. Curators should be able to anticipate questions that haven't been asked yet.

Why **should** multiple-use land management agencies (e.g., non-NPS lands) manage fossils at all?

Why **should** hobbyists adhere to some seemingly arbitrary regulations?

Why **should** our scientific colleagues care about the needs of other disciplines – when their field time is extremely limited, and they need to publish rapidly in their particular specialty?

In the "Tragedy of the Commons," the selfish herdsman was the problem, not the solution. We encourage paleontologists of ALL disciplines to re-think legislative efforts and management plans on a broad scale, making the fossil commons less tragic for curation and study.



POSTER

Developing a Fossil Management Program at Tule Springs Fossil Beds National Monument

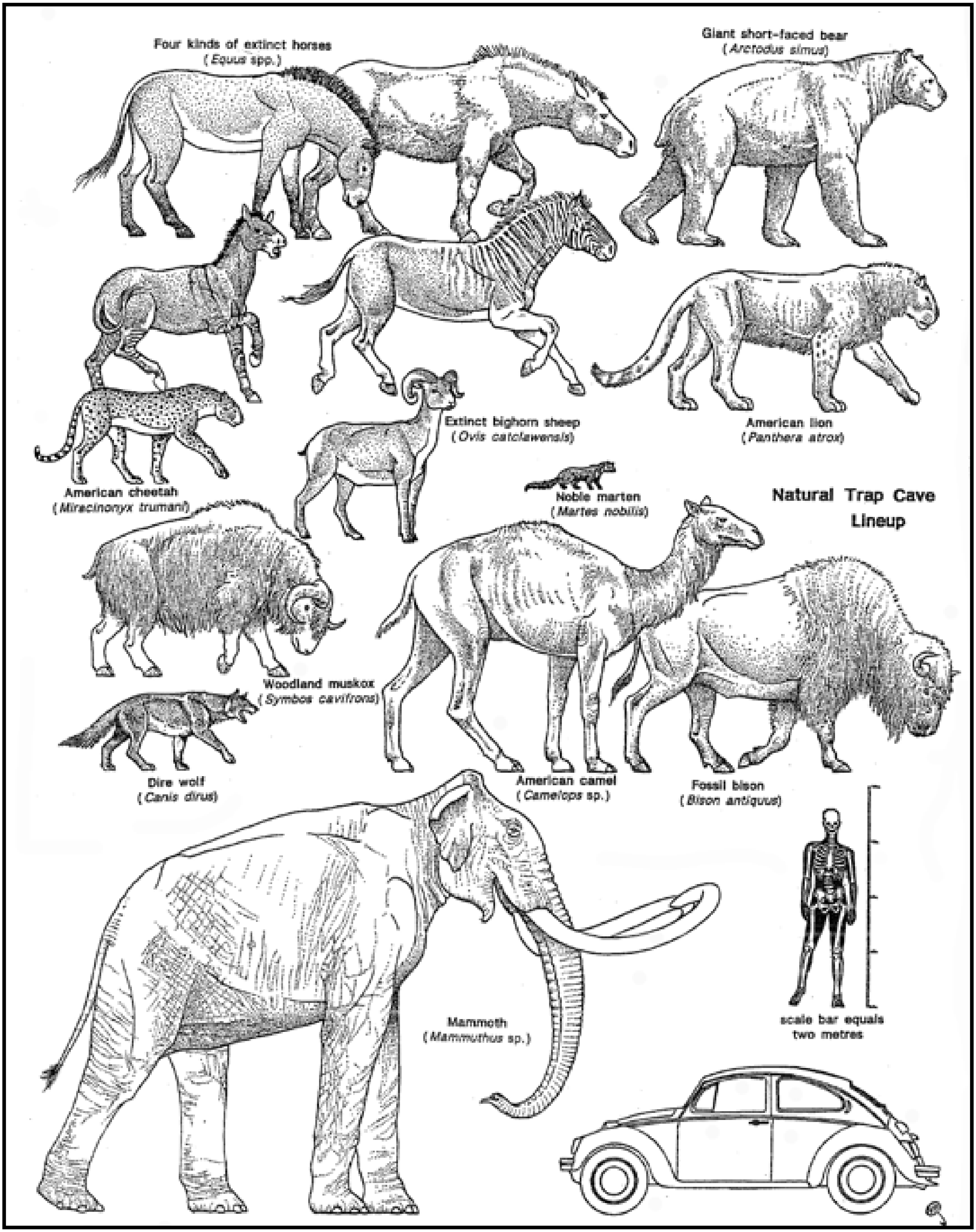
Susan E. Hertfelder, Tule Springs Fossil Beds National Monument
Erin Eichenberg, Tule Springs Fossil Beds National Monument

Tule Springs Fossil Beds National Monument (TUSK) was created in 2014 to preserve and protect a diverse fossil assemblage from the upper Las Vegas Wash (ULVW) in Clark County, Nevada. The Late Pleistocene Las Vegas Formation is the fossil-bearing geologic formation within TUSK and is exposed as a series of dissected and weathered deposits that form badlands topography. A diverse vertebrate fauna has been identified from deposits within TUSK that range from ~100 – 12.5 ka. Fossils have been collected from the Las Vegas Formation sporadically from 1903 to the 1990s by numerous institutions, then systematically from 2001 to 2014 by the San Bernardino County Museum (SBCM) for the Bureau of Land Management (BLM). Over 500 fossil localities were documented in TUSK before the land became managed by the National Park Service (NPS), with the majority of these localities discovered by the SBCM.

The primary goals of this project are to collect baseline paleontological resource data for previously documented fossil localities within TUSK and to create a fossil monitoring program for the in situ fossil resources in the monument. This project includes three primary components: (1) Relocate documented fossil localities, collect updated locality information, and document new localities as they are discovered; (2) Determine the monitoring priority of each locality and create a schedule for locality condition assessments throughout TUSK; and (3) Create an Access database and update the existing TUSK ArcGIS geodatabase to manage and document fossil monitoring and collection within TUSK.

For the first component of this project, we conducted condition assessments and collected geological data for new and previously discovered localities from February-July (2018). The GPS coordinates were available for the majority of the previously documented localities, but we collected additional geospatial data including mapping the extent of the fossil resources at each locality (to create locality polygons in ArcGIS), the locations of individual fossils within the locality boundary, and establishing photograph points for repeat photography. During this inventory, we documented over 650 existing and new fossil localities within TUSK.

The data management components of this project are ongoing but will be completed by August 2019. We have established a preliminary protocol for determining the monitoring priority and recommended monitoring frequency for each locality, following the vital signs outlined by Santucci et al., 2009. The completed results of this project will include monitoring and condition forms for each locality, a working Access database to be used for fossil resource management and monitoring, established points for repeat photography, and maps for localities with multiple in situ specimens. This project aims to create a framework for establishing a robust fossil monitoring program at TUSK, compile all relevant fossil resource data into a working database for resource management and paleontological research, and to protect the paleontological resources while TUSK becomes a developed and established monument.


Four kinds of extinct horses
(Equus spp.)
Giant short-faced bear
(Arctodus simus)
American lion
(Panthera atrox)
Extinct bighorn sheep
(Ovis catclawensis)
American cheetah
(Miracinonyx trumani)
Noble marten
(Martes nobilis)
Natural Trap Cave Lineup
Woodland muskox
(Symbos cavifrons)
Dire wolf
(Canis dirus)
American camel
(Camelops sp.)
Fossil bison
(Bison antiquus)
Mammoth
(Mammuthus sp.)
scale bar equals two metres

POSTER

Ten Years of Ichnological Research and Photogrammetic Documentation at the BLM Mill Canyon Dinosaur Tracksite, Utah

Neffra A. Matthews, US Bureau of Land Management
ReBecca K. Hunt-Foster, Dinosaur National Monument
Brent H. Breithaupt, Bureau of Land Management
Martin G. Lockley, University of Colorado-Denver

The Mill Canyon Dinosaur Tracksite (MCDT) was discovered in 2009 and is located approximately 14 miles north of Moab, Utah, on land managed by the Bureau of Land Management's Moab Field Office. Initial investigation of this Early Cretaceous tracksite yielded a unique vertebrate ichnofauna, including dinosaurian, crocodilian, and avian tracks. Didactyl tracks of Dromaeosauripus represent the first trackways of this ichnotaxon reported from North America (Lockley et al., 2014-a). The scientific importance of the site, along with its proximity to outdoor recreation opportunities and internationally known tourist destinations, supported a resource management approach that emphasized scientific research, public visitation, and education.

Beginning in 2009 an international team of scientists collaborated to study the site. From the onset of the project, documentation and mapping were conducted by experienced ichnologists. These data were integrated with digital documentation, including photogrammetry and GIS. Hand-held, close-range photogrammetric documentation of isolated, exposed areas was conducted in 2010. Partially exposed by natural processes in a dry wash, an enhanced picture of the tracksite was gained by uncovering a larger surface through permitted excavation. Between 2013 and 2015, overlying sediment was removed from the site for ichnological research, resulting in the discovery of at least 10 morphotypes. Included in the census were an additional *Dromaeosauripus* trackway, as well as large-, medium- and small-sized tridactyl theropod tracks and trackways. Also present were *Caririchnium*-like ornithopod trackways and sauropod trackways (Lockley et al., 2014-b).

In 2014, after spring excavation and prior to the construction of the boardwalk, systematic photogrammetric documentation of the main track surface was conducted using a high-resolution digital camera with a remote trigger mounted on a monopod, to acquire nadir, overlapping photographs. (Figure 1) photogrammetric processing resulted in an orthophoto map of the exposed tracks surface (Matthews et al., 2016). A preliminary ichnological map was produced that identified the main trackways and features. This map was spatially informed by the orthophoto map (Figure 2). Between 2015 and 2017, ADA compliant footpaths, boardwalks, interpretative signs, a shade structure, an expanded parking area, and a pit toilet were installed.

In May 2017, after completion of the boardwalk and facilities, the entire developed area was photogrammetrically documented using a 3DR Solo equipped with a Ricoh GR II camera. The MCDT was photographed at a variety of heights ranging from 7.5 meters above the main track surface to 76 meters over the developed area. Due to the approach utilized to capture photogrammetric imagery of the site, all three episodes of photography were processed together in Agisoft PhotoScan ver 1.4 in a unified coordinate system. The resulting digital data set provides a unique look at the evolution of a tracksite from a documentation and interpretation perspective; both in terms of the impact of exposure to the elements on potential morphological changes to the tracks themselves and how limiting the window to the track surface may impact current and future interpretations. Currently, the main exposed area of the tracksite covers approximately 598 square meters (not including outlying areas that reveal additional ichnites). When work at the site began in 2009, the area that was naturally exposed, or which could be exposed with sweeping and minimal disturbance, was approximately 65 square meters of what would become the main exposed area today. (Figure 3) The present exposures constitute an order of magnitude increase (~ x10) in track-bearing surface area. There is no doubt that the increased "window to the past" provides an opportunity to gain more insight into track formation dynamics and paleoecology of the site.

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Figure 1. A. Hand-held, close-range photogrammetric documentation was conducted in the isolated, exposed areas in 2010. B., Systematic photogrammetric documentation of the main track surface using a high-resolution digital camera with a remote trigger mounted on a monopod in 2010. C., Remotely Piloted, Unmanned Aerial Vehicle imaging the main track surface in 2017.

Figure 3. A., Composite stack of 2010, 2014, and 2017 orthophoto imagery. Of particular note is the expanded view of the track surface versus the small area initially available for study (circled in red), also of note is the virtual removal of a portion of the boardwalk. B., GIS track data is color-coded according to the area exposed in 2010 (depicted in light gray outlines) and overlain on 2014 orthophoto map. C., Ichnology map depicting selected trackways by MG Lockley. Note map is oriented to magnetic north.

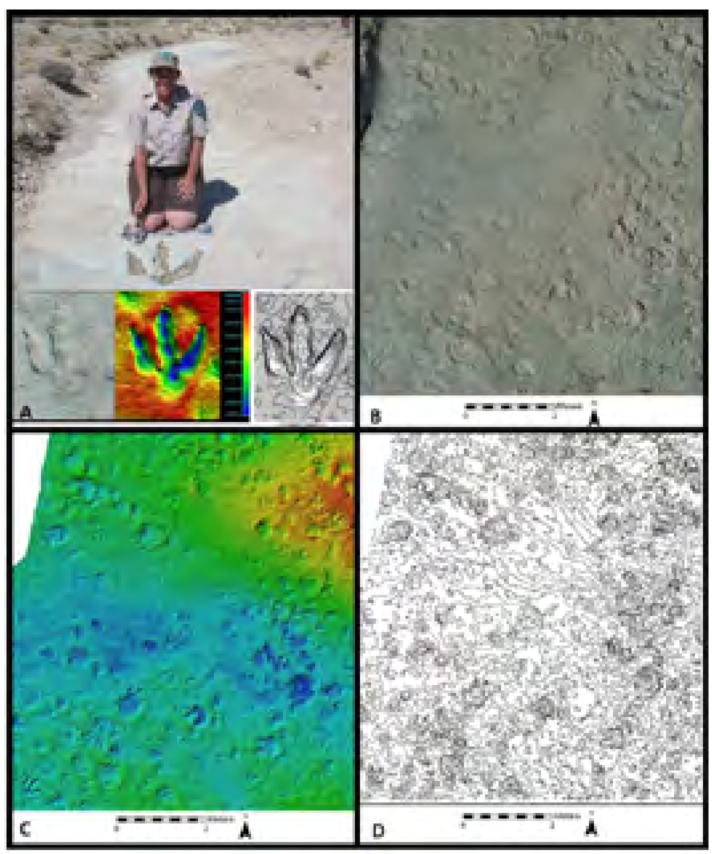


Figure 2. Photogrammetric documentation was conducted of individual tracks A. as well as portions of the main track surface. Products included orthophoto maps B, color depth maps C, and topographic contour maps D.

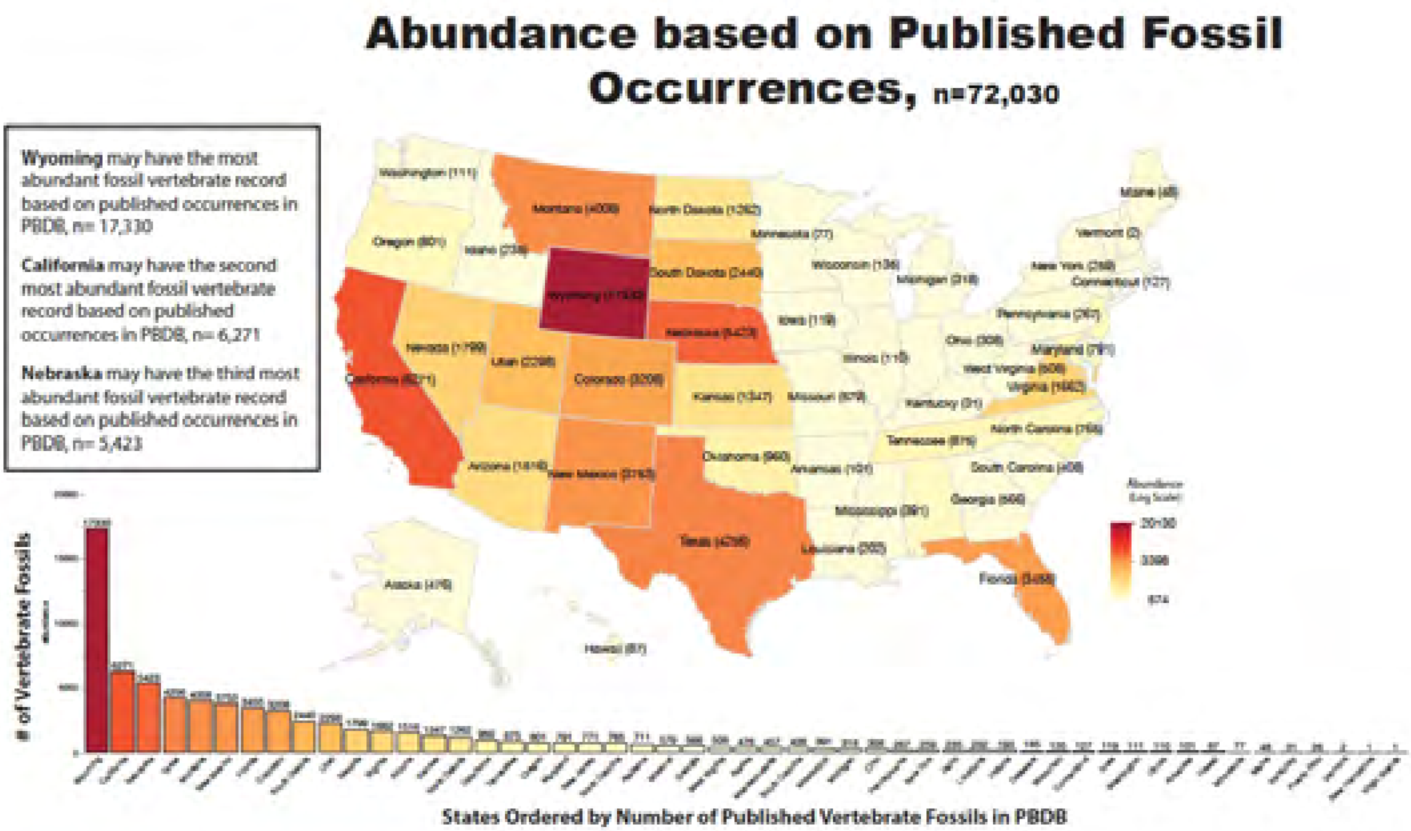
POSTER

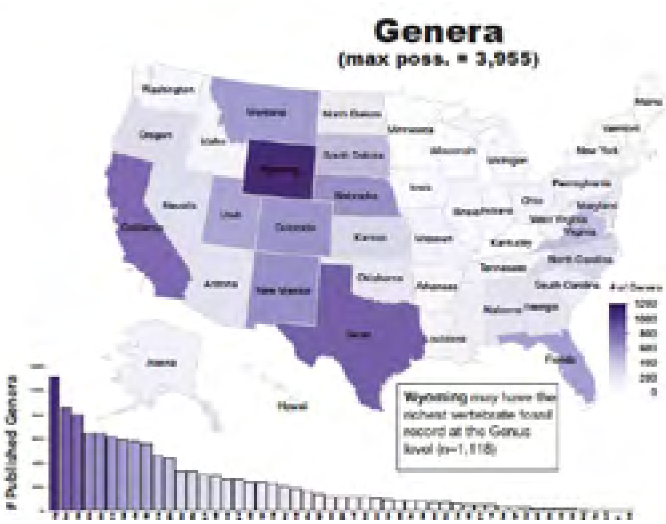
Who's the Best? A Cross-State Comparison of Fossil Vertebrate Richness, Temporal Completeness, and Biodiversity in the USA

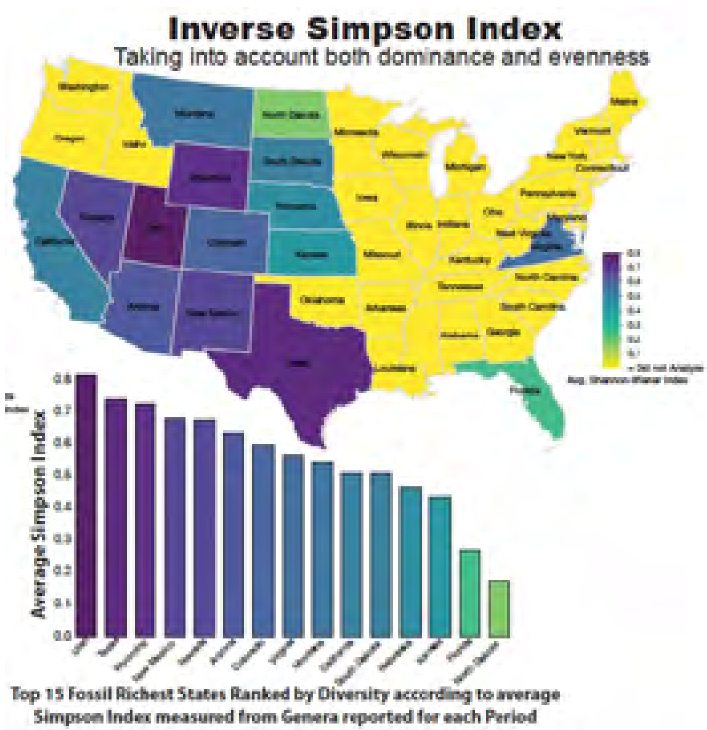
Laura Vietti, University of Wyoming Geological Museum

Researchers visit Wyoming to collect and study our fossil vertebrate resources every year, and much of these collection activities occur on public land (federal and state). As the University of Wyoming Geological Museum and Collections Manager, museum visitors often ask me "Why (do) researchers often visit Wyoming and is it because Wyoming has the best fossil record in the USA?" To address this vague question, I used data drawn from the Paleobiology Database (paleobiodb.org) to calculate a variety of biodiversity and temporal metrics for each state to ascertain which states' fossil vertebrate record may be considered "the best." Biodiversity metrics considered in this study include taxon abundance and richness at the Class, Order, Family, and Genus level for the entire Phanerozoic and by Period. To account for differences in evenness and sampling, I also calculated the Shannon-Wiener index, Simpson index, and rarefaction curves at the genus level for each state by geologic Period. Although I was unable to calculate statistics specifically for federally owned specimens, I assumed, based on the collections at the University of Wyoming, that a significant portion represents specimens collected from public lands (~50% of our vertebrate collections), and my findings will also characterize publicly-owned fossil resources.

A total of 72,033 fossil vertebrate occurrence records from the USA were returned. Utah and Nevada have the most temporally complete fossil record (~36% of the geologic Ages represented), and Wyoming is ranked third (26% of the geologic Ages represented). Wyoming has the most abundant fossil vertebrate record in the USA (24% of total returned records, n= 17,330, trailed by California and Nebraska) and Wyoming also has the richest vertebrate fossil record at the Order, Family, and Genus levels; California and Texas ranked second or third. When taking taxonomic evenness into account, on average, the Shannon-Wiener index and the Simpson index rank Wyoming third behind Texas and Utah. Rarefaction curves regularly rank New Mexico, Utah, and Nevada as having higher biodiversity sampling rates; however, Wyoming's record is better sampled based on curve length. In summary, under the consideration of the inferred collecting and publishing biases inherent with the Paleobiology Database data set, no single state consistently ranked first; however, Wyoming was found to have the most abundant and richest vertebrate fossil record in the USA, and Texas, Utah, New Mexico have either the most temporally complete vertebrate fossil record or the most diverse fossil vertebrate record in the USA, depending on the taxonomic level or time bin.


Abundance based on Published Fossil Occurrences, n=72,030
Wyoming may have the most abundant fossil vertebrate record based on published occurrences in PBDB, n= 17,330
California may have the second most abundant fossil vertebrate record based on published occurrences in PBDB, n= 6,271
Nebraska may have the third most abundant fossil vertebrate record based on published occurrences in PBDB, n= 5,423
# of Vertebrate Fossils
States Ordered by Number of Published Vertebrate Fossils in PBDB


Genera
(max poss. = 3,955)
Wyoming may have the richest vertebrate fossil record at the Genus level (n=1,118)
Published Genera


Inverse Simpson Index
Taking into account both dominance and evenness
Average Simpson Index
Top 15 Fossil Richest States Ranked by Diversity according to average Simpson Index measured from Genera reported for each Period

POSTER

The Sifter: A New Mechanical Wet and Dry Matrix Sieving Machine, With a Comparison to the Traditional Manual Wet Sieving Method

Joey T. Raum, Paleo Solutions, Inc.
Paul C. Murphey, Paleo Solutions, Inc.

Wet sieving of sedimentary matrix, also known as screen washing, is the most effective method of obtaining taxonomically diverse and numerically abundant samples of small vertebrate and invertebrate fossils. It is the third stage in a four-stage process which involves 1) matrix sampling; 2) soaking, drying and other techniques to break apart the cement in the matrix; 3) wet sieving to remove the fine-grained sedimentary fraction resulting in a concentrate; and 4) picking the fossils from the concentrate, a process which may be greatly expedited using heavy liquid flotation. Similarly, dry sieving is the most effective method of obtaining diverse and abundant samples from sedimentary matrix that does not require disaggregating techniques and washing. Although effective, traditional "manual" methods of wet and dry sieving are both labor and time intensive. Paleo Solutions has developed a new wet and dry portable matrix sieving system called the Sifter. It is an electrically powered automatic sieving apparatus consisting of a lightweight steel frame with a mounted vibrating ring, interchangeable stainless-steel mesh screens and a 115-volt motor (Figure 1 and Figure 2). The unit is used in conjunction with a self-contained water circulating system with a small reservoir positioned beneath the sieve with attached water pump. The pump recirculates water between the reservoir and two attached adjustable spray nozzles. The fine fraction accumulates in disposable bags, which are tied to the end of an accordion tube and aluminum funnel and can be discarded or processed using finer sieves. For dry sieving of sedimentary matrix, the unit is used without the water circulating system, reservoir, water pump, and spray nozzles.

The Sifter's efficiency and effectiveness were compared to manual wet sieving using matrix of Pleistocene age composed of moderately consolidated silty clay and fine-grained sand from a locality which produces small vertebrate, invertebrate, and plant fossils. An additional comparison was made to manual dry sieving using matrix of Pleistocene age composed mostly of loosely consolidated fine- to coarse-grained sand from a locality which produces small vertebrate and invertebrate fossils. The tests were also designed to determine the amount of fossil loss and breakage using the Sifter.

For the comparison of wet sieving methods, test samples of 13.6 kg (30 lbs.) were washed using each method. Manual wet sieving took 85 minutes to fully process the sample, whereas the Sifter took 66 minutes, a difference of 19 minutes. Due to the limited screen sizes available for the Sifter (a maximum of 16 holes per square inch for the Sifter versus a maximum of 30 holes per square inch for the manual screen), the Sifter method required a manual washing component to process the finest sludge that was collected beneath the electric Sifter. For the Sifter method, the electric step took 41 minutes to initially process the sample, and the manual step took 25 minutes to process the remaining sludge material. Furthermore, while the labor required to manually wash the sample took 85 minutes, only 20 minutes of labor were required to operate the Sifter, which included only the time needed to pour the sample into the machine, activate the vibrator motor and pump, periodically adjust the sprayers, and then remove the washed concentrate. Furthermore, the manual method failed to fully breakdown the matrix, leaving granule- to pebble-size clay clumps. In contrast, the Sifter yielded a cleaner concentrate with less residual sediment, and its high-frequency vibration was highly effective at disaggregating clay clumps. There was no apparent damage to fossils using either method.

For the comparison of dry sieving methods, test samples of 10.0 kg (22.0 lbs.) were sieved using each method. In contrast to the wet sieving comparison, only screen sizes of 16 holes per square inch were used for each method. Manual dry sieving took 13 minutes to fully process the sample, whereas the Sifter took 9 minutes, a difference of 4 minutes. Furthermore, while the labor required to manually sieve the sample took 13 minutes, only 2 minutes of labor were required to operate the Sifter, which included only the time needed to activate the vibrator motor, pour the sample into the machine and then remove the sieved concentrate. There was no apparent damage to fossils using either method.

The Sifter was designed by Paul Jette(1) and Geraldine Aron(1). Operation and experimental procedures were developed by Geraldine Aron(1), Cecilio Garcia(1), Paul Murphey(1), and Joey Raum(1).

Figure 1. Complete sedimentary matrix washing set-up, including the electronic Sifter unit, water reservoir and water pump. Additional support equipment includes a self-contained and recirculating sink (the Qnk) and a shop vacuum.

Figure 2. Sedimentary matrix washing using the electronic Sifter and attached water sprayer.

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