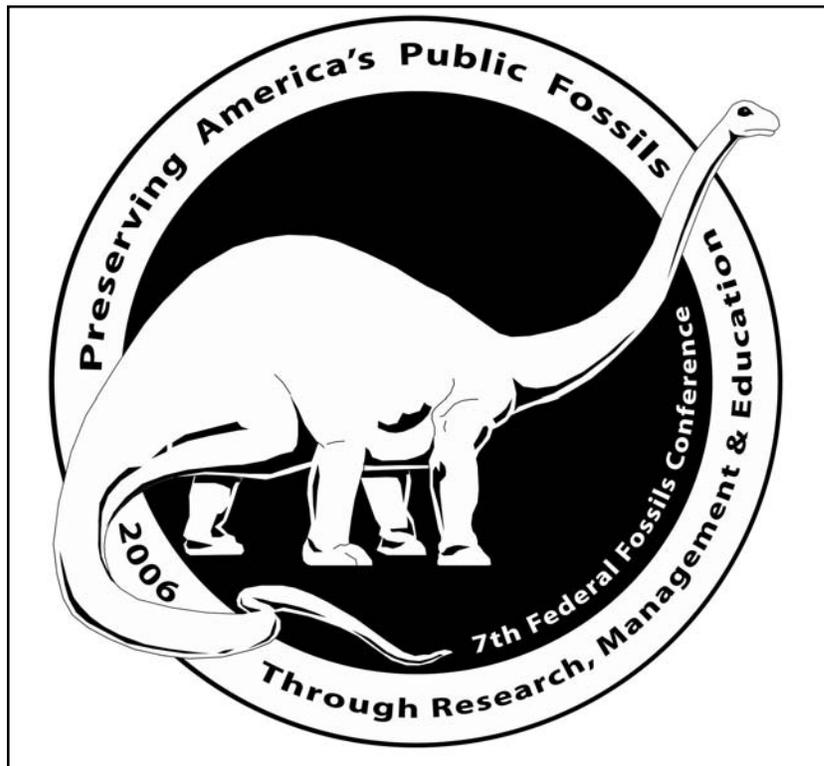


Bulletin 34

New Mexico Museum of Natural History & Science

A Division of the
DEPARTMENT OF CULTURAL AFFAIRS

**America's Antiquities:
100 Years of Managing Fossils on Federal Lands**



edited by

**Spencer G. Lucas, Justin A. Spielmann, Patricia M. Hester,
Jason P. Kenworthy and Vincent L. Santucci**

Albuquerque, 2006

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PREFACE

The year 2006 represents two major milestones in the history of managing paleontological resources on public lands of the United States: the passage of the 1906 Antiquities Act 100 years ago, and the convening of the first fossil resource conference 20 years ago in 1986. The theme of the Seventh Federal Fossil Resource Conference, “America’s Antiquities: 100 Years of Managing Fossils on Federal Lands,” reflects this century of paleontological resource management by such federal land management agencies as the Bureau of Land Management, Bureau of Reclamation, and National Park Service, all of the Department of the Interior, and the United States Forest Service of the Department of Agriculture.

President Theodore Roosevelt signed the Antiquities Act into law on June 8, 1906, primarily to protect “antiquities” such as prehistoric American Indian ruins and artifacts on Federal lands. The act also gave the President authorization to create national monuments on federal lands that preserve such antiquities and “other objects of scientific interest.” Within six months, paleontological resources were considered “objects of scientific interest,” forming the basis for the establishment of Petrified Forest National Monument (now a national park) in December of 1906. For nearly 75 years, the Antiquities Act served as the primary piece of legislation directing the permitting and protection of fossils on lands administered by the departments of Agriculture and Interior.

This meeting, in Albuquerque, New Mexico, is the seventh of the somewhat regular Fossil Resource Conferences. Dinosaur National Monument hosted the first in 1986, with approximately 30 attendees. Subsequent conferences were hosted by Petrified Forest National Park (1988), Fossil Butte National Monument (1993), Florissant Fossil Beds National Monument (1995), and Badlands National Park (1998). The Sixth Federal Fossil Resource Conference was held in Grand Junction, Colorado in 2001, with 150 attendees. The conferences have evolved and broadened greatly in scope. The first three conferences focused primarily on NPS fossil resources. They now serve as platforms to share new paleontological research and management issues, and also to foster the relationships between federal land management agencies and the paleontological community as a whole.

Over this 20-year span, awareness of paleontological resources public lands and their associated management requirements and goals grew dramatically. For example, when the first fossil resource conference convened in 1986, the National Park Service identified 12 units known to preserve fossils. Through the efforts of many people and partnerships, today more than 180 NPS units preserve fossils either *in situ* or in park collections. A similar increase in knowledge of paleontological resources has occurred throughout America’s public lands.

The convergence of 100 years of federal fossil resource management and 20 years of fossil resource conferences is significant. While an amazing assemblage of paleontological resources has been found within federal lands and contributed immeasurably to the science of paleontology, most of what is to be learned about the history of life remains to be discovered. The organizers of this seventh conference expect that the fossil resource management successes (and pitfalls) of the last 100 years will drive forward the next century of federal fossil resource management while the partnerships forged by these conferences over the last 20 years will continue to fuel this drive.

Two volumes have been produced as a result of this meeting. This volume includes abstracts and papers submitted as part of the Federal Fossil Resource Conference. A separate companion volume has been produced for the “Current Research on Late Cretaceous Vertebrates from the Western Interior Symposium” held concurrently on the second day of the Federal Fossil Resource Conference. We thank the many authors and reviewers of the submitted papers and abstracts contained within both volumes. They represent a cross section of the great diversity of paleontological resource issues addressed by federal land management agencies and their many valuable partners.

—Spencer G. Lucas, Justin A. Spielmann, Patricia M. Hester, Vincent Santucci and Jason Kenworthy (conference planning and editorial committee)

**America's Antiquities: 100 Years of Managing Fossils on Federal Lands
Seventh Federal Fossil Resource Conference**

Monday May 22-Tuesday May 23, 2006

MONDAY MAY 22, 2006

***denotes speaker**

8:00am **Welcome**—*Conference planning committee*

8:10am **Keynote Speaker**
Preserving fossils in the national parks: A history—*R. W. Sellars*

8:40am **Fossils, objects of antiquity, and the Antiquities Act (1906)**—*V.L. Santucci*

9:00am **Preserving America's fossil heritage**—*J. Hatcher*

9:20am **What is our mandate to manage fossil resources on federal lands?**—*S. Foss*

9:40am **Paleontological permitting on Bureau of Land Management administered lands in Utah**—*S. Foss*

10:00am BREAK

America's Antiquities—Paleontological Resource Inventory Strategies Session

10:20am **"Peetrified" Resources: National Park Service fossils found in cultural resource contexts**—*J.P. Kenworthy**
and V.L. Santucci

10:40am **A preliminary inventory of fossil fish from National Park Service units**—*R.K. Hunt**, *V.L. Santucci* and *J.P. Kenworthy*

11:00am **Paleontological resource inventory of California's Jurassic trackways**—*R.E. Reynolds*

11:20am **Paleontological resource inventory of Miocene(Barstovian) trackways at Owl Canyon Campground, Barstow, California**—*R.E. Reynolds*

11:40am **Implementing Inventory-Monitoring, Research, and Interpretive Plans for El Bosque Paleontologico Piedra Chamana in the northern Andes of Peru**—*H. W. Meyer**, *D. Woodcock*, *J. Young*, *W.McIntosh*, *N. Dunbar*, *L. Lutz-Ryan* and *K. Sikoryak*

12:00-1:20pm LUNCH

America's Antiquities—Paleontological Resource Partnerships session

1:20pm **Volunteers and partnerships: Effective management of fossil resources on National Forest System lands**—*B.A. Schumacher** and *V. Tidwell*

1:40pm **A Bureau of Land Management Paleontological Site Stewardship Program for Washington County, southwestern Utah: The beginning of a nationwide program?**—*A.R.C. Milner**, *D. Ferris-Rowley* and *J.I. Kirkland*

2:00pm **Utah Geological Survey: A valuable partner in the management of federal fossil resources**—*J.I. Kirkland**, *D.D. DeBlieux* and *M. Hayden*

2:20pm **Initial results of a five year cooperative interagency paleontological survey, Grand Staircase-Escalante National Monument, Utah and surrounding area: The proof is in the pooling (of resources)**—*A.L. Titus**, *S.S. Sampson*, *J.I. Kirkland*, *D.D. DeBlieux*, *D.D. Gillette*, *L.B. Albright* and *M.A. Getty*

2:40pm **The Friends of the Florissant Fossil Beds: Partnership support of education and research in geology and paleontology**—*S.W. Veatch*

3:00pm BREAK

The Following Sessions are Held Concurrently

America's Antiquities—Panel Discussion

3:20-4:40pm **Managing federal paleontological collections**—*Panelists:*

Ron Wilson, Museum Program Curator, Department of the Interior, Office of Property and Acquisition Management

Carolyn McCellen, Group Manager, Division of Cultural, Paleontological Resources and Tribal Consultation, BLM

Dale Hanson, BLM Regional Paleontologist, Wyoming State Office

Brent Breithaupt, Director, University of Wyoming Geological Museum

Mary Thompson, Idaho Museum of Natural History

Lucia Kuzion, Paleontology Program Manager, USFS, USDA

America's Antiquities—Paleontological Resource Science and Research Session

3:20pm **Correlation of a Rare Plant Species with Fossil Sites on the Grand River National Grassland**—*K. Hansen*

3:40pm **Fossiliferous nodules from New York Gateway beaches**—*J.A. Chamberlain, Jr. *, P.W. Stoffer, R.A. Scal and P. Messina*

4:00pm **A New Middle Miocene terrestrial fauna from the Temblor Formation of central California**—*J.D. Stewart*, E. Zaborsky, and M. Hakel*

4:20pm **Rare earth element fingerprinting of vertebrate fossils from the Eocene-Oligocene White River Group, Toadstool Geologic Park, Crawford, Nebraska**—*D.O. Terry* and D. Grandstaff*

TUESDAY MAY 23, 2006

*** denotes speaker**

America's Antiquities—Paleontological Resource Management Session

8:00am **Management of significant paleontological localities: Intragency and interagency**—*T.J. Fremd*

8:20am **Use of Geographic Information Systems in managing fossils on federal lands: The U.S. Department of Agriculture Fossil Yield Potential Classification (FYPC) System**—*B. Beasley*

8:40am **The application of photogrammetry, remote sensing, and Geographic Information Systems to fossil resource management**—*N.A. Matthews*, T.A. Noble and B.H. Breithaupt*

9:00am **Preserving the past: Geologic mapping and paleontologic investigation, Las Vegas Formation, North Las Vegas**—*K. Springer*, J.C. Sagebiel, C. Manker and E. Scott*

9:20am **Mowry Shale ichnofossils: Management of a unique fossil tracksite in an off-highway vehicle recreation park**—*D.A. Hanson* and M. Connely*

9:40am **Mitigation of fossil resources during oil and gas development**—*S. Landon**

4

10:00am **Good data vs. bad data: The importance of quality data management in paleontology**—*R. Benton* and R. Hargrave*

10:20am BREAK

America's Antiquities—Paleontological Resource Interpretation Session

10:40am **Cleveland-Lloyd Dinosaur Quarry: Restabilization and interpretation; Successes and pitfalls**—*M. Leschin*

11:00am **The Red Gulch Dinosaur Tracksite: Public participation in the conservation and management of a world-class paleontological site**—*B.H. Breithaupt*, E.H. Southwell, T. Adams, N.A. Matthews*

11:20am **Developing scientifically accurate paleontology exhibits for the National Park Service**—*T.J. Fremd*

11:40am **Innovative strategies to develop interpretive media for paleontological sites at Curecanti National Recreation Area, Colorado**—*A.L. Koch* and P.J. Zichterman*

12:00pm **Planning for the future: A program for preserving and interpreting paleontology and geology in Joshua Tree National Park**—*E. Scott*, K. Springer, J.C. Sagebiel and M. Hakel*

12:20-1:40pm LUNCH

America's Antiquities—Paleontological Resource Protection Session

1:40pm **Investigating fossil theft from National Forest System lands**—*S. Ruppert and B. Schultz**

2:20pm **Appraisal of fossil resources and specimens**—*L. Kuizon*

2:40pm **Theft and vandalism of *in situ* fossil vertebrate tracksites**—*V.L. Santucci*

3:00pm **Paleontological resource damage from “poor science”: Examples from Petrified Forest National Park**—*W.G. Parker* and K.A. Dorn*

3:20pm **Historical Resources Act designation of the Grande Cache Dinosaur Tracksite (Lower Cretaceous; Albian), Grande Cache, Alberta, Canada**—*D.N. Spivak*, D.E. Wetzel and J. Cailliau*

CURRENT RESEARCH ON LATE CRETACEOUS VERTEBRATES FROM THE WESTERN INTERIOR

Conveners- Robert M. Sullivan and Spencer G. Lucas

***denotes speaker**

Morning Session

8:45am **Welcome** -*Adrian P. Hunt*, Director, New Mexico Museum of Natural History and Science; *Spencer G. Lucas*

9:00am **Lithostratigraphy and biostratigraphy of the Fruitland Formation (Upper Cretaceous) of the San Juan Basin, New Mexico**—*S. G. Lucas*, A. P. Hunt and R. M. Sullivan*

9:20am **Kirtlandian land-vertebrate “age”— Faunal composition, temporal position and biostratigraphic correlation in the nonmarine Upper Cretaceous of western North America**—*R. M. Sullivan* and S. G. Lucas*

9:40am ***Dinamosaurus imperiosus* and the earliest discoveries of *Tyrannosaurus rex* in Wyoming and the West**—*B. H. Breithaupt*, E. H. Southwell and N. A. Matthews*

- 10:00am **BREAK**
- 10:20am **Tetrapod ichnofacies of the Cretaceous**—*A. P. Hunt** and *S. G. Lucas*
- 10:40am **Tetrapod footprints from the Cretaceous Dakota Group of the Western Interior**—*M. Lockley*
- 11:00am **Theropod dinosaur tracks from the Late Cretaceous (Turonian) Moreno Hill Formation of New Mexico**—*D. Wolfe*
- 11:20am **Duckbill dinosaur chin skin scales: ups, downs, and arounds of surficial morphology of Upper Cretaceous Lance Formation dinosaur skin**—*M. D. Wegweiser**, *S. A. Hartman* and *D. M. Lovelace*
- 11:40am **Cenomanian bonebed faunas from the northeastern margin, Western Interior Seaway, Canada**—*S. Cumbaa*, *C. Schröder-Adams*, *R. G. Day* and *A. J. Phillips**

12:00noon **LUNCH (two hour break)**

Afternoon Session

- 2:00pm **Investigation of the ichthyofauna of the Mowry Shale (early Cenomanian) of Wyoming**—*J. D. Stewart** and *Marjorie E. Hakel*
- 2:20pm **The nonmammalian vertebrate microfossil assemblages of the Mesaverde Formation (Upper Cretaceous, Campanian) of the Wind River and Bighorn basins, Wyoming**—*D. DeMar** and *B. H. Breithaupt*
- 2:40pm **Nonmarine turtles from the Cerro del Pueblo Formation (Campanian), Coahuila State, Mexico**—*D. Brinkman** and *R. Rodriguez de la Rosa*
- 3:00pm **The giant crocodylian *Deinosuchus* from the Upper Cretaceous of the San Juan Basin, New Mexico**—*S. G. Lucas*, *R. M. Sullivan* and *J. A. Spielmann**
- 3:20pm **BREAK**
- 3:40pm **Preliminary observations on an iguanodontid dinosaur from the Zuni Basin (Cretaceous) of New Mexico**—*A. T. McDonald*
- 4:00pm **Large hadrosaurine dinosaur from the latest Campanian of Coahuila, Mexico**—*J. I. Kirkland**, *R. Hernández-Rivera*, *G. S. Paul*, *S. Nesbitt*, *C. I. Serrano-Brañas* and *J. P. Garcia-de la Garza*
- 4:20pm **Responses of Late Cretaceous vertebrate paleocommunities to climate change in southern North America (Big Bend National Park, Texas)**—*J. Sankey*
- 4:40pm **Mammals from Cedar Canyon, Upper Cretaceous, southwestern Utah**—*J. G. Eaton*
- 5:00pm **Concluding Remarks**

Posters (Posters will be up all day on both Monday and Tuesday)

Using a Relational Geodatabase to Manage Paleontological Resources at Florissant Fossil Beds National Monument—*M.A. Barton*, *B. Frakes*, and *H.W. Meyer*

Results of a Three-Year Paleontology Inventory at Hagerman Fossil Beds National Monument, Southern Idaho—*P. Gensler* and *M.C. Carpenter*

Stratigraphic positions of marine reptile and dinosaur specimens in the Moreno Formation, in the Tumey Hills and Panoche Hills, Fresno County, California—*K. W. Ford*

Cooperative agreements, tools for partnership management of public fossil resources: One example—*P.M. Hester*

Paleosensitivity map for New Mexico: A tool for land use planning—*P.M. Hester and D. Simmons*

Legislative and regulatory history of paleontological resources—*L. Kuizon*

The diversity and stratigraphic distribution of pre-dinosaurian communities from the Triassic Moenkopi Formation, Capitol Reef National Park and Glen Canyon National Recreation Area, Utah—*D.L. Mickelson*

Subaqueous Tetrapod swim tracks from the Middle Jurassic: Bighorn Canyon National Recreation Area, Wyoming U.S.A.—*D.L. Mickelson, M.R. King, P. Getty and K.A. Mickelson*

Dinosaur tracks from the Upper Cretaceous Iron Springs Formation, Iron County, Utah—*A.R.C. Milner, G. S. Vice, J. D. Harris and M. G. Lockley*

Federal, state, and volunteer cooperation on vertebrate paleontology projects on federal land: Examples from Pleistocene sites in New Mexico—*G.S. Morgan, P.M. Hester, B.A. Schumacher and L. Gore*

Late Cretaceous marine reptiles (Mosasauridae And Plesiosauria) from New Mexico and their biostratigraphic distribution—*J.A. Spielmann and S.G. Lucas*

Establishing a future for fossils in the National Park Service: The development of a service-wide guidebook and paleontological database—*C.C. Visaggi, V.L. Santucci, J.P. Kenworthy, A.L. Koch, and T.B. Connors*

Paleowildfire characteristics and behavior: Diagenetic changes occurring in vascular bone during cremation by wildfire reveal ancient fire behavior—*M.D. Wegweiser*

A pachycephalosaurine pachycephalosaur from the Dinosaur Park Formation, Alberta —*T. Williamson* and T. Carr*

Transfer of UALP San Juan Basin vertebrate collection to the New Mexico Museum of Natural History and Science—*T.E. Williamson, P.M. Hester, and S.P. Bednarski*

USING A RELATIONAL GEODATABASE TO MANAGE PALEONTOLOGICAL RESOURCES AT FLORISSANT FOSSIL BEDS NATIONAL MONUMENT

M.A. BARTON¹, B. FRAKES² AND H.W. MEYER¹

¹Florissant Fossil Beds National Monument, National Park Service, Florissant, CO 80816, m.alanebarton@gmail.com; Herb_Meyer@nps.gov; ²Rocky Mountain Inventory and Monitoring Network, National Park Service, Ft. Collins, CO 80525, Brent_Frakes@nps.gov

Abstract—Florissant Fossil Beds National Monument, as of 2006, has 63 documented paleontological sites. Many of these sites are vulnerable to visitor disturbance, vandalism and theft, and all are affected by the elements, including weathering. Sites are monitored on cycles ranging from one to five years according to various factors such as fragility, proximity to trails and abundance of fossils. In order to monitor and protect these sites, an inventory and monitoring program was established by the park in 1992. The program operates primarily in summer, by workers who take Global Positioning System readings, photographs, notes, fossil surveys and condition evaluations of the sites.

Initial efforts to manage this information included maintaining printouts and photographs in binders and the creation of a simple IDEALIST database to organize the information contained in the paper records. As the Inventory and Monitoring program grew in complexity and scope, this database proved inadequate for efficient record storage.

In response, a new relational database application was designed and developed in the summer of 2005 to better serve the needs of the park's inventory and monitoring program. This database consolidates information from the original tables, site evaluation files, plot monitoring data and digital photographs. Forms were customized to facilitate data entry and minimize entry errors, while a variety of reports were developed for common reporting requirements. The new database allows for more detailed documentation of monitoring procedures, such as photograph information. The tabular information is also related to feature classes (georeferenced points and polygons) that describe the location of the various sites and study areas within the park.

To minimize use problems and loss of information the database is fully documented. Documentation includes relationships among the tables, data definitions and data collection procedures (i.e., monitoring protocols). The thorough documentation minimizes the learning curve for new student interns managing the database and ensures that the information will survive in perpetuity.

In the future, the park hopes to obtain portable digital photo viewers for workers to take with them when monitoring sites. This new database improves the organization of Florissant Fossil Beds National Monument's Inventory and Monitoring program as well as encouraging more complete documentation and evaluation of paleontological sites.

USE OF GIS IN MANAGING FOSSILS ON FEDERAL LANDS, THE USDA FOREST SERVICE FOSSIL YIELD POTENTIAL CLASSIFICATION (FYPC) SYSTEM

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Abstract—The Rocky Mountain Region of the USDA Forest Service has actively developed a paleontological program since 1992. In that time, the program has refined a number of management tools used by agency paleontologists for planning purposes. Although the primary functionality of these tools is land management, they also serve a useful role in education and research.

The primary tool employed by the USFS Paleontological Program is the Fossil Yield Potential Classification (FYPC). The FYPC assigns a numerical value to all geologic units on national forests and grasslands. The FYPC values indicate the probability of fossil resources occurring, on the surface and shallow subsurface. FYPC values are determined primarily by base geologic maps, but other factors are surficial deposits, vegetative cover, topography and accessibility.

GIS is used to combine all of this information and produce FYPC maps. Maps are produced at the finest resolution possible, usually limited to the degree of geologic resolution available. Map scale is variable and is determined by the overall size of a particular Forest or Grassland. These predictive potential maps allow non-specialists to quickly get an overall sense of the paleontological scenario in any particular part of the Forest System. By consulting such maps, planners can qualitatively assess the likelihood that management-relevant paleontological resources will be impacted by land management activities. Likewise, agency paleontologists use the maps to determine prolific fossil areas to target for survey and salvage efforts.

The Forest Service is in the process of formalizing FYPC efforts across the Rocky Mountain and Northern Rocky Mountain regions. The intent is to produce a widely utilized national model. As we continue to accumulate baseline data about paleontological resources on National Forest System lands, the FYPC system will continue to be refined and updated. Ultimately, the goal of the FYPC system is to establish a permanent cyclical program of survey, salvage, conservation, and law enforcement efforts that provide the maximum preservation and protection to fossil resources on public lands.

GOOD DATA VS. BAD DATA: THE IMPORTANCE OF QUALITY DATA MANAGEMENT IN PALEONTOLOGY

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Abstract—Data collection management should begin in the early planning stages of project development. For example, emphasis is often placed on field work, and not enough funding is secured for fossil preparation and curation. Unfortunately, when follow-up fossil preparation and curation are not completed in a timely manner, field notes are often lost, key researchers leave for other positions and uncataloged collections are often scattered. These deficiencies became apparent when the staff at Badlands National Park received funding to catalog collections that had been acquired over 30 years ago. Field notes were missing, and the fossil specimens were not stored in an orderly fashion. Efforts are now being made to archive field notes for all research completed in the park regardless of whether collections were made or not. All grant proposals drafted for paleontological projects now include funding for fossil preparation and curation in the proper proportion to the amount of field work completed and fossils collected.

Several ongoing paleontological projects at Badlands National Park provide important examples of the use of data management in vertebrate paleontology. Many of these projects have lasted for several years and have included a large number of participants. Certain strategies have been used to ensure that data collection is consistent and accurate. During the past six years, the park has completed two major paleontological field surveys. To ensure accurate field notes, all survey participants are given a note-taking template in which to follow. Global Positioning System units with associated data dictionaries are used to document site localities. Aerial photos are used as a secondary backup when satellite signals cannot be obtained in rough terrain. For paleontological quarry operations, a quarry protocol has been developed and is revised on a yearly basis. A Pentax electronic total station is used in addition to a meter grid mapping system to document the position of individual fossils. “Data Checks” are integrated into the data collection process to ensure that major errors are not being made. These include, taking three readings off of known fixed points at the beginning of each data collecting session and recording all readings on paper as well as collecting data via the data logger. Data are also exported into ArcView on a weekly basis to ensure proper output. Field technicians are also encouraged to check all total station readings immediately after recording to see if numbers match the proper grid address.

Because shape files are generated for both the paleontological field surveys and quarry collection, detailed metadata are developed to document all aspects of Global Positioning System and Geographic Information System data collection. Metadata provide a way to document the type of equipment and software used, give details on data collection methods and list any types of problems encountered and their subsequent resolution. They also include a listing of people involved and their contact information. Because paleontological locality data can be highly sensitive, metadata include a discussion on data access and recommended security levels.

THE RED GULCH DINOSAUR TRACKSITE: PUBLIC PARTICIPATION IN THE CONSERVATION AND MANAGEMENT OF A WORLD-CLASS PALEONTOLOGICAL SITE

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Abstract—The Rocky Mountain West contains some of the most important vertebrate paleontological remains in North America. Most of these fossils are located on public lands managed by the federal government. To help facilitate the preservation and protection of these nonrenewable scientific and educational resources, partnerships have been formed between institutions and land management agencies. As these fossils are public resources, it is also vital for the public to be actively involved with research projects. An example of this type of cooperative project was the work done at the Red Gulch Dinosaur Tracksite. In 1997, this project brought together researchers, students and volunteers from around the country to work with land managers to assess the paleontological significance of a previously unknown dinosaur tracksite in the Bighorn Basin of Wyoming.

The Red Gulch Dinosaur Tracksite is a 1600 square meter area of public land administered by the Bureau of Land Management. The Red Gulch Dinosaur Tracksite (the most extensive tracksite known in Wyoming) is the best studied of the various sites within the “Sundance Ichnofaunal Province” of the eastern Bighorn Basin. At this site over 1,000 tridactyl pes impressions are preserved in a ripple-bedded, oolitic, limestone of the Bathonian Canyon Springs Member of the Lower Sundance Formation. At the Red Gulch Dinosaur Tracksite (UW V-98066), the activity patterns of over 100 small- and medium-sized (10-230 kg) carnivorous dinosaurs (ranging in hip height from approximately 32-120 cm) are preserved. Irregular step lengths, variable straddle widths and swerving, parallel trackway paths may relate to variations in substrate microenvironments, tidal cycles and intracommunity dynamics. In addition, dramatic differences in track morphology both within and between scores of distinct trackways (ranging from 2 to 45 steps) may reflect lateral and vertical substrate variations, differential preservation and weathering, variable track generation episodes, ontogenic variability and individual trackmaker characteristics. Analysis of the ichnological data supports interpretations about the family structure and community dynamics of gregarious dinosaurs walking/trotting (and perhaps foraging) on the water-saturated, thixotropic sediments close to the shore of the Sundance Sea. The evidence of family groups of a monotaxonomic community of primitive tetanurine theropods (possibly ranging in age from yearling to adult) implies proximity to a nesting area and the semi-precocial nature of young dinosaurs. Interpretations of the intricate “dance” of these organisms on an ancient tidal flat is fascinating as a “live-action” glimpse of the past becomes clearer through continual, intensive research. As research work on this project continues, new chapters are being written about this Mesozoic “dark age” in Wyoming, and a better understanding is coming to light about the life and times of the Middle Jurassic of North America.

The Red Gulch Dinosaur Tracksite is a unique site not only for our understanding of a previously unknown Middle Jurassic dinosaur fauna, but also as an experiment in resource protection and public interpretation. After five years of dedicated research, the project area has now been developed for public visitation and interaction. However, the public was never distanced from the project, but rather encouraged to visit and participate during the research investigations. Thus, the public can not only claim the site as one of their own national treasures, but also know that they assisted in making this the most intensively documented dinosaur tracksite in the world. However, as with any project involving the close association (sometimes in harsh weather conditions) of a diversity of people with various backgrounds and agendas, the “sailing of the seas” was not only always smooth. In fact, various turbulent times led to dissolving of partnerships and mutinying of volunteers. Fortunately, the project reached fruition and valuable lessons were learned regarding lines of communication and established plans, guidelines and responsibilities, as the protection and preservation of the resource needs to take precedent over personal agendas. Although the Red Gulch Dinosaur Tracksite project illustrated what was “the best and the worst of times” in a team endeavor, it also showed that a national policy for the protection of fossil resources can only succeed if scientists agree to work in a communicative and professional manner with the public. In conjunction, land managers need to help facilitate these projects and encourage, support, and acknowledge the participation of those involved. Through the efforts of hundreds of individuals, paleontological and geological work at the Red Gulch Dinosaur Tracksite resulted in a previously unknown dinosaur community coming to light, which has caused a dramatic reinterpretation of the Middle Jurassic paleoenvironment of northern Wyoming.

FOSSILIFEROUS NODULES FROM NEW YORK GATEWAY BEACHES

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Abstract—Nodules preserving Holocene, and perhaps older, fossils frequently wash ashore on ocean beaches of the New York Bight. We collected nodules over a nine year span at two Bight locations in Gateway National Recreation Area—Rockaway Spit, NY, on the north shore of the Bight and Sandy Hook, NJ, on the western side—that show patterns in lithology and fossil content that suggest a complex history of nodule formation and transport. At Rockaway the most common nodules consist of small, water-worn fragments of indurated, tan-colored, micaceous sand, many of which contain shells of oysters, whelks and other species whose modern representatives typically inhabit brackish, estuarine environments rather than fully marine waters or sandy, ocean beaches. Hardened, black mud casts also occur at Rockaway, sometimes baked to a brick red color by either man-made or natural fires, and containing plant debris, and mussel and clam impressions. Sandy Hook has a wider range of common nodule lithologies. These include: (1) indurated, mica-rich sands, similar to those of Rockaway, but often with prominent *Ophiomorpha*-like burrows; (2) conglomeratic concretions composed primarily of rounded quartz grains and often preserving abundant *Anomia*, *Mytilus* and small gastropod shells; and (3) greenish, glauconite-rich, sandy concretions, occasionally with burrows. Nodules occurring at Rockaway often contain largely intact remains of juvenile, estuarine crabs, but crabs in nodules are rare at Sandy Hook. The surf clam *Spisula* and other common clams typical of New York Bight beaches today are in nodules or missing entirely from them.

The presence of undistorted shells and bioturbation structures in the nodules, as well as acicular aragonitic and high magnesian calcitic cements, implies their very early, perhaps syndepositional lithification. The fauna preserved in nodules at Rockaway are characteristic of bay-side, estuarine environments rather than fully marine, oceanic environments, while Sandy Hook nodules preserve a more oceanic fauna. We infer from this that most of these nodules derive from Holocene and perhaps late Pleistocene estuarine and beach sediments (e.g., Gardiners Clay). The nodules were probably formed from hardened material within these units that was eroded and mobilized during landward migration of the New York Bight shoreline associated with Flandrian sea level transgression. Some nodular material, especially at Sandy Hook, probably derives from glauconitic Cretaceous sediments that crop out nearby.

PALEONTOLOGICAL PERMITTING ON BLM-ADMINISTERED LANDS IN UTAH

SCOTTE FOSS

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Abstract—The need to apply for a permit to do paleontologically-related research, collecting or mitigation on BLM-administered lands seems onerous to many. One-hundred years ago people were able to collect from federally-owned lands with impunity and were encouraged to sell their finds to colleges, museums and research individuals for study. This is the founding history of the science of vertebrate paleontology in North America. Those days ended exactly 100 years ago with the signing of the Antiquities Act of 1906. Over the past century competing use of federal lands has made a permitting system necessary. Recent congressional mandates make it necessary for land managers to track all paleontological sites on federal lands and all specimens collected from federal lands. The combination of a new computerized database, GIS technology, and complete record-keeping from the past decade has allowed the Utah state office of the BLM to assemble a database that will allow land managers to issue and track paleontological use permits. This system allows land managers to keep track of all of the data required for annual and quarterly submissions to Congress, while continuing to allow the permittee to spend more time in the field collecting fossils and conducting research.

WHAT IS OUR MANDATE TO MANAGE FOSSIL RESOURCES ON FEDERAL LANDS?

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Abstract—The combination of increased commercial leasing activity for energy production, continued agricultural leasing (including grazing and timber harvesting), and ever-growing recreational use are putting strains on federal lands in a way that has not been foreseen. Fossil resources are affected by many of these developments and uses of federally-administered lands. New fossil sites are continually discovered, excavated, interpreted, and protected; whereas other sites may be trampled, illegally collected, or ignored. The BLM is mandated to manage public lands “in a manner that protects the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archaeological values” while at the same time managing public lands “in a manner that recognizes the Nation’s need for domestic sources of minerals, food, timber, and fiber.” The need to preserve paleontological resources is recognized by both the American public and federal land managers. However, protecting fossil resources is only incidentally recognized in federal legislation. What are the greatest threats to fossil resources on federal lands, what can be done and what should be done?

DEVELOPING SCIENTIFICALLY ACCURATE PALEONTOLOGY EXHIBITS FOR THE NATIONAL PARK SERVICE

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Abstract—Many complexes of fossil localities, such as can be found in the John Day Basin of Oregon, are very good places to be if you are a paleoecologist, but very complex places if you are not. To clarify an important, but daunting, scientific area the NPS constructed a new museum facility which opened in 2005, the Thomas Condon Paleontology Center. It was designed to facilitate research and explain the scientific and curatorial aspects of paleontology, the excitement of ongoing discoveries and expose the public to concepts such as “deep time” and evolutionary theory.

The basin consists of roughly 10,000 square miles of outcrop and subcrop containing a fossiliferous section over 3,000 meters thick and there are sites throughout the column entombing rich floras and faunas. The decision was made to focus on 8 critical “slices” of this composite section, approximately 5 million years apart, so as to display the profound changes in climate and the ecosystems tracking them.

Initially, we were confronted with certain parameters for new fixed exhibitry, such as “reduce terminology to a minimum”, “target specific audiences”, “comprehension to a 6th grade level or less” and so forth. Instead, our project has applied a “get everybody with multiple layers of info” approach. Our methodology can be summarized as follows:

- Scientific exhibits prepared by scientists, working in collaboration with contracted writers, professional designers *and* input from NPS interpreters.
- If the significance of the resource is its very complexity, don’t oversimplify and don’t apologize for it.
- Everything should undergo rigorous scientific peer review, akin to the professional vetted literature.
- Employ a “Shakespearean” approach: something for everyone.

An important component of the facility is to permit an interface between the visitor and the actual functions of the museum. Viewing areas with associated lobby cases were designed into the building to permit the usual examination of the laboratory function, but also other critical components of the discipline: field and accession areas, dedicated systematic storage and the library function. In addition, the active process of scientific investigation has been highlighted using lobby cases covering topics such as radiometric dating, taphonomy, biostratigraphy, fossilization, curation, preparation, fieldwork and more.

The exhibit gallery itself features rockwork produced from actual molds of the locality outcrop in many cases, with realistic features cast in massive layers of cementitious materials. The striking colors of these rock artifices are easily associated with the colors of the actual geologic features in the field; and a series of “icons” was developed to reinforce the point that there is not just one “fossil bed”, but a great many stacked throughout a wide area spanning 45 million years. Across from the rockwork are panels with actual rock samples and a detailed treatment of the stratigraphy. Atop or within the rockwork are displayed nearly 500 fossil specimens, ranging from massive skulls and leaves to tiny teeth stored in drawers equipped with magnifiers. In each of the eight separate “time slices”, detailed and painstakingly accurate murals were created – each the best “testable hypothesis” at this point in our analysis. If new data falsify some of the scenes or reconstructions, the murals will be painted over to reflect the new information and this point is made clear in additional interpretive panels.

Reconstruction of many aspects of the biotas was challenging in that most had never been illustrated before. These include a full sized reconstruction of *Pogonodon davisi*, a hypertragulid and some mylagaulids as well as a variety of different paleoflora elements. A central exhibit concerns the “lessons learned” from analysis of the fossil record, including specialized panels on coevolution, global climate change, functional morphology and a new depiction of the detailed sequence of equid phylogeny. This features what is possibly the longest and most complete biostratigraphic sequence of equid morphotypes in an accessible (if complex) tree.

Contrary to some expectations, it appears most of the visiting public consumes this information quite readily. Some have wondered why the NPS has such scanty or bland information at other visitor centers. It may be that the conventional wisdom that the public will not consume scientific information at parks without translation/interpretation by non-scientists may be askew. Displays should be flexibly designed and written based on the nature of the data, rather than forcing the data to fit a pre-existing static interpretive methodology. This should lead to digestible content meant to inform and challenge the interested visitor.

MANAGEMENT OF SIGNIFICANT PALEONTOLOGICAL LOCALITIES: INTRA-AGENCY AND INTERAGENCY

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Abstract—Within the NPS, the paleontological focus has traditionally and reasonably been focused “inside” existing park boundaries, usually in parks established specifically because of the fossil deposits. Paleontologists have long known that strata “cross fences”, of course, and in many instances localities of equal or greater scientific importance are proximal to such “fossil park” boundaries or are found in parks with little or no idea that such paleobiotas exist.

NPS paleontologists are developing projects of various scales that analyze strata both within and external to parks. The idea for doing this dates back a long time. In 1960, the NPS directorate fostered a series of analyses concerning “NPS participation in the preservation of paleontological values.” A key objective was “... to encourage participation of other Federal, State, university, scientific, conservation, and similar organizations so as to provide a well-rounded program for the preservation of paleontological values in the United States.” This concept seems to embody the ideal of an agency with the word “Service” in its title – being of benefit to others and thinking beyond the “my institution” plan.

Forty-five years since those words were written, we see that the inventory and monitoring of parks with paleontology as a “core mission” is well underway. The Geological Resources Division established a service wide paleontologist position, the Western Region includes a paleontologist as one of the Regional Science Council and there are more paleontologists working for the agency than at any time previously. These are major strides along what apparently is a rather long and winding road.

Assuming that the idea of preserving paleontological values is still of interest, there are now a number of steps that remain undone in order to establish a “well-balanced” program, using a variety of organizations. Among the important considerations include:

- Within a given age or depositional environment, what are the most significant localities or “values,” and are they being preserved?
- How is this significance evaluated, and by whom?
- What is the extent of the deposits, both spatial and temporal?
- What are the research and conservation options, with what “organizations”?

Two examples of different approaches and scales of conservation are presented: The Wrangell-St. Elias NP and Preserve in Alaska (intra-agency) and the John Day Basin in Oregon (inter-agency). In the Alaskan example, paleontologists assisted a “non-core paleontology” park assess remarkable fossil resources. While WRST is certainly not known as a “paleo park” the literature suggested there probably were some interesting assemblages. In consultation with the park geologist, a reconnaissance survey was initiated. Workers provided management with an overview of the important units of strata and preliminary sections, identification of new localities, review of the available literature and curation of collected specimens. Thanks to this fieldwork funded by the NPS GRD, WRST emerges as an important paleontological park.

In the Oregon example, we see that many of the resources that make the basin significant are actually outside of the congressional boundaries. The NPS simply assumed management of some pre-existing State park lands and rejected several that were very scientifically significant (for reasons unknown). It turns out that the vast majority of interesting localities are on lands administered by the BLM; thus, for a cohesive management program to exist, cooperative agreements over a large basin have been required. The goal of this effort is to encompass the complete geographic range of important strata, using all investigative methods available throughout the entire range of depositional sequences and taxonomic affinities, with a long-term funded commitment to structured fieldwork and research. The products have included dozens of new peer-reviewed interdisciplinary research papers, region-level approved management plans and in this instance a new paleontology center devoted to curation, research and education concerning 750 major localities covering 10,000 square miles.

To achieve protection and understanding of a variety of localities managed by different agencies, a number of tools are available. For example, a very important locality (Logan Butte, one of the most important Oligocene deposits in North America) administered by the BLM has been established as an Area of Critical Environmental Concern (ACEC). Using designations such as an ACEC, Resource Natural Area (RNA) and/or a National Natural Landmark (NNL) we hope to establish a new system of protecting and providing for the study of important paleontological areas in eastern Oregon. Most are on BLM, and many are on USFS and FWS lands. A unified network of localities, administered by different agencies and private organizations such as the Paleontology

Academy, can be recognized as Cooperative Areas for the Management of Paleontology (CAMPs) that use one or more of the management designations. Perhaps such a network in other significant paleontological strata will achieve the long-proposed but bureaucratically elusive goal to establish “a well-rounded program for the preservation of paleontological values in the United States.”

RESULTS OF A THREE-YEAR PALEONTOLOGY INVENTORY AT HAGERMAN FOSSIL BEDS NATIONAL MONUMENT, SOUTHERN IDAHO

PHIL GENSLER AND MARY C. CARPENTER

Hagerman Fossil Beds National Monument, Hagerman, ID

Abstract—Hagerman Fossil Beds National Monument in southern Idaho contains one of the richest Pliocene-aged (Blancan NALMA) vertebrate fossil localities in the world. The nearly 183 m (600 ft) of loosely consolidated stratigraphy exposed here contain fossils that date from 3.0-4.0 Ma and are spread throughout the relatively small 4,300-acre monument.

Using crews of summer seasonal employees and Student Conservation Association volunteers, the monument has conducted a three-year (1999-2001) inventory of paleontological resources located in the monument. The goal of this inventory was to collect baseline paleontological resource data to support the protection and management of these non-renewable fossils and their associated localities.

This inventory was accomplished by relocating previously identified fossil localities for which spatial data was available and by identifying new paleontological localities. Vertebrate paleontology research in the Hagerman area spans nearly 80 years. Important collectors in the past include paleontologists from the U.S. Geological Survey, the Bureau of Land Management, the University of Michigan, Los Angeles County Museum and Idaho State University. A base map of paleontological localities discovered by the previously mentioned entities was compiled by G. Cunningham in 1983 under contract with the Bureau of Land Management. This map was digitized and used as a primary source of information in the relocation of these historical fossil localities. Unfortunately, locality data for many of the sites were unclear or nonexistent, some indicated only by a hand drawn point and locality number on a map.

At the end of this three-year survey nearly 600 historic and new fossil localities were recorded within the Monument boundary. The remains of the Hagerman Horse, numerous species of rodents, artiodactyls, carnivores, birds, fish, mollusks and ostracods were recovered. Notable discoveries include nearly complete skeletons of a peccary (*Platygonus pearcei*), the giant marmot (*Paenemarmota barbouri*) and a pond turtle (*Clemmys owyheensis*). Locality information includes Global Positioning System data (X,Y,Z), photographs, locality description, locality condition, specimen information and any geologic information. The results of this three-year project is a working database that is used to make resource management decisions, establish monitoring timeframes for the localities and as an aid in paleontological research.

CORRELATION OF A RARE PLANT SPECIES WITH FOSSIL SITES ON THE GRAND RIVER NATIONAL GRASSLAND

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Abstract—The Grand River National Grassland (GRNG) lies in northwestern South Dakota in Perkins, Corson and Ziebach counties. The terrain is a mixture of rolling hills and isolated buttes intersected by the North and South Forks of the Grand River and its tributaries. These drainages have cut through several sedimentary layers including the Upper Cretaceous Hell Creek Formation. This formation is known to be very fossiliferous on the Grand River National Grasslands. These areas are also a habitat for Dakota buckwheat (*Eriogonum visheri*), an endemic plant found only in western South Dakota, western North Dakota and extreme southeastern Montana. On the GRNG, Dakota buckwheat has been found to be very abundant in recent, extensive surveys of potential buckwheat habitat. It appears to favor the badlands clay slopes and outwashes of the Hell Creek and Ludlow formations. The correlation of the Dakota buckwheat populations to the existing fossil sites is very closely related and appears to be more than coincidence. Preliminary findings suggest that Dakota buckwheat could be used as an indicator species for finding additional fossil sites on the GRNG. This connection is also more evident as preliminary surveys of disjunctive Hell Creek exposures on the GRNG have yielded neither Dakota buckwheat populations nor fossils to date. Therefore, data from the Dakota buckwheat surveys have the potential to be utilized to target specific areas for future fossil surveys.

MOWRY SHALE ICHNOFOSSILS – MANAGEMENT OF A UNIQUE FOSSIL TRACKSITE IN AN OFF-HIGHWAY VEHICLE RECREATION PARK

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Abstract—A recently rediscovered ichnofossil locality in central Wyoming contains a variety of tracks and traces, including tracks and body impressions that are probably crocodylian in origin, plus examples of *Asterichnites octoradiatus*, unusual star-shaped impressions attributed to a cephalopod. These ichnofossils are preserved by a sandpaper-like, thin ash coating on the uppermost layer of the Mowry Shale (upper Lower Cretaceous) where it locally contacts the “Clay Spur” bentonite. A shallow water paleoenvironment is suggested based on long, curving impressions, probably from the swimming motion of tails and feet dragging through the mud. Numerous wide shallow impressions are also quite evident, probably indicating body imprints. The locality is within a BLM designated Off-Highway Vehicle (OHV) Recreation Park and receives a moderate level of use by riders of ATVs, motorcycles and four-wheel drive vehicles. The area is the site of an abandoned bentonite mine, which was flooded by the hard, track-bearing layer. Remnant mounds and layers of the bentonite-bearing unit remain and protect any underlying tracks and traces. Where exposed, the track-bearing layer weathers readily to fragments. A brief study was done in late 2004 to quickly record, photograph and document the tracks and traces, with the goals of determining the present condition and trend of the tracks and traces, developing short-term management directions and establishing some baseline data for a larger research project. Based on this study, it was decided to allow the OHV Park to remain open at this time, but to begin a long-term monitoring project to document any change in condition of the tracks caused by both OHV actions and natural weathering. It is intended that this long-term project continue the detailed research of this site and conduct a survey of surrounding areas to determine the extent of the fossil-bearing layer. The junior author has received an NSF grant to continue research efforts at this locality and BLM is exploring options for cooperative efforts.

COOPERATIVE AGREEMENTS, TOOLS FOR PARTNERSHIP MANAGEMENT OF PUBLIC FOSSIL RESOURCES, ONE EXAMPLE

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Abstract—New Mexico State Legislation created the New Mexico Museum of Natural History and Science (NMMNH&S) to serve as the state museum of natural history and to collect, preserve, study and interpret materials representative of the natural history of the state and region. For the benefit of the citizens, the NMMNH&S is responsible for developing and maintaining educational exhibits and programs. The Federal Land Management Policy Act of 1976 (FLPMA) gives the Bureau of Land Management (BLM) the authority to enter into cooperative agreements. The Federal Grant and Cooperative Agreement Act of 1977 (FGCAA) established agency procedures to award Federal assistance. Since BLM manages important fossil-producing formations in New Mexico and has the responsibility to manage those resources for the public benefit, the cooperation serves the mission of both BLM and NMMNH&S. Initially established as a Memorandum of Understanding in 1989 with no funding involved, a Cooperative Agreement replaced the MOU in 1992 and included the New Mexico Museum of Natural History and Science Foundation (NMMNHF). The NMMNHF allowed for funding to go directly to the support of the NMMNH&S. The agreement includes a repository agreement for public fossils discovered on BLM lands in New Mexico. The preparation of an umbrella agreement identified a broad range of acceptable activities appropriate for support and the final agreement created built-in flexibility to accommodate changing priorities. In addition to curation of public fossils, projects completed under the agreement include: development and upkeep of an on-line database for collections, exhibits, teachers notes, brochures, retrieval of at risk public collections held by other institutions and educational films. The cooperative agreement continues to be an effective tool that benefits the public through preservation of public fossil resources, educational outreach and scientific study.

PALEOSENSITIVITY MAP FOR NEW MEXICO— A TOOL FOR LAND USE PLANNING

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Abstract—A paleontology sensitivity map was developed for New Mexico using bedrock geology and classifying geologic formations based on Potential Fossil Yield Classification (PFYC), which will assist BLM field offices in the management of public land fossil resources. PFYC ranks geologic formations on their potential to produce significant fossil material with ranks ranging from 1 (lowest) to 5 (greatest). The BLM planning handbook (1601-1) requires specific land use decisions for paleontology. During planning, BLM must identify area wide criteria or site-specific use restrictions to ensure those areas containing, or likely to contain, vertebrate or noteworthy occurrences of invertebrate or plant fossils that are identified and evaluated prior to authorizing surface-disturbing activities. Although limitations of scale are great, the purpose of the GIS layer is to raise awareness level for field personal in New Mexico and give the field a tool to address paleontological resources. The map and associated database provide formation descriptions, rationale for classification, ranking and range of ranking within a formation that can help BLM New Mexico meet planning and management requirements for paleontological resources. The map coupled with other data, including resource specialist knowledge, digital orthophoto quads, the nature of a specific project and locality information, will enable reasonable and effective resource decisions to be made.

MITIGATION OF FOSSIL RESOURCES DURING OIL AND GAS DEVELOPMENT

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Abstract—Vertebrate fossils from the San Juan Basin have contributed and continue to contribute to our understanding of Cretaceous, Paleocene and Eocene ecosystems. Over the last 60 years, the basin has been an important producer of oil and gas resources. Drilling activity continues through infill of fields and development of unconventional gas resources. Since areas known to produce significant fossil resources and active energy development continues, an efficient method for mitigation of the paleontological resource while expediting the permitting process is required. Where exposed bedrock occurs at the surface within areas of known potential, pedestrian surveys for fossil resources are conducted. The focus of the fieldwork is to locate paleontological resources within the boundary of a project area. Mitigation occurs when: (1) data and fossil material are collected; (2) by obtaining representative samples of the fossils; (3) by avoidance; or (4) in some cases by no action. In some cases, surface disturbance may have a beneficial impact on paleontological resources where it exposes additional outcrop area to erosion. When significant fossil material is discovered, a locality form is completed, GPS coordinates are taken and the material is collected. The Field Office holds the material until transport, with locality data, to the New Mexico Museum of Natural History and Science in Albuquerque. If significant fossil material occurs on the surface that cannot be completely collected, a digital photo is taken, locality information and GPS data are recorded. The project can be modified to avoid the locality; this is done immediately to allow the project to proceed.

CLEVELAND-LLOYD DINOSAUR QUARRY: RESTABILIZATION AND INTERPRETATION; SUCCESSES AND PITFALLS

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Abstract—Fossils are often the spark for a lifetime’s passionate interest in the world we live in. Seeing and experiencing an authentic paleontological site often has a much greater impact than seeing specimens or replicas in a school or museum setting. Making a federally-managed paleontological site available to be visited by the public has many benefits both to the visitors and to the surrounding communities. Unfortunately, it also has the potential to see the resource destroyed by thieves, vandals or inappropriate stewardship. Renovations begun late in 2005 at the BLM-managed Cleveland-Lloyd Dinosaur Quarry National Natural Landmark and the planning preceding them are an example of the opportunities and challenges faced by government employees involved in managing such a site. Structural engineering, mechanical engineering, landscape architecture, interpretive programming, display design, resource protection, visitor expectations, local involvement, partnering, cooperative agreements and budgeting are issues that came up during the planning process. Some of the problems raised and how they were dealt with will be presented in this talk.

IMPLEMENTING INVENTORY-MONITORING, RESEARCH AND INTERPRETIVE PLANS FOR EL BOSQUE PALEONTOLOGICO PIEDRA CHAMANA IN THE NORTHERN ANDES OF PERU

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Abstract—El Bosque Paleontológico Piedra Chamana is an Eocene petrified forest located in the northern Peruvian Andes (northern Cajamarca; 79°10'E, 6°35'S). The site is designated as protected under the Cultural Patrimony of the Nation by the government of Peru. Our work, supported by a grant from the National Science Foundation, involves a dynamic combination of scientific research, conservation, development of an inventory and monitoring database and design of an interpretive plan.

The petrified forest occurs in volcanic and volcanoclastic rocks of the Huambos Formation and contains a diverse assemblage of well-preserved permineralized woods. Preliminary 40Ar/39Ar dating of associated rocks yields a date of 39 Ma (Middle Eocene). The fossiliferous sequence includes a paleosol overlain by ashfall and lahar deposits. Woods and leaves associated with the paleosol and ashfall deposits, including trees buried in situ, provide a highly localized representation of the paleovegetation. Fossil wood is also present in high abundance and diversity in the overlying lahar. Various lines of evidence, such as the diversity of monocots (palms and other monocots) and the low incidence of growth rings among the dicot woods, indicate that the assemblage represents wet tropical forest growing at an elevation at or close to sea level. This suggests significant post-depositional uplift.

The site was brought to attention during the early 1990s and is rarely visited, providing opportunities to assess its condition while it is still relatively undisturbed and to make recommendations for conservation. Our work has involved completing a paleontological inventory of the site, preparing a map and database showing the distribution of 14 individual localities, identifying potential natural and human threats and providing recommendations for stabilization and preservation.

The National Science Foundation grant that supports this project includes funding to develop a research station on site, and two buildings were constructed for this purpose in 2005. In addition, we are developing an interpretive plan following the guidelines that are used by the U.S. National Park Service to identify the interpretive themes and develop plans for exhibits and brochures that will help to educate the local people, school students and tourists. The route for a trail has been mapped, and a trail brochure will provide another format for interpreting the significance of this important site. Development and promotion of ecotourism to aid the local economy remains an important concern for the nearby community of Sexi.

THE DIVERSITY AND STRATIGRAPHIC DISTRIBUTION OF PRE-DINOSAURIAN COMMUNITIES FROM THE TRIASSIC MOENKOPI FORMATION, CAPITOL REEF NATIONAL PARK AND GLEN CANYON NATIONAL RECREATION AREA, UTAH

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Abstract—Recent discoveries in the Moenkopi Formation (Early Triassic) of Capitol Reef National Park, Glen Canyon National Recreation Area and San Rafael Swell, Utah have revealed important new terrestrial and subaqueous vertebrate track localities. The San Rafael Swell area to the north has also yielded important footprint horizons. These well-preserved tracks occur on multiple stratigraphic horizons and are the oldest and most laterally extensive Mesozoic track-bearing horizons documented in the western U.S. The ichnogenera *Chirotherium*, *Rhynchosauroides* and *Rotodactylus* are the dominant forms. Rare fish fin drag marks (*Undichna*) and fish skeletal remains have been identified in the Torrey Member and equivalent strata of the Moenkopi Formation.

Tracks are preserved either as positive relief “casts” filling impressions in the underlying mudstones or on plane bed surfaces as negative relief “impressions.” Exposed traces occur on the undersides of resistant sandstone ledges where the mudstone has eroded away and in finer-grained sediments such as mudstones and siltstones. The Torrey Member represents deposition on a broad, flat-lying coastal delta plain. Both nonmarine (fluvial) and marine (principally tidal) processes influenced deposition. Even-bedded mudstones, siltstones, claystones and fine-grained sandstones, containing abundant ripple marks and parallel laminations dominate lithologic types. Ichnites indicating swimming/floating behavior are associated with the walking trackways. The water depth was sufficiently shallow to permit the vertebrates to touch the substrate with manus and pes when moving through the water.

Tracks form locally dense concentrations of toe scrape marks that sometimes occur with complete plantigrade manus and pes impressions. Well preserved, skin, claw and pad impressions are common. Occasional, well-developed tail-drag marks frequently occur in many of the trackway sequences. Fish fin drag marks and fish skeletal material are preserved with tetrapod swim tracks. In addition to vertebrate ichnites, the fossil invertebrate traces *Arenicolites*, *Paleophycus*, *Fuersichnus*, *Kouphichnium* (horseshoe crab), centipede and fossil plants of *Equisetum* are abundant.

Lateral correlations of the ichnostratigraphic units identified in the Moenkopi Formation throughout Utah’s National Parks and Public Lands will aid interpretations about the paleoecology and diversity of the Western Interior during the Early Triassic, “the dawn of the dinosaurs.”

SUBAQUEOUS TETRAPOD SWIM TRACKS FROM THE MIDDLE JURASSIC: BIGHORN CANYON NATIONAL RECREATION AREA (BCNRA), WYOMING, U.S.A.

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Abstract—Recent discoveries indicate that marine carbonates and carbonate-rich siliciclastics of the Middle Jurassic (Bajocian) Gypsum Spring Formation contain tetrapod tracks of swimming animals. There are two distinctive vertebrate swim track types tentatively assigned to crocodylians and to possible bipedal dinosaurs. This swim track horizon is laterally extensive and can be traced throughout the Bighorn Canyon National Recreation Area (BCNRA) wherever the Gypsum Spring Formation crops out.

Importantly, the swim track horizon is located stratigraphically one meter above a well-documented, multiple-layered, tridactyl dinosaur footprint bed. The tridactyl tracks are preserved on multiple surfaces and geographic localities in the northeastern Bighorn Basin. The swim tracks are preserved as convex hyporelief “negative relief impressions” on a single, exposed, flat bedding-plane surface. The swim traces are subparallel and parallel scrape marks or dimples” that occur either in pairs or (rarely) in threes. Lateral spacing between the sub-parallel marks is typically a few centimeters. Many traces in the Gypsum Spring Formation are characterized by two parallel, 1-cm-wide grooves, spaced approximately 3.5 cm apart. Each groove set is approximately 4-8 cm long. “Dimples” are subequal or equal, non-linear, indentations sometimes preserved in twos, threes and rarely in fours. Tracks exhibit “impact rims” and/or “pressure release structures” at the termination of the “grooves” or “dimples,” suggesting a piling-up of the sediment behind the track. In most cases, the grooves are perpendicular to the bedding plane. However, some arcuate forms have been found. These traces are interpreted to represent toe/claw scratch marks made by buoyed animals briefly touching bottom while swimming over a muddy carbonate substrate.

These unusual, nearly in-line Gypsum Spring traces reflect swimming behavior of a dinosaur rather than crocodile. The in-line traces do not seem to be consistent with a sprawling swim pattern, but rather a more erect motion of bipedal (?) swimming. The more arcuate (inclined to the bedding plane) traces may, however, reflect a more crocodile-like, sprawling-gait swim behavior.

FEDERAL, STATE AND VOLUNTEER COOPERATION ON VERTEBRATE PALEONTOLOGY PROJECTS ON FEDERAL LAND: EXAMPLES FROM PLEISTOCENE SITES IN NEW MEXICO

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Abstract—Various agencies of the U. S. Government, including the Bureau of Land Management (BLM), Forest Service (USFS), Bureau of Reclamation (BOR), National Park Service (NPS) and the White Sands Missile Range (WSMR) of the U. S. Army, have worked in close cooperation with the New Mexico Museum of Natural History and Science (NMMNH&S) and the NMMNH&S-sponsored volunteer group, the New Mexico Friends of Paleontology (NMFOP), on vertebrate paleontology projects throughout New Mexico located on Federal land. We briefly discuss several of those projects involving the excavation and collection of Pleistocene fossils. The NMMNH&S is the official natural history museum of the State of New Mexico and as such serves as the designated repository for paleontological specimens from the State and for several Federal agencies through signed Memoranda of Understanding and Cooperative Agreements.

While hiking, Frederick Haessly discovered a proboscidean tusk eroding from Starvation Draw, an arroyo located on BLM land north of Deming in Luna County, southern New Mexico. Dr. Haessly contacted archaeologists at the Las Cruces BLM office, who then contacted Michael O'Neill, the former paleontologist at the BLM office in Albuquerque. The BLM (including PMH and MO'N), NMMNH&S (including GSM) and NMFOP, with help from archaeology professors and students at New Mexico State University, excavated the Starvation Draw site (NMMNH&S locality 4637) during several days in January and February 2001. The most important fossils found at the Starvation Draw site were two complete associated tusks of the Columbian mammoth (*Mammuthus columbi*). The tusks measured just a few inches short of 10 feet in length (about 3 m) along the outside curve, the largest mammoth tusks yet found in New Mexico. The site also yielded several other mammoth bones, including a nearly complete scapula, as well as a lower tooth of a horse (*Equus conversidens*). Large samples of aquatic snail shells and frog (*Rana*) bones were found in the sediment surrounding the tusks, which suggests deposition in a freshwater environment such as a pond or marsh. We tried to obtain a radiocarbon date from one of the mammoth tusks but were unsuccessful, suggesting the Starvation Draw site is older than 40,000 years Before Present.

Vertebrate fossils were first discovered along Perico Creek in northeastern New Mexico in the early 1990s by USFS archaeologists James Hall and Joseph Tainter. The Perico Creek site (NMMNH&S locality 4638) is located on the Kiowa/Rita Blanca National Grassland, southeast of Clayton in Union County. The site was revisited in 1997 by Greg Liggett, a paleontologist from the Sternberg Museum of Natural History in Hays, Kansas and again in 2000 by BAS. The Perico Creek site was excavated for three days in October 2001 by personnel from the USFS (including BAS), NMMNH&S (including GSM) and NMFOP and again for a week in June 2004 by GSM, Amy Sheldon from Oklahoma Panhandle State University (OPSU) and a group of high school students participating in Dr. Sheldon's summer program sponsored by OPSU. The fossils are derived from an actively eroding cutbank on the north side of Perico Creek and occur in channel sands distributed through a stratigraphic interval of about 5 m. The Perico Creek vertebrate fauna consists of 15 species, the most common of which are the giant llama (*Camelops hesternus*), the flat-headed peccary (*Platygonus compressus*) and an extinct horse (*Equus niobrarensis*). The presence of mammoth confirms a Pleistocene age.

In the spring of 2004, firefighters at the Jemez Ranger Station on the Santa Fe National Forest found several horse teeth while digging a small hole. The site is located north of Jemez Springs on the east side of the Jemez River in Sandoval County, northwestern New Mexico. Preliminary examination of the site in March 2004 indicated that more of the horse was present and the site was excavated in May and August 2004 by personnel from the USFS, Santa Fe National Forest (LG, Rita Skinner and summer interns Katrina Gobetz and Elizabeth Chessler), NMMNH&S (GSM and volunteer Warren Slade) and Kevin Madalena from Jemez Pueblo. The Jemez Springs horse site (NMMNH&S locality 5767) occurs in a Quaternary terrace deposit associated with the nearby Jemez River. The fossil consists of a partial articulated skeleton (skull, lower jaws, most of the vertebral column, both front limbs and one hind limb) of the large extinct horse *Equus niobrarensis*, as well as several associated bones of a smaller individual of the same species.

DRAFT PALEONTOLOGY RESOURCE MANAGEMENT PLAN FOR GLEN CANYON NATIONAL RECREATION AREA, SOUTHERN UTAH AND NORTHERN ARIZONA

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Abstract—This draft resource management plan for fossils in GLCA is the first comprehensive approach to paleontology in that park. Paleontologists and managers have recognized the existence of fossils in the Park for several decades, but the importance of paleontology became apparent only recently with the discoveries of plesiosaur skeletons and other fossils in the park and new dinosaur track sites found as a consequence of low lake level in Lake Powell. The recognition of nationally significant fossils in the newly established Grand Staircase-Escalante National Monument, adjacent to GLCA, signaled increasing potential for important discoveries in GLCA. The Paleontological Resource Management guidelines in NPS 77 identify the nature of management actions available to managers, reasonable options that should be considered for intensive management, and roles and responsibilities of each park, each region and the Washington Office. The present draft resource management plan for paleontology in GLCA seeks to establish a long-term plan that meets these standards. Specific recommendations for application of the provisions of NPS-77 are elaborated in the plan. This plan is one product of a series of research projects conducted by researchers from the Museum of Northern Arizona sponsored by GLCA.

PALEONTOLOGICAL RESOURCE DAMAGE FROM “POOR SCIENCE:” EXAMPLES FROM PETRIFIED FOREST NATIONAL PARK

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Abstract—A quick perusal through various NPS publications and guidance dealing with paleontological resource management will turn up numerous references to the threat of fossil resource damage due to theft and/or natural processes. However, a recent paleontological inventory of Petrified Forest National Park (PEFO) has determined that the majority of the damage done to vertebrate fossil resources is the result of “poor science” being conducted by permitted researchers. Examples include a significant specimen that was partially excavated, abandoned and later destroyed by exposure; an important specimen that was improperly prepared and heavily damaged; as well as numerous specimens collected without a clear research plan and without proper documentation. Various sites have been “vacuumed” by untrained collectors working for permittees with minimal locality data being collected, obfuscating later attempts by park staff to relocate these sites for the purpose of documentation. The scientific data lost as a result of these activities far outweighs that lost due to minimal visitor theft or vandalism of vertebrate fossils. Whereas some of these examples occurred before the issuance of NPS policy regarding management of paleontological resources (NPS-77), many have occurred since. Theoretically, researcher ethics should prevent such resource damage; however, ultimate blame lies with the resource managers of NPS units. Resource managers need to apply the guidelines listed in NPS 77, ensure that researchers understand these policies and enforce them. Failure to do so not only causes irreparable damage to paleontological resources and their stratigraphic context but also hinders managers in meeting reporting goals (GPRA) mandated by Congress for paleontological resources and localities.

PALEONTOLOGICAL RESOURCE INVENTORY OF CALIFORNIA'S JURASSIC TRACKWAYS

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Abstract—California's only tracks of dinosaurs, therapsids and pterosaurs occur in the early Middle Jurassic Aztec Sandstone of the Mescal Range in eastern California. Ongoing inventory of these unique trackway panels and associated sedimentary structures began in 1986 and was augmented in 2001 with the use of GPS/GIS equipment. The latter inventory used a Trimble Pro-XRS GPS Unit (with submeter accuracy) to precisely map 116 track panels. This information was gathered along with bedding plane attitudes (dip and strike) and digital photographs of each panel. Annual re-inventory has resulted in detailed measurement of individual tracks and trackways, scale drawings and additional digital photographs. Replication of selected trackway panels has been accomplished using Room Temperature Vulcanizing (RTV) silicone rubber technique.

The inventory of quadruped tracks has resulted in recognition and systematic morphometric description of three named and five unnamed therapsid ichnospecies, and the description of the westernmost occurrence of pterosaur tracks from North America. Associated research produced a systematic classification and categorization of the quadruped tracks.

Twenty-five years of annual prospecting and inventory demonstrates that site visitation is derived from five sources: museum researchers under BLM permit; biologists; cactus collectors; seasonal game hunters; and collegiate groups intent on "studying" the tracks without BLM authorization. Track resource integrity has been consistent over the last 25 years, but interest in the site by the latter group has compromised certain panels by poor replication techniques, lack of clean up after replication and removal of loose tracks without permission. One removed trackway designated as an ichnogenus holotype is no longer available for study. Recent inventory noted that the sandstone panel containing California's only pterosaur tracks had been severely compromised by chisel marks from attempted removal.

Considering the recent removal of one important specimen and the continuing damage to track panels at the locality through illegal collecting activities, an active resource management plan for the nation's westernmost Jurassic dinosaur tracks and California's only dinosaur, therapsid and pterosaur track locality is required. A stewardship program including cyclic field surveys for new trackways, annual inventory of known panels and museum quality replication is recommended. In addition, all materials gathered through this program, including observations of the area by stewards, should be deposited in a suitable museum repository. Identified panels should be routinely reburied to prevent malicious or inadvertent damage. Research team members must be recruited for this stewardship program. Interested college students and their professors should be instructed about the necessary permits required to study and replicate the tracks and should receive training in non-destructive replication techniques to ensure trackway panels are not damaged. Once trained, these individuals may form a nexus for the stewardship program. Partners in the stewardship program should, in cooperation with the identified repository, develop a comprehensive database where the location of all research results, along with replicas, are stored for future study, research and exhibit.

PALEONTOLOGICAL RESOURCE INVENTORY OF MIOCENE (BARSTOVIAN) TRACKWAYS AT OWL CANYON CAMPGROUND, BARSTOW, CALIFORNIA

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Abstract—Volunteers from the Mojave River Valley Museum (MRVM) and the Bureau of Land Management’s Desert Discovery Center (DDC), under the direction of LSA Associates, Inc. (LSA), conducted a fossil trackway inventory in the vicinity of the Owl Canyon Campground. This area is managed and maintained by the Barstow Field Office of the Bureau of Land Management (BLM). This work was done under BLM permit CA-05-00-01P.

In 2005, paleontologists and BLM management reacted with concern to reports of vandalism to 15 million-year-old trackways of North American camels in the Barstow Formation. This prompted the BLM to initiate an inventory of paleontological resources within one-half mile of the Owl Canyon Campground. This inventory provides base-line data for ongoing management of paleontological resources in the high-use campground area and serves as a resource assessment to help planning proposed campground renovations.

A previous BLM-supported paleontological inventory was conducted by the author in 1982, with replication of selected trackway panels completed in 1996. These prior data were expanded and precise locality information was gathered through use of Global Positioning System Receivers. Data were recorded and stored electronically into a database that includes images of the locality in overview, the complete bedding plane panel showing track relationships and images of individual tracks. The data recovered by this inventory were structured to aid in locality relocation and annual evaluation of resource condition as part of the Agencies Resource Management Plan. Trackway panel status can change through natural erosion and burial, degradation through foot trampling and by non-permitted efforts to replicate or remove tracks. The vandalism reported in 2005 was from efforts to collect the trackways with hammer and chisel. This illegal activity probably destroyed the tracks in the process of removal. Elsewhere in Rainbow Basin, amateur attempts at replication without mold release have left tracks covered with latex or have physically damaged tracks when the latex was peeled from the panel.

The 2005 inventory recorded 36 localities comprised of 32 trackways, two sedimentary structures and two fossil skeletal elements within one-quarter mile of the Owl Canyon Campground. Sixteen localities have been identified since the 1982 inventory. Five of the previously recorded localities could not be relocated. The inventory noted that two localities were destroyed by erosion and the *Amphicyon* trackway, documented by the Alf Museum, was buried for preservation. Fossil tracks along ridgelines showed evidence of damage by foot scuffing. One track panel within 100 feet of a camp pergola was narrowly missed by graffiti, and the aforementioned camel tracks one-quarter mile north of the campground were removed by hammer and chisel.

As part of the Resource Management Plan for BLM lands this inventory helps form a database to identify impacts to these significant, nonrenewable, paleontological resources by visitors to the area and during campground renovation. The inventory will also be used during land-use planning to ensure these resources are protected. The possibility of indirect impacts—visitor distribution points (patterns) and increased erosion from channeled runoff—must be considered in campground planning. This baseline will allow the condition of the resource to be monitored on an on-going basis and will assist in developing improved management strategies for the BLM. Trackways susceptible to damage, or ones that have already been damaged, can be replicated to capture the surviving data.

INVESTIGATING FOSSIL THEFT FROM NATIONAL FOREST SYSTEM LANDS

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Abstract—In recent years, due to necessity, U.S. Forest Service Law Enforcement and Investigations personnel have aggressively pursued criminal cases against individuals that illegally remove and steal paleontological resources from National Forest System lands. Unfortunately, within the Rocky Mountain Region of the U.S. Forest Service, in particular the states of South Dakota, Wyoming and Nebraska, incidents involving the theft of paleontological resources from NFS lands continue to increase.

This presentation will address how two separate fossil theft cases, occurring in two different states, were investigated and successfully prosecuted by the U.S. Attorney's Office. In addition to interviewing witnesses and suspects, evidence gathering and protection, to eventually presenting a fossil theft case to an Assistant U.S. Attorney, this presentation will show that a "team" effort from both law enforcement personnel and non law enforcement personnel is imperative for each successful prosecution.

FOSSILS, OBJECTS OF ANTIQUITY AND THE ANTIQUITIES ACT (1906)

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Abstract—Historically, the Antiquities Act of 1906 served an important role in the establishment and protection of paleontological sites on federal lands. Despite conflicting interpretations of whether Congress intended the phrase “*objects of antiquity*” to include paleontological resources, the Antiquities Act served for nearly 75 years as the primary authority for the protection and permitting of fossils on lands administered by the Departments of Agriculture and Interior. The Antiquities Act was utilized to protect a number of significant paleontological localities through the establishment of national monuments. Since 1906, the administrative and legislative histories of the Act, combined with a number of solicitor’s opinions, changed the way federal agencies have interpreted the Antiquities Act and the phrase “*objects of antiquities*” as it relates to fossils.

THEFT AND VANDALISM OF *IN SITU* FOSSIL VERTEBRATE TRACKSITES

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Abstract—The growth experienced within the science of vertebrate ichnology has been accompanied by a near explosion in the discovery and documentation of new fossil track localities worldwide. The descriptions and interpretations of fossil vertebrate tracks have infiltrated scientific journals, popular publications and news media. A number of fossil vertebrate tracksites have been developed for public education. The growing popularity of fossil vertebrate tracksites is paralleled by the increasing documentation of their theft and vandalism. During 2001, over two dozen incidents of either theft or vandalism of *in situ* fossil vertebrate tracks were documented. These incidents range from damages resulting from poor or inappropriate casting techniques to the unauthorized collecting of tracks in units of the National Park Service. A well-known dinosaur tracksite in a Utah state park was vandalized by members of a Boy Scout group and received considerable national and local media attention. Fossil vertebrate tracks are becoming more visible on the commercial fossil market. The management and protection of *in situ* fossil vertebrate tracksites has become challenging. Human impacts to vertebrate ichnofossils include incidents of damage/destruction, intentional vandalism, casual theft and systematic theft. Sound management and protection strategies employed for *in situ* fossil vertebrate tracksites include: tracksite inventories, site mapping, photodocumentation, track replication, specimen collection, site stabilization, burial, site closure, construction of maintenance barriers/fencing and a variety of site monitoring strategies.

VOLUNTEERS AND PARTNERSHIPS, EFFECTIVE MANAGEMENT OF FOSSIL RESOURCES ON NATIONAL FOREST SYSTEM LANDS

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Abstract—In 1994, the USDA Forest Service acquired a 16,000 acre area of the Purgatoire River valley in southeastern Colorado called Picket Wire Canyonlands. In this steeply carved, rugged valley the Purgatoire River has swept vast stretches of Jurassic limestone free from surrounding shale, exposing dozens of dinosaur trackways along its banks. In the last decade the Comanche National Grassland has conducted paleontological reconnaissance of this valley, leading to the discovery of significant Jurassic dinosaur skeletons and Cretaceous-aged trace fossils, including vertebrate trackways and plants.

The excavation and preparation of a large sauropod skeleton from the upper Morrison Formation discovered in 2003 is the focus of recent management efforts. The quarry lies within floodplain shale just centimeters above a 2 m thick fluvial sandstone. The uppermost surface of the sandstone bears a complex folded and contorted architecture attributable to intense trampling around the sauropod carcass. The quarry also produces numerous commingled shed carnivore teeth, and some sauropod bone bears distinct scratches and gouges attributable to tooth marks. Thus, the scattered distribution and fragmentation of some bony elements, trampling around the carcass, numerous shed carnivore teeth and bite marks all suggest an episode of scavenging prior to burial.

With about fifty percent of a large skeleton so far excavated, no duplicate elements are present suggesting a single individual. Articulated portions of axial skeleton include strings of trunk and caudal vertebrae, confirming the common association of much of the skeleton. Despite the amount of skeletal material exposed, the identity of the remains is yet elusive. A relatively elongate cervical rib, a fibula with anterior divergence of the main shaft and an equidimensional anterior caudal centrum are indicative of *Camarasaurus*. Morphology of a scapula, and tall neural spines of trunk vertebrae suggest a robust diplodocid such as *Apatosaurus*. Taphonomy of the site is complicated by the presence of two camarasaurid teeth located high within the quarry and two diplodocid teeth located at a lower level. All four sauropod teeth bear complete roots, suggesting close proximity to cranial material.

With few professional paleontologists and a small workforce, the Forest Service alone cannot provide responsible stewardship of such paramount fossil resources. Volunteerism and partnerships are crucial elements to successful management. Survey and excavation of fossils is being conducted wholly by trained volunteers along with agency paleontologists through the Forest Service Passport in Time program. The Denver Museum of Nature and Science serves as a vital partner, preparing and housing the skeleton through its own dynamic volunteer program.

HISTORICAL RESOURCES ACT DESIGNATION OF THE GRANDE CACHE DINOSAUR TRACKSITE (LOWER CRETACEOUS, ALBIAN), GRANDE CACHE, ALBERTA, CANADA

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Abstract—Paleontological Resources in Alberta are managed under the Historical Resources Act (HRA) and its associated regulations. The basic tenet of the HRA is that all historical resources (including palaeontological resources) found within Alberta are a Crown (government) owned resource and that private ownership of paleontological resources in Alberta is allowed only in specific situations. For the majority of palaeontological resources in the province, the protection afforded under sections 30 (Excavation Permits), 31 (Notice of discovery of historical resources), 32 (Title to historic resources), 33 (transport of historic resources out of Alberta), 34 (Damage of historic resources prohibited) and 37 (Requirement of pre-impact studies) of the act is sufficient to legally protect them.

In situations where the paleontological resource (locality) has a high scientific value it can be designated as a Provincial Historic Resource by the Minister of Alberta Community Development (ACD) pursuant to section 20 of the HRA. Designating a locality allows for greater control over research, collecting and industrial activities, it raises the status of the site in land management systems and allows local non-profit groups to access more funding for preservation and interpretation. Although there is no specific clause requiring higher penalties for illegal activities at designated localities, designation of a locality as a Provincial Historic Resource can increase the significance of a site in the view of the judicial system and increase the likelihood of a significant penalty being imposed.

Located approximately 20 km north of Grande Cache, Alberta, the Grande Cache Dinosaur Tracksite is one of the most extensive dinosaur track localities in Canada. The majority of the tracks are found in three main areas (West Limb of 12-mine, 9 Mine and South Pit Lake) within the former Smoky River Coal Mine where they were exposed after the removal of Coal Seam No. 4 of the Gates Formation (Lower Cretaceous, Albian). Several ichnotaxa are known from the tracksite including at least four types of theropod tracks, ankylosaur tracks, several types of bird tracks and possible crocodylian swim traces. Other remains include tree stump and log impressions, various plant fossils and the rare bivalve, *Murraia*.

The site was selected for designation after its tourism potential was brought to the attention of ACD by Alberta Economic Development and the Town of Grande Cache and its scientific significance was brought to the attention of ACD by Mr. Rich McCrea, a Ph.D. student studying the site. Some of the significant features of the site include the large number of footprints (over 10,000 documented tracks from the W3 locality alone), the relatively wide variety of palaeoenvironments represented and the overall size of the area (the largest footwall is approximately 2 km long and 60 m high).

Once the site was selected for designation, a stakeholder consultation process was initiated. Stakeholders included Grande Cache Coal Company (GCC), the coal mine currently working in the area, the Town of Grande Cache, the Friends of the Grande Cache Dinosaur Footprints, a volunteer non-profit organization dedicated to the preservation and promotion of the tracksite, paleontologists and several provincial government departments. From the consultation process, which consisted of several public and closed-door meetings, ACD was able to determine the expectations and concerns of the various stakeholders and develop a policy that would allow for the long-term preservation of the tracksite while accommodating many of these issues.

The biggest challenges encountered were: (1) assuring GCC, the residents of Grande Cache and other stakeholders that the designation would not impact GCC ability to mine coal from the area; and (2) developing a plan that would allow for some tourism opportunities and the long-term protection of the tracks within an active coal mine. Ultimately it was decided that an active open-pit coal mine operating in the vicinity of the tracks was beneficial to their long-term preservation. The benefits of the coal mine include: (1) restricted access to the site; and (2) new tracks are bound to be uncovered as mining progresses. Since the proposed area of designation has already been mined out, the current coal mining operations should not directly impact the tracks.

Although the stakeholder consultation process took a relatively long time to complete and required several meetings, public discussions, phone calls and e-mails, the thoroughness paid off as all stakeholders, including GCC, finally agreed that the designation could be applied to the Grande Cache Dinosaur Tracksite. The formal designation process should be completed by May 2006, and ACD can now start to work towards achieving our

short and long-term goals for the site. Short-term goals include working with GCC to discover, preserve and study new tracks within the mine site, determining whether it will be possible to stabilize the footwalls on which the tracks occur and develop a limited tourist attraction at the site including interpretive pathways and safe viewing areas for the public. In the long-term, an on-site interpretive center may be built to showcase this wonderful resource.

PRESERVING THE PAST: GEOLOGIC MAPPING AND PALEONTOLOGIC INVESTIGATION, LAS VEGAS FORMATION, NORTH LAS VEGAS

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Abstract—Paleospring deposits as indicators of elevated water tables and increased groundwater discharge during the Pleistocene have been recognized and described throughout the southern Great Basin. These fine-grained sediments previously thought to be strictly lacustrine in origin have led to a wealth of paleoclimatic data of the last two major glacial periods.

The Las Vegas Formation, in the Tule Springs region of North Las Vegas, has yielded an assemblage of invertebrate and vertebrate fossil remains that comprise one of the best-studied late Pleistocene assemblages known from the southern Great Basin. Although recent studies have focused on the paleoclimatic and hydrologic indicators of high discharge glacial events (spring deposits, wet meadows, seeps and streams) in the southern Great Basin, vertebrate paleontologic evidence recognized from these same high discharge lithologies has been little studied or reported upon. Vertebrate faunas in deposits from the southern Great Basin recording these high discharge events demand synthetic reporting and treatment. This study is part of an effort to incorporate these records into the larger paleoclimatic and hydrologic framework of the last two glacial maxima.

Studies from the 1930s through the 1960s documented one of the most significant late Pleistocene faunas from the Mojave Desert in the Tule Springs area of North Las Vegas. Recent field investigations by the San Bernardino County Museum have broadened our knowledge of this fauna across the upper Las Vegas Wash. Seven stratigraphically ascending units, designated A through G, were first recognized in the early 1960s and were defined in several sections within the upper Las Vegas Wash. Units B₂, D and E₁ have proven fossiliferous in this area and date to >40,000 yrs, approximately 25,500 yrs, and about 14,500 to 9,300 yrs, respectively. These units have been extended beyond the original locality to deposits throughout the southern Great Basin. Paleospring discharge features in these units demonstrate correlation of spring recharge and climate changes in the late Quaternary in this region. Sedimentologic evidence, mollusk studies and most recently, ostracod analyses have clarified the paleoenvironmental conditions and related hydrologic changes through time. Radiocarbon dating on mollusks, augmented by organic carbon, combined with d¹⁸O values from the ostracod studies have constrained the timing of the glacial episodes and clarified specific paleoenvironments of the high discharge events.

Research by the SBCM across the Las Vegas Wash has resulted in the discovery of 526 new fossil localities since 1990. By describing the geology of these localities and exposures in the wash, the SBCM has expanded the definition and mapping of the subunits of the Las Vegas Formation to include lateral facies changes, which allowed the accurate placement of fossils within the proper stratigraphic context. Extensive geologic mapping of the bluffs that encompass the upper Las Vegas Wash was necessary to discriminate between the various units of the Las Vegas Formation and to place the fossils in the appropriate temporal context. The fossil sites are located along the wash and occur throughout deeply eroded badlands. The units of the Las Vegas Formation, through successive periods of dissection, deflation and deposition, are inset into each other and are laterally discontinuous. The methodology that we employed to recover the maximum amount of data was more comprehensive than simply creating a geologic map in plan view, but was one that extended the detail to the third dimension by using digital photography and mapping the units directly onto the images. This allowed definitive location of all of the fossil localities in space and time. Temporal and spatial clarity of >500 fossil localities was the ultimate goal for this study, and understanding the complex geologic framework of this portion of the upper Las Vegas Wash provided us with the stratigraphic control we sought.

Newly recognized faunal components include the microvertebrates *Rana* sp., *Masticophis* sp., cf. *Arizona* sp., *Marmota flaviventris*, *Neotoma* cf. *N. lepida* and cf. *Onychomys* sp. The list of megafauna has also been expanded to include a large bovid similar in size to *Euceratherium* and the first definitive fossils of *Bison* from Unit E₁. Radiocarbon dating results from locality SBCM 2.6.74 indicate that specimens of *Bison* recovered from Unit E₁ fall within the published dates for that unit, yielding a conventional radiocarbon age of 14,780 +/-40 yrs. By our study, we have undisputed confirmation of *Bison* from Unit E₁ and the youngest reliably dated record from this genus in the Mojave Desert/southern Great Basin. Radiocarbon dating (14,780 +/- 40 yrs) confirms this locality is within the reported range of unit E₁ in the southern Great Basin.

It was noted that the high discharge events of units B₂, D and E₁ are lithologically similar in that they all contain green silts and mud, as well as abundant mollusks. These lithologies result from the complex mosaic of aquatic settings, including flowing springs with or without fault influences, wet meadows, streams and wetlands. Verte

brate remains apparently are preferentially preserved in these environments, likely because increased clay and organic content results in lowered post-depositional oxidation. Ancient spring deposits may have also been animal traps.

Ongoing research by the San Bernardino County Museum focuses on synthesizing GIS mapping, digital photography of three dimensional stratigraphy, traditional mapping and geologic description with vertebrate paleontology. This synthesis has added depth of knowledge to both the geology and paleontology of southern Nevada.

A NEW MIDDLE MIOCENE TERRESTRIAL FAUNA FROM THE TEMBLOR FORMATION OF CENTRAL CALIFORNIA

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Abstract—In 1913, a paleontological field party from the University of California, Berkeley, discovered a quarry that produced terrestrial vertebrate fossils in a Miocene marine sandstone (Temblor Formation) on the western edge of the San Joaquin Valley, north of the town of Coalinga, California. This occurrence permitted an important tie point for correlating terrestrial mammalian evolution events with the marine temporal and evolutionary sequences. The fauna from this quarry became known as the “*Merychippus zone*” and the North Coalinga fauna. While surprisingly diverse, these mammalian fossils were rather abraded and no associated, much less articulated, specimens were found. Bird, reptile and amphibian fossils were not represented. Ninety years after the discovery of the North Coalinga quarry, no example of a nearby terrestrial deposit containing a similar mammalian fauna had been detected.

Construction of the Path 15 500-kV Power Transmission Line from Los Banos to Avenal, California was required to mitigate its impact to paleontological resources by the National Environmental Policy Act and the California Environmental Quality Act. A small fraction of the 213 structures in the paleontologically sensitive portions lay on Federal lands. Pad construction for a tower in section 16, T16S, R13E uncovered a bonebed in a large block of landslide debris in 2004.

That section had been obtained by the Bureau of Land Management (BLM) within the previous decade. Although permission for construction and paleontological mitigation had already been granted for the pertinent sections, a mutually agreeable fossil recovery and preservation plan was negotiated among the construction firm (Maslonka and Associates), the environmental mitigation firm (Jones and Stokes), the California offices of the Bureau of Land Management and the Western Area Power Administration.

The bonebed occurs in terrestrial facies of the Temblor Formation. Fifty-three days of excavation of the top six inches of the cross section of the upended bonebed produced more than 1,200 identifiable vertebrate fossils. These were catalogued into the collections of the University of California Museum of Paleontology. It is most probable that many times that amount of fossils remain in the unexcavated portion of the bonebed, which was covered until additional excavation is deemed appropriate.

The vertebrate fauna is dominated by merychippine horses, with a smaller representation of anchitheres. Additional ungulates include two camel species, a merycodont antilocaprid and a rhinoceros. The most abundant carnivore is a species of *Amphicyon*. Also present are two borophagine canids, *Pseudalurus*, *Martes* and an undescribed large mustelid. Rodent remains are rare. Avian remains are fairly abundant, especially passeriform bones in the microfauna. Abundant *Hesperotestudo* remains have been recovered. Freshwater and terrestrial gastropods are also present.

This collection demonstrates a terrestrial environment in the Temblor Formation 30 km (19 mi) north of the North Coalinga quarry that could have supplied the organisms found there in marine sediments. The two sites have several horse species in common.

FOSSIL COLLECTION STORAGE: A STATE-OF-THE-ART CASE STUDY

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Abstract—The main goal of fossil collection storage is to protect the objects and information associated with them and to accommodate researchers. Museums housing Federal collections must pay particular attention to their collections, their accessibility, and their security and adhere to Federal policies. Failure to do this may result in loss of funding and their collections.

One of the most important variables in the long term preservation and conservation of objects and associated records is the overall storage environment. This encompasses both the physical area(s) where collections are kept, as well as the physical safety of the items. Oversight of the storage environment is oriented towards mitigating the risks to collections, including: physical forces (e.g., flood, earthquake, etc.), fire, water, theft, pests, pollutants, light and radiation, incorrect temperature, incorrect relative humidity (RH), health of staff, and custodial neglect. Policies and procedures, such as a detailed risk management plan, should be in place to address controlling and minimizing these risks. Their negative effects can also be minimized through proper training, decreasing handling of objects and records, controlling access, and maintaining housekeeping procedures.

The Idaho Museum of Natural History Vertebrate Paleontology Collection, with the implementation of a National Science Foundation Biological Collections Improvement Grant, addressed deficiencies in its storage area. Installation of a state-of-the-art mobile storage system and the resulting changes have created a storage layout that has minimized the risks to the collection, while maximizing accessibility for staff and researchers.

INITIAL RESULTS OF A FIVE-YEAR COOPERATIVE INTERAGENCY PALEONTOLOGICAL SURVEY, GRAND STAIRCASE-ESCALANTE NATIONAL MONUMENT, UTAH AND SURROUNDING AREA: THE PROOF IS IN THE POOLING (OF RESOURCES)

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Abstract—The Kaiparowits Basin, located mostly in Grand Staircase-Escalante National Monument, preserves the only relatively complete Cenomanian to Maastrichtian (Late Cretaceous) foreland basin stratigraphic sequence in southern Utah. Totalling over 2000 m in thickness, the Kaiparowits Basin section is mostly nonmarine and highly fossiliferous through much of its thickness. Based on microvertebrate sampling, several specialists concluded that the Kaiparowits Basin preserves one of the most continuous records of Late Cretaceous terrestrial vertebrates in a small geographic area in the world. Ironically, at the time Grand Staircase-Escalante National Monument was created in 1996, very few identifiable macrovertebrate remains had been collected. This is in spite of the relative abundance of such remains in the upper portion of the section. To gain a better understanding of the significance and scope of the Kaiparowits Basin Late Cretaceous vertebrate fossil resource, Grand Staircase-Escalante National Monument sought out specialists with either work histories in the Kaiparowits Basin or specialized knowledge of Late Cretaceous macrovertebrates. By coincidence, three separate institutions (Utah Museum of Natural History, Utah Geological Survey and the Museum of Northern Arizona) had all independently decided that Grand Staircase-Escalante National Monument held exciting research opportunities and were planning extended field campaigns in the region. By combining the collective resources of these three partners, all of which had independent research goals in the area, the Monument was able to achieve a five year, field-intensive inventory of the Kaiparowits Basin with a substantially lower funding level that would normally be required from such an effort. Also critical to the economy of the project was the Colorado Plateau Ecosystems Study Unit collective agreement through which partners agree to keep overhead below 17.5%. After five years and 45,000 acres (5% of area) of inventory, the Monument has reaped a bountiful harvest of data. Cenomanian and Turonian marine units previously perceived as barren have yielded several large associated plesiosaur, turtle and fish sites, and even a rare therizinosaurid dinosaur. The middle Campanian portion of the Wahweap Formation has produced several sites yielding potentially new dinosaur taxa, including what may be one of the most spectacular ceratopsid skulls ever found from that time period. The Late Campanian Kaiparowits Formation has also yielded a wealth of new data, including the world's oldest known caiman fossil, a new genus of oviraptorosaur, a new genus of ceratopsid, a new species of *Gryposaurus* hadrosaur and a new genus of tyrannosaurid. Preservation in some cases is exceptional and at least one dozen dinosaur specimens showing preservation of integument or other soft tissue have been collected or field documented. As our appreciation of the significance of this resource grows, so does the concern that it be carefully researched, managed and protected. The knowledge gained from this inventory is a crucial first step.

THE FRIENDS OF THE FLORISSANT FOSSIL BEDS: PARTNERSHIP SUPPORT OF EDUCATION AND RESEARCH IN GEOLOGY AND PALEONTOLOGY

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Abstract—The Friends of the Florissant Fossil Beds, Inc. was organized in 1987 as a 501(c) (3) non-profit organization by a group of dedicated individuals interested in assisting the National Park Service in its mission to preserve and protect the natural and cultural resources of Florissant Fossil Beds National Monument. As the official private sector partner to the Monument, the Friends is a membership organization that raises funds from members, individuals, corporations, other non-profit organizations and foundations to assist the Monument in meeting its mission. Generally, Friends' groups work with national parks to preserve, restore and enhance natural and cultural resources, provide improved services and facilities and increase visitor awareness and support of the park.

The Friends of the Florissant Fossil Beds is emerging as a national leader in developing innovative programs for enhancing educational, interpretive and research activities in paleontology. These programs and initiatives include many projects and activities. An accredited summer seminar series attracts adults and teachers and involves the Monument's paleontologist as the instructor of record. Each seminar carries graduate credit for teacher recertification through Adams State College. Every summer the Friends present a keynote geology field trip that is technical in nature and investigates a significant regional site. These field trips, conducted by the site expert, benefit area college students, regional scientists and other interested parties. During the fall and winter, the Friends sponsor community science seminars for the general public at The Colorado College. The Friends supported the production of an interpretive film for visitors that emphasizes the paleontology of the park. The quarterly Friends' newsletter features science, nature and history of the Monument and the Pikes Peak region.

Support of the Monument's paleontology program includes: (1) financial support for paleontological research and attendance at conferences for the Monument's paleontologist; (2) funding to assist other geologists and paleontologists in attending conferences relating to Florissant; (3) establishment of a perpetually-funded internship that directly supports a paleontology intern each summer; (4) funding and support for interns, student scholars and others to contribute to original research and investigation at the Monument; and (5) sponsorship of special events in paleontology, including the 2006 Centennial of the T.D.A. Cockerell Florissant Expeditions. These activities demonstrate that as budgets grow tighter, partnerships with Friends groups can be a beneficial means for units of the National Park Service to expand their capability to preserve, research and understand their fossil resources.

ESTABLISHING A FUTURE FOR FOSSILS IN THE NATIONAL PARK SERVICE: THE DEVELOPMENT OF A SERVICE-WIDE GUIDEBOOK AND PALEONTOLOGICAL DATABASE

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Abstract—The stewardship of non-renewable paleontological resources in parks across the nation requires service-wide baseline information. Nearly half of all 388 park units administered by the National Park Service contain fossiliferous material, but very few of these parks actively monitor paleontological resources as part of a management program. NPS fossils consist of invertebrates, vertebrates, plants, ichnofossils and more that cover almost the entire expanse of geologic time in the history of life. Present methods for assessing paleontological resources include: (1) comprehensive park-specific inventories; (2) service-wide thematic inventories; (3) state by state inventories; and (4) research as grouped by Inventory and Monitoring Networks. These survey strategies are useful for individual parks or groups of parks; however, the future of fossils in parks nationwide necessitates an alternate course of action that incorporates the entire park system.

The assembly of a preliminary guidebook highlighting the stratigraphic and paleontologic context of all areas managed by the National Park Service provides a foundation for the development of innovative monitoring techniques. The report utilizes customized graphics and conceptual diagrams for straightforward interpretation and establishment of icons in future NPS publications. Two main sections constitute the outline of the paleontological guidebook. The first portion focuses on the age of rocks mapped at the park as divided by geologic period or epoch. Temporal slices are regarded as fossiliferous, potentially fossiliferous or not at all fossiliferous based on geologic descriptions of park formations and the presence of fossils at the park or elsewhere. Fossils catalogued in NPS collections that do not correspond to local rocks are also noted. This chart offers the chance for park staff to recognize current fossil-bearing units, evaluate potentially prolific units and minimize investigation of non-fossiliferous units.

The second section exhibits the range of fossils observed inside park boundaries and management concerns including collections, interpretation and probable threats. Paleontological resources are categorized in five basic taxonomic groups that consist of invertebrates, vertebrates, plants, ichnofossils and other (e.g., stromatolites). Inventories completed for individual parks (park-specific, thematic, state-wide, I&M network) and collection location (park, outside repository, prior to NPS status) are also documented. Forms of interpretation (e.g., exhibit, wayside, brochure, etc.) and resource threats such as erosion, theft and vandalism that may affect paleontological resources are identified. These numerous paleontological fields of interest depicted for all fossiliferous parks impart an opportunity for comparison of resources and developing management plans. Data-mining fundamental to this project is still in progress as many parks are unaware of their paleontological status or potentially fossiliferous stratigraphic units.

Types of fossils and corresponding geologic units are recorded for most parks containing paleontological resources; however, ongoing research continues to uncover new resources and new parks not previously recognized as fossiliferous. The next step is compiling service-wide data on management issues as only a handful of parks supplied that level of information in response to initial paleontological queries.

One final aspect of this project is the development of a paleontological database. The guidebook allows for a basic understanding of current paleontological resources in the entire park system; however the establishment of a formal National Park Service database serves a greater purpose as a means for efficiently updating paleontological resource information over the years. Database categories follow the classification scheme outlined in the preliminary guidebook and incorporate more detailed information of unique paleontological occurrences such as state fossils, holotypes and historically significant fossils. Links to NPS geologic maps, reports and collections are an additional benefit of having information stored in the form of a database.

The documentation of baseline geologic and paleontologic data is essential for effective stewardship of paleontological resources in parks nationwide. The production of a service-wide guidebook gives park employees a comprehensive source for future paleontological research and education. The often overwhelming complexity of scientific information is reduced in this user-friendly publication as difficult concepts are conveyed through graphical means. The creation of customized symbols promotes paleontological awareness and sets a standard for reinforcing these ideals in future NPS publications. The database initiative compliments guidebook objectives and presents a future direction for the preservation of paleontological resources in national parks.

Fossils possess great scientific and educational value in parks across the nation. Prospective growth for paleontological research and education in national parks is unlimited as long as fossils are maintained for future generations. The assembly of a National Park Service paleontological guidebook and associated database provides a framework for parks to expand their knowledge of current paleontological concepts and thereby learn how to effectively protect these non-renewable resources. The future of NPS paleontology becomes more secure once a service-wide guidebook and formal database are established that can meet the changing needs of individual parks as management issues are continually revisited.

TRANSFER OF UALP SAN JUAN BASIN VERTEBRATE FOSSIL COLLECTION TO THE NMMNH

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Abstract—The University of Arizona Laboratory of Paleontology (UALP) collected Late Cretaceous (Judithian and Lancian), early Paleocene (Puercan and Torrejonian) and early Eocene (Wasatchian) vertebrates from BLM lands of the San Juan Basin in the 1970's from over 400 localities. Most specimens are accompanied by precise locality information based on plots on USGS 7.5' maps. These collections were utilized in numerous theses, dissertations and scientific publications. However, for approximately the last decade, the University of Arizona had stored the collection off campus among various facilities, making it nearly inaccessible to researchers. Ultimately, the University of Arizona (UA) agreed to transfer this collection to the New Mexico Museum of Natural History and Science (NMMNH).

In September 2005, a crew from the NMMNH traveled to Tucson to pack up and move this collection to Albuquerque. Specimens were stored offsite in two different storage areas: one a commercial storage facility and the other, the Duval Street garage building. A rented U-Haul truck was loaded with storage cabinets at the NMMNH and driven to Tucson. The packing and transfer of specimens were accomplished in just three days. The specimens have subsequently been cataloged into the NMMNH collection (a total of over 2,800 cataloged specimens). The locality database has also been incorporated into that of the NMMNH. In addition, the UTM coordinates have been estimated for all locality plots so that data can be easily shared between agencies and utilized for land-use decisions.

FOSSILS AND FIRE: A STUDY ON THE EFFECTS OF FIRE ON PALEONTOLOGICAL RESOURCES AT BADLANDS NATIONAL PARK

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Abstract—National Park Service policies stipulate that each park with vegetation capable of burning will prepare a fire management plan. Badlands National Park completed its fire management plan in 2004. Fossils are a principle resource of the park and the fire sensitivity of fossils is the focus of this study. The surface temperatures of fossil specimens and fire behavior characteristics were monitored in prescribed fires on the landscape and in laboratory burns to develop an understanding of the relationship between burning conditions and changes in fossil specimen properties. Under laboratory conditions, low intensity and low to intermediate rates of spread, the surface temperatures of fossil specimens showed limited temperature increases and no surface discoloration. The fossils included invertebrates from the Cretaceous Pierre Shale and fossil mammal remains from the Eocene/Oligocene White River Group. All specimens had been confiscated during law enforcement activities within the park. The results from burns under these conditions showed that only fossil specimens that were in contact with burning fuel showed increased surface temperatures and discoloration. The laboratory results from burns conducted under high intensity and high rates of spread conditions showed increased surface temperatures and surface discoloration and that the changes in fossil specimen properties were not dependent upon contact with fuel. In field trials during the spring of 2001, prescribed burn treatments were limited by environmental conditions to low rate of spread and low intensity burns. Under these conditions high surface temperatures and surface discoloration were observed on samples that were in direct contact with fuel. Samples that were not in contact with fuel did not show surface discoloration or significant surface heating. Both laboratory and field burns suggest that low to moderate fire conditions have minimal impact on fossil resources except in areas where the fossils are in contact with fuel. The laboratory portion of this study suggests that significant fire effects would be found under high spread rate and high intensity conditions even though there is no fuel contact.

INTRODUCTION

Staff at Badlands National Park (BADL), the Black Hills Fire Use Module and the Midwest Regional Office worked in partnership with researchers from the U.S. Forest Service (USFS) Fire Sciences Laboratory in Missoula, Montana to determine the effects of fire in a prescribed setting on fossil resources within Badlands National Park.

Badlands National Park is world renown for its fossil resources. Paleontological research began in western South Dakota in 1846 with the discovery of a brontothere jaw by fur traders while traveling along the Ft. Pierre to Laramie trail (Prout, 1846). Following this discovery, museums and research institutions sent out surveys to the Dakota Territories from the 1850s through the 1880s. Paleontological research has continued on into the present. Every major museum in North America and Europe has White River Group Collections from western South Dakota.

Paleontological resources were a major reason for originally establishing Badlands National Monument in 1939, for adding the 133,000-acre Stronghold District in 1976 and for obtaining national park status in 1978 (Presidential Proclamation Number 2320 [53 Stat. 2521] and 16 USC 441; National Parks and Recreation Act of November 10, 1978). The congressional report accompanying the 1929 Organic Act for Badlands National Park described the reasons for setting aside the area as the preservation of a unique geological and eroded landscape and because, "vast beds of vertebrate fossil remains are a vast storehouse of the biological past" (Report Number 2607 of the Committee on the Public Lands, 70th Congress – 2nd Session – March 4, 1929).

National Park Service (NPS) Management Policies (National Park Service, 2001) mandate that each park with vegetation capable of burning must prepare a fire management plan, designed to guide a program that responds to the park's natural and cultural resource objectives. Within

Director's Order 18 (National Park Service, 2002), wild land fuel complexes are managed to achieve resource benefits and management goals such as hazard fuel reduction, ecosystem restoration and maintaining ecosystem health. One form of hazard fuel reduction is the use of prescribed burns.

Fire effects on paleontological resources has not been well studied. Studies of fire effects on native rock such as obsidian and chert have shown a wide range of responses (Buenger, 2003) due to key fire behavior characteristics such as intensity and duration (Traylor et al., 1983). Small temperature changes have great impacts on fossil specimens and several papers outlining proper storage conditions for fossil specimens have echoed this conclusion (Ashley-Smith, 1987; Brunton, et al., 1985; Fitzgerald, 1995; Howie, 1978; Howie, 1979; Johnson and Horgan, 1979; Stolow, 1966; Thomson, 1986).

The Badlands National Park Fire Management Plan, mandates that the park implement a prescribed burn cycle spanning 15 years, burning over 60,000 acres. As a result of fire management planning, badlands geologic formations have been routinely designated as fire breaks. This study was conducted to address concerns about the potential effects of increased burn activity on the fossil resources at BADL.

METHODS AND RESULTS

This study included prescribed burns conducted in BADL during the spring of 2000 and 2001 and laboratory burning at the USFS Fire Sciences Laboratory in Missoula, Montana in 2001.

2000 FIELD STUDY METHODS

In the spring of 2000, a pilot study was conducted to evaluate fire effects on paleontological resources within a prescribed burn setting.

The prescribed burning was conducted on the Pinnacles Burn Area, which is located on the northeastern boundary of the Badlands Wilderness Area (Fig. 1). The selected study areas within the prescribed burn unit were composed of different fuel types and loadings.

The ground cover in the burn unit ranged from bare soil to areas of mostly continuous grass or grass/shrub cover. Representative study sites were selected in a woody draw (small natural drainage areas covered by trees and shrubs), an area of sparse grass and forb cover, a bare outcrop and a grass covered site.

Six study plots, each consisting of a single fossil specimen from the Eocene/Oligocene White River Group (Fig. 2; Appendix 1) and one tile coated with heat sensitive paint were arranged for the study. The tiles were placed within the burn unit in conjunction with fossil specimens that were either brought in or in situ.

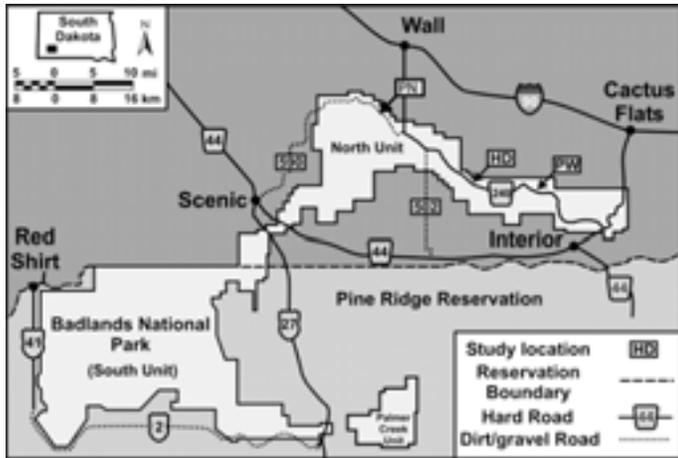


FIGURE 1. Map of Badlands National Park showing study locations. (HD = Hamms Draw; PW = Prairie Winds; PN = Pinnacles; Adapted from Benton et al., 2001).

2000 FIELD STUDY RESULTS

The burn was a low intensity backing fire that primarily burned down hill through the study area. Three of six specimens were damaged during this prescribed burn. The damaged samples were present in the grass and woody draw sites. Post-burn analysis of the specimens from these sites showed surfaces with a brown tar build-up and some smoke staining. Specimens naturally occurring in areas between two and ten meters away from flames were not affected. No change in color of the tiles was observed.

2001 FIELD STUDY METHODS

The 2001 field study was conducted to develop an understanding of the fire environment associated with fossil specimen changes observed during prescribed fires. The fire characteristics that were measured during prescribed burning served as the basis for the development of experimental treatments for the laboratory portion of this study.

The field component of this study included four study sites that were established in the Roadside Burn unit. The burn unit was located on the south side of Rt. 240 between Big Foot Road and Quinn Road intersections (Fig. 1). Data collected from these study sites were representative of the grassland/shrub fuel type found at BADL. The Prairie Wind #1 and Hamms Draw #1 sites were located on flat areas dominated by grassland fuels at an estimated loading of approximately 1000 lbs/acre. Prairie Wind #2 was located in sparse shrub land directly adjacent to badlands. The Hamms Draw #2 site was located in a small draw with a 5-10% slope and was dominated by grass and shrub fuels (Table 1).

The ground cover at Prairie Wind #1 and Hamms Draw #1 was continuous. These sites were considered unnatural settings because fos-

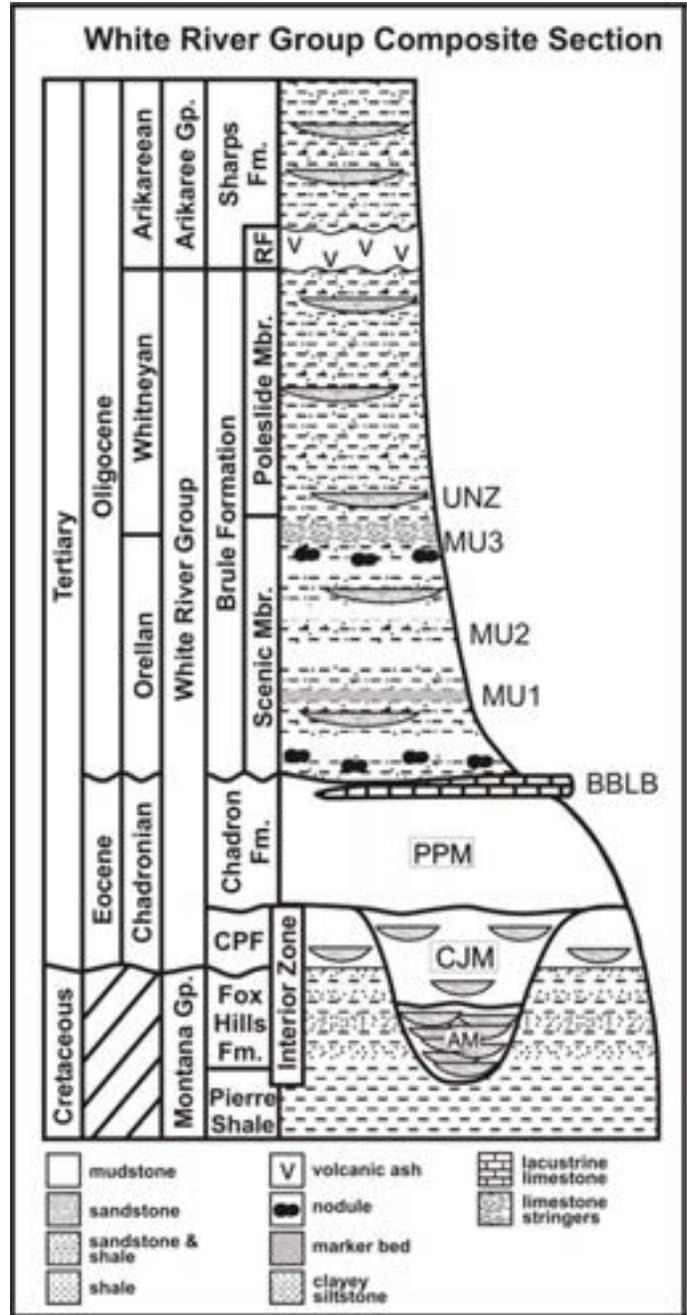


FIGURE 2. Stratigraphic column showing rock formations exposed at Badlands National Park. (AM, CJM and PPM = the Ahearn, Crazy Johnson and Peanut Peak Members of the Chadron Formation, respectively; BBLB = Bloom Basin Limestone Beds; CPF = Chamberlain Pass Formation; LNZ = Lower Nodular Zone; MU = Marker Unit; RF = Rockyford Ash; UNZ = Upper Nodular Zone; Adapted from Benton et al., 2001).

sils are normally found in areas with exposed soil and bedrock and not in areas with continuous grass cover (Table 1).

Fossil specimens from the Cretaceous Pierre Shale and Eocene/Oligocene White River Group were placed on the ground surface at each site (Fig. 2; Appendix 1). Temperatures were measured on the surface of each specimen by small gauge thermocouples attached to the samples. Thermocouples were also used to make temperature measurements on the soil surface and at depths below the soil surface (Figs. 3 and 4).

Radiant heat flux is a measure of the amount of energy transferred from the flaming combustion zone to the surface of the specimens and the soil surface. Radiant heat flux was measured at the soil surface adja-

TABLE 1. Study Site Characteristics – 2001 Field Study. (Radiant flux is measured in kw/m²; na = measurements not available).

STUDY SITE	FUEL	SLOPE (%)	FIRE TYPE	RADIANT FLUX	SETTING TYPE
Hamms Draw #1	Grass	None	Head fire	15.8	Unnatural
Hamms Draw #2	Grass/woody shrubs	5-10	Head fire burning uphill	8.1	Natural
Prairie Wind #1	Dense grass	None	Backing fire	10.7	Unnatural
Prairie Wind #2	Sparse grass/shrubs	None	Head fire	na	Natural

cent to the specimens at each site. Sampling was conducted at two-second intervals for both the temperature and flux. Measurements at each site were recorded with data-logging equipment.

A line of fire was ignited adjacent to each study area and the fire spread though each study site. The fires on the Hamms Draw #1 and Prairie Wind #2 were primarily wind driven head fires while the fire on Prairie Wind #1 was a backing fire. The Hamms Draw #2 site was ignited at the base of the draw and the fire moved up slope through the shrub and grass fuels. All of the 2000 and 2001 prescribed burns followed the Northern Great Plains Prescription for Management of Ignited Prescribed Fires utilizing following ranges: an air temperature of 1.7-32°C (35-90°F, a relative humidity of 20-60% and a mid-flame wind speed of 3.2-16.1 km/h (2-10 mph) (Rothermel, 1983; Andrews, 1986).

2001 FIELD STUDY RESULTS

The study plots were burned mid-morning to early afternoon under conditions of low wind speed, moderate temperature and relative humidity. Although study site differences were noted in flame front characteristics, fires on these study sites were all characterized by relatively low rates of spread and low intensities. All temperature, humidity and wind speed parameters fell within the Northern Great Plains Prescription for Management of Ignited Prescribed Fires

The peak radiant flux (amount of radiant heat that a fossil surface would receive from flames during burning) measured at the surface of the sites range from 8 to 15.8 kw/m² (kilowatts per square meter). Observations at the time of burning showed that the radiant flux was greatest on the Prairie Wind #1 site and lowest on the Hamms Draw #2 site (Table 1). The flame front on the Prairie Wind #2 site failed to reach the radiant flux and soil temperature sensors. Rates of spread and flame angle for two of the four sites were estimated from video imagery taken at the time of the burn. Prairie Wind #1 had a rate of spread of 0.7-0.8 m/min (meters per minute) and a vertical to one-degree flame angle. Hamms Draw #2

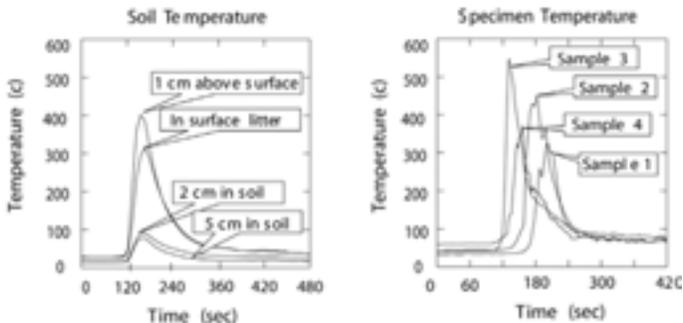


FIGURE 3. Prairie Wind #1; Soil Temperature (left) and Specimen Surface Temperature (right).

TABLE 2. Maximum Specimen Surface Temperatures – 2001 Field Study. (Average maximum temperature increases are calculated from pre-burn ambient temperatures).

STUDY SITE	AVERAGE MAXIMUM SURFACE TEMPERATURE (°C)	TEMPERATURE INCREASE (°C)
Hamms Draw #1	139	129.6
Hamms Draw #2	61	44.3
Prairie Wind #1	439.3	416.3
Prairie Wind #2	45.3	23.03

had a rate of spread of 0.5-0.6 m/min and a flame angle of 1-2 degrees. Higher rates of spread and longer flame lengths were observed on areas similar to our study sites in the late afternoon when wind speed and temperature increased and relative humidity decreased.

Above ground temperatures associated with soil temperature measurement were greatest at the Prairie Wind #1 site (Fig 3). The maximum above ground surface temperature was 418°C and the soil temperature at 5 cm depth was 82°C. Above ground and soil temperature changes were lowest on the Hamms Draw #2 (Fig 4). Maximum soil surface temperature on this site was 31°C and the temperature at the 5 cm depth was 21°C.

The greatest specimen surface temperature changes occurred at Prairie Wind #1. Maximum temperatures ranged from 324 to 439.3°C (Fig. 3). Specimens at Hamms Draw #2 showed limited changes in specimen surface temperatures. Maximum temperatures on this site ranged from 55 to 67°C (Fig. 3). The lowest increases in specimen surface temperature were measured on the Prairie Wind #2 site (Table 2). However, the results at the Prairie Wind #2 were inconsistent. Three specimens showed surface temperature increases to 45°C and no damage, while the remaining specimen showed an increase to 250°C for a 24 sec interval and sustained damage (Appendix 1).

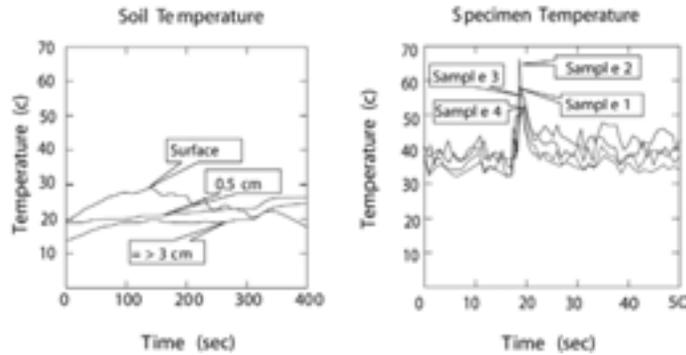


FIGURE 4. Hamms Draw #2; Soil Temperature (left) and Specimen Surface Temperature (right).

Pre- and post-burn comparison of the fossil specimens showed some surface color changes from light color to chocolate brown. The effects were sporadic in sparse fuel settings on Hamms Draw #2 and Prairie Wind #2 sites with partial discoloration in some specimens (Fig 5a). Fossils that were placed in contact with fuel showed consistent discoloration (Fig 5b).

LABORATORY STUDY METHODS

Predicting the fire effects on fossil specimens requires an understanding of the factors affecting the heat transfer from a flaming fire front to the surface of the specimens. As a consequence, the level of fire effects is a function of interrelated factors such as fire intensity, rate of spread

TABLE 3. Maximum Specimen Surface Temperatures – 2001 Laboratory Study. (Average Maximum temperature increases are calculated from pre-burn ambient temperatures).

TREATMENT	AVERAGE MAXIMUM SURFACE TEMPERATURE (°C)	TEMPERATURE INCREASE (°C)
1	31.86	13.74
2	31.64	14.11
3	59.22	40.95
4	44.61	28.59
5 WT	328.77	304.49
6 WT	492.33	467.51
7	493.75	471.5

and flame angle. The laboratory portion of this study concentrated on the relationship between the fire effects on fossil specimens and fire behavior characteristics in a controlled setting.

Laboratory burns were designed to simulate commonly occurring prescribed burning conditions which range from slowly spreading, low intensity fires to quickly spreading, high intensity fires. A range of potential fire effects was created by the seven burn treatments. For burns #1-#7 increases in fire intensity levels were achieved by increased rates of fire spread. Increased spread rates were obtained by increased fuel bed slope or by burning in a wind tunnel (Albini and Baughman, 1979; Rothermel, 1983). Burn treatment #7 was conducted at an intensity similar to burns #3 and #4 but designed to simulate a non-typical or unnatural fossil sites where the fossils were in contact with the fuel.

Burning was done in a controlled environment at the USFS Rocky Mountain Research Station, Fire Sciences Laboratory. We used standard laboratory procedures developed for the measurement of fire behavior



FIGURE 5. A, Photo showing sparse burn coverage at Hamms Draw Site #2 (BADL 39764). B, Pre-burn and post-burn photos of field specimens from Prairie Wind #1 (BADL 39766).

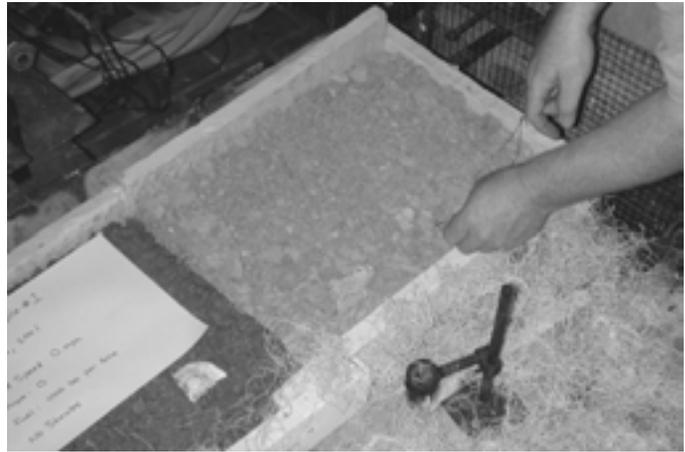


FIGURE 6. Photo of laboratory setup for burn studies.

model parameters (Catchpole et al., 1998).

Grass and grass-shrub fuels are common in BADL. Fire behavior in these grassland communities is dominated by herbaceous fuels (Anderson, 1982). Typical fuel loadings were simulated with grass and grass/shrub treatments. Fuel beds (4.5 x 1 m, L x W) were created using excelsior and multi-flora rose. Excelsior, which is composed of fine aspen wood shavings, was used as a grass fuel surrogate at 1000 lbs/acre. Partially dried multi-flora rose shrubs were added to simulate shrub fuel loadings associated with grassland/shrub fuel complex. The addition of this material increased the fuel loading to approximately 1200-1400 lbs/acre. A total of seven burns were completed.

A rock bed (0.5 x 1.0 m, L x W) was placed at the end of each fuel bed to simulate bare ground adjacent to burning fuel. The rock bed was divided into two parts with a rock matrix composed of either Pierre Shale or mudstones from the White River Group (Fig. 6).

The burns were conducted using fossil samples from two geologic time periods: specimens of marine invertebrates from the Cretaceous Pierre Shale and vertebrates from the Eocene/Oligocene White River Group. For each burn treatment fossil specimens were placed on the rock surface between 2.5 and 7.6 cm from the end of the fuel beds. A total of 28 fossil specimens from the Cretaceous Pierre Shale and Eocene/Oligocene White River Group were used in this study (Fig. 2; Appendix 1).

Thermocouples were attached to the surface of each fossil sample to measure temperature at 0.05 second intervals. Video camera imagery taken during each burn was analyzed to determine the rate of spread and

TABLE 4. Burn Treatment Characteristics – 2001 Laboratory Study. (Effective wind speed was calculated for burns 3, 4 and 7 based on slope of the fuel bed. Radiant and total surface flux is reported in kw/m². WT = wind tunnel, G = grass fuel loading treatment, GS = grass/shrub fuel loading treatment, na = measurements not available).

Burn	Rate of Spread (meters/minute)	Flame Angle (degrees)	Fuel Type	Slope (%)	Wind Speed (mph)	Maximum Radiant Surface Flux	Maximum Total Surface Flux
1	10.6	1.6	G	0	0	13.0	25.6
2	0.6	1.2	G/S	0	0	13.0	45.6
3	2.1	37.3	G	39	4-6	21.5	32.3
4	2.3	29.5	G/S	39	4-6	22.2	63.4
5 WT	8.8	47.7	G	0	10-15	NA	NA
6 WT	10.4	42.9	G/S	0	10-15	47.4	60.0
7	2.5	35.5	G/S	39	4-6	18.4	36.7

flame angle. Radiant and total heat flux was measured at the rock surface.

LABORATORY STUDY RESULTS

There were no observable differences between the measured surface temperatures of the marine invertebrates and vertebrate fossil samples.

Burns #1 and #2 had the lowest rates of spread, flame angles and intensity of all of the laboratory studies (Table 4). The spread rates of the grass and grass/shrub fuel treatments were similar. Flames were nearly vertical for both treatments but flame angles were slightly greater for the grass fuel treatment. No difference was present in the surface temperature produced by the grass and grass/shrub fuel treatments. Although radiant intensities were similar, the total intensity was greater for the grass/shrub treatment.

Under these conditions, limited increases in sample surface temperatures were recorded (Fig. 7). The average maximum temperature increase of the specimens was 13-14°C (Table 3). There was no change in the fossil specimen condition in the eight fossil specimens used for burns #1 and #2 (Appendix 1).

Burns #3 and #4 showed rates of spread, intensities and flame angles greater than burns #1 and #2 (Table 4). The spread rate of grass and grass/shrub fuel treatment were similar and the flame angles were greater for the grass treatment. Radiant intensities were similar but total intensity was greater for the grass/shrub treatment.

Change in fossil specimen condition was limited to one of eight fossil specimens used in burns #3 and #4 (Appendix 1). The average maximum temperature increase for this treatment was greater than burns #1 and #2 (Table 3).

Burns #5 and #6 represented a high rate of spread/high intensity conditions. The fire intensity and flame angle were consistent with fire behavior model predictions for these conditions. The spread rates, intensity and flame angles were greater than both the low and intermediate burns. Spread rate was greater for the grass/shrub fuel treatment and flame angles were slightly greater for the grass fuel treatment (Table 4).

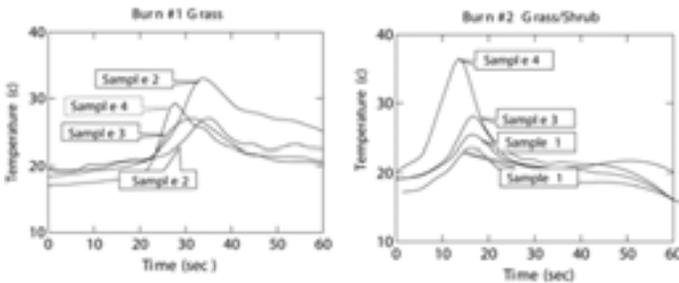


FIGURE 7. Low intensity laboratory burns #1 and #2, Specimen Surface Temperatures.

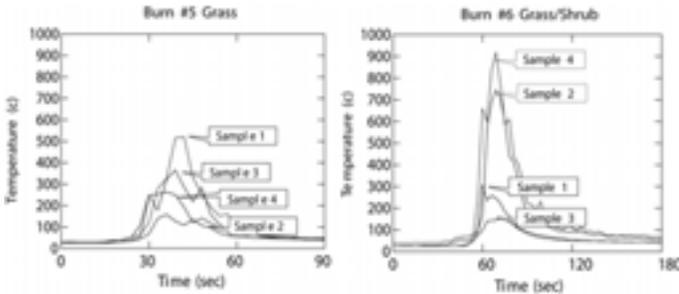


FIGURE 8. High intensity laboratory burns #5 and #6, Specimen Surface Temperatures.

Fire effects were observed in seven of the eight fossils used in burns #5 and #6 (Appendix 1). The average maximum surface temperature increase of the samples was greater than lower intensity burns (Table 4). Maximum surface temperatures were greater for the grass/shrub treatment (Fig. 8).

Burn #7 represented an intermediate grass/shrub fuel treatment where specimens were in direct contact with fuel. The measured spread rate and flame angle was similar to the previous intermediate spread rate burns (Table 4). The average maximum surface temperature for this burn treatment was 493.7°C (Table 3). All fossils specimens in this treatment were covered with tar build up and had significant discoloration but no cracking or splitting was observed. (Fig. 9; Appendix 1).

DISCUSSION

The prescribed burn conducted in 2000 was a low intensity backing fire that primarily burned down hill. Post burn observations noted that burn patterns were extremely variable. Fires often died out before they reached a grassland/bedrock interface and in areas with greater fuel loading, (woody draws and grass cover) the burn was more extensive and complete in coverage. Although the heat sensitive tiles showed no change, damage was observed in three of the six specimens used in this burn. The results show that the tiles coated with heat sensitive paint are not good



FIGURE 9. Pre-burn and post-burn photos of study specimens used in burn #7 (BADL 39758 and BADL 39759).

indicators of damage under a range of low intensity burning conditions.

The fire behavior of the field burns conducted during the spring of 2001 can be characterized as slow rate of spread and low intensity burns. There were differences present in the soil temperature measurements across the study sites. The soil profiles measured at the Prairie Wind #2 and Hamms Draw #2 had both bare soil and a thin layer of surface litter, while the soil surface of the Prairie Wind #1 and Hamms Draw #1 site was dominated by a layer of litter and sod produced by smooth brome (*Bromus inermis*). The limited increase in soil temperatures suggests that on typical fossil sites with sparse cover there would be minimal effect from soil heating of fossil material buried in the soil. The disparity between maximum soil temperatures and specimens on the Prairie Wind #1 site was primarily the result of fuel differences.

The maximum fossil surface temperatures were linked with maximum soil surface temperatures. The most extensive specimen surface changes occurred on the flat grassy expanses of uniform fuel distribution. Discoloration occurred on all specimens that had contact with fuel. Based on field observations, specimens exposed on bare bedrock that were at a distance from fuel or were not in contact with fuel were not affected.

The results of the laboratory burning, show levels of damage increasing with faster rates of spread, higher intensities and greater flame angles. Increases in intensity and rate of spread lead to increased heat transfer from the flame front to the specimen surfaces. No damage was observed in burns of low intensity where there was no contact with fuel or flames. Surface temperatures for the grass/shrub fuel treatment were greater than the grass fuel. In high intensity fires with quickly spreading flame fronts there was an effect on all exposed fossils. Significant fire effects were also observed under intermediate intensity when the specimens were in direct contact with the fuel. These results suggest that the size of the buffer zone needed to protect the samples was dependent on fire behavior and fuel distribution.

The comparison of laboratory fire behavior and field burn observations suggests that the 2001 field burns were similar to the low intensity laboratory burns. No fire effects were found on fossil specimens resulting from laboratory burning under low spread rates, low intensities and without physical contact with fuel. However, damage was observed on samples in the field burns of 2001.

The most significant sample damage was observed on Hamms Draw #1 and Prairie Wind #1. Sites were not considered typical or unnatural fossil sites due to continuous fuel cover. Maximum specimen surface temperatures on the Prairie Wind #1 site were comparable with surface temperatures measured during high intensity laboratory burns. Surface temperatures on the Hamms Draw #1 site were between the intermediate and high intensity laboratory burns. Similarities in radiant flux measurements in conjunction with differences in surface temperatures suggest that the fuel and specimen distribution played an important role in higher specimen surface temperatures on these sites.

Less damage was observed on Hamms Draw #2 and Prairie Wind #2 and the effects were greater than those measured in similar low intensity laboratory burns. These sites were more representative of typical

fossil sites, with sparse vegetation and bare ground. Although the radiant intensities of the laboratory and field burns were similar, specimen surface temperatures of the field burns were greater than the surface temperatures on the low intensity laboratory burns.

The results show that the maximum radiant energy was greater from the field burns, than the low intensity and lower than the intermediate intensity laboratory burn #7, but the maximum total flux measured during the field burns was comparable with higher intensity laboratory burns. Under laboratory conditions of moderate spread rate and flame angle, significant energy was contributed to the specimen surface by conductive and convective processes. The results demonstrate that in complex fuel and fossil distributions radiant flux alone is not a good predictor of fossil damage.

While there was no physical damage (cracking or fracturing) to the specimens observed in the laboratory studies, the field studies did show fracturing on one specimen from Hamms Draw #2. Physical damage to native rocks has been observed in fires of grassland/shrub land fuels in a number of studies (Buenger, 2003).

The most consistent fire effect found in both the field and lab studies was chemical discoloration or "sooting" of the specimens. The interaction of combustion, smoke and surface temperature appeared to create these effects. These features did not vary with the size or type of fossil. The data suggest that the interaction between fossil surface temperature and the distance from fuel are important predictors of fire effects on exposed specimens. Flame angle and flame height play a key role in these surface temperatures.

As with any research project, many new questions are often generated. The results of this study have shown the significance of the relationship of fire effects with flame and fuel contact. An improved understanding of the dynamics of a fossil protective "buffer zone" size for a range of prescribed and wild fire conditions is needed to develop a predictive relationship between burning and levels of resource damage. The data from these studies is essential to the development of burning prescriptions that minimize expected resource damage. The results of this future study might be applicable to a wide range of resource questions.

CONCLUSION

There are paleontological resource management concerns over the use of prescribed fire at BADL. A number of these concerns can be addressed during fire prescription development. Through the integration of paleontological resource distributions with practical burning constraints, operational burning plans can be developed that will incorporate firing techniques to minimize expected resource damage. The implementation of burning strategies includes black lining, burning away from important resource areas and burning sensitive areas with low rates of spread and low intensities. In addition to the above listed techniques, the control of foot and vehicle traffic in fragile fossil rich areas would also minimize paleontological resource damage.

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APPENDIX 1. FOSSIL SPECIMENS USED FOR 2000 AND 2001 FIELD AND LABORATORY BURN STUDIES.

<i>Study Number</i>	<i>Site/Burn Number</i>	<i>Specimen Number</i>	<i>Taxa</i>	<i>Element</i>	<i>Formation/Group</i>	<i>Comments</i>
2000 Field Study	Site #1	Specimen #1	Oreodont	Skull	White River	No change
	Site #2	Specimen #2	Oreodont	Molar Fragment	White River	No change
	Site #3	Specimen #3	Oreodont	Skull	White River	No change
	Site #4	Specimen #4	Oreodont	Skull	White River	Discoloration
	Site #5	Specimen #5	Oreodont	Premaxilla Fragment	White River	Discoloration
2001 Field Study	Site #6	Specimen #6	Oreodont	Molars	White River	Discoloration
	Hamms Draw #1	Specimen #1	Oreodont	Jaw Fragment	White River	Discoloration
		Specimen #2	Oreodont	Maxillary Fragment	White River	Discoloration
	Hamms Draw #2	Specimen #3	Baculite	Fragment	Pierre Shale	No change
		Specimen #4	Baculite	Fragment	Pierre Shale	No change
		Specimen #5	Oreodont	Jaw Fragment	White River	Discoloration
		Specimen #1	Oreodont	Skull Fragment	White River	No change
		Specimen #2	Rhinoceros	Maxillary Fragment	White River	Discoloration
	Prairie Wind #1	Specimen #3	Baculite	Fragment	Pierre Shale	No change
		Specimen #4	Inoceramus	Cluster	Pierre Shale	No change
		Specimen #1	Rhinoceros	Partial Jaw	White River	Discoloration
		Specimen #2	Oreodont	Jaw fragment	White River	Discoloration
		Specimen #3	Baculite	Fragment	Pierre Shale	Discoloration
		Specimen #4	Baculite	Cluster	Pierre Shale	Discoloration
		Specimen #1	Oreodont	Maxillary Fragment	White River	Discoloration
2001 Lab Study	Burn #1	Specimen #2	Oreodont	Vertebral Column	White River	No change
		Specimen #3	Scaphite	Parital Shell	Pierre Shale	No change
		Specimen #4	Baculite	Fragment	Pierre Shale	No change
		Specimen #1	Oreodont	Femur, head	White River	No change
		Specimen #2	Oreodont	Mandible	White River	No change
	Burn #2	Specimen #3	Baculite	Fragment	Pierre Shale	No change
		Specimen #4	Baculite	Fragment	Pierre Shale	No change
		Specimen #1	Mammalia	Acetabulum	White River	No change
		Specimen #2	Mammalia	Limb Element	White River	No change
		Specimen #3	Baculite	Fragment	Pierre Shale	No change
	Burn #3	Specimen #4	Oreodont	Molar	White River	No change
		Specimen #1	Mammalia	Podial, distal end	White River	No Change
		Specimen #2	Mammalia	Vertebral Fragment	White River	No Change
		Specimen #3	Baculite	Fragment	Pierre Shale	No Change
		Specimen #4	Mammalia	Astragalus	White River	No Change
Burn #4	Specimen #1	Mammalia	Phalanx, distal end	White River	No Change	
	Specimen #2	Mammalia	Tibia, distal end	White River	No Change	
	Specimen #3	Baculite	Fragment	Pierre Shale	No Change	
	Specimen #4	Mammalia	Tibia, distal end	White River	Discoloration	
	Burn #5	Specimen #1	Mammalia	Astragalus	White River	Discoloration
Specimen #2		Mammalia	Femur, head	White River	No Change	
Specimen #3		Mammalia	Molar Fragment	White River	Discoloration	

<i>Study Number</i>	<i>Site/Burn Number</i>	<i>Specimen Number</i>	<i>Taxa</i>	<i>Element</i>	<i>Formation/Group</i>	<i>Comments</i>
		Specimen #4	Mammalia	Phalange, distal end	White River	Discoloration
	Burn #6	Specimen #1	Oreodont	Femur, head	White River	Discoloration
		Specimen #2	Oreodont	Mandible	White River	Discoloration
		Specimen #3	Baculite	Fragment	Pierre Shale	Discoloration
		Specimen #4	Baculite	Fragment	Pierre Shale	Discoloration
	Burn #7	Specimen #1	Mammalia	Tibia, distal end	White River	Discoloration
		Specimen #2	Mammalia	Tibia, distal end	White River	Discoloration
		Specimen #3	Baculite	Fragment	Pierre Shale	Discoloration
		Specimen #4	Mammalia	Tibia, distal end	White River	Discoloration

PRESERVING AMERICA'S FOSSIL HERITAGE

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From New York to San Diego and New Haven to Atlanta, the United States is world renowned for its prestigious museums of natural history. Institutional names such as Philadelphia's Academy of Natural Sciences, the American Museum of Natural History in New York City and the National Museum of Natural History at the Smithsonian Institution in our nation's capital are familiar to academics, tourists and dinosaur enthusiasts around the globe. Throughout history, these institutions have led field parties throughout the world in an attempt to amass a large collection of fossils, artifacts and relics of both historic and pre-historic significance. At times, these field expeditions have led to bitter rivalries and feuds which have become legendary in their own right, though ultimately leading to the advancement of science for all mankind. Today, people can tour the exhibit halls in the American Museum of Natural History and see *Tyrannosaurus rex*, collected in 1902 by Barnum Brown in the badlands of Hell Creek, Montana, or dinosaur trackways collected by Roland T. Bird in the Paluxy River bed near Glen Rose, Texas. While these museums are visited by thousands or even millions of tourists each year in our nation's largest cities, most of which lie east of the Mississippi River, what of the original sites of discovery?

Enter the National Park Service of the United States Department of the Interior. Preserving nature, culture and history in the form of national parks, historic sites, monuments and battlegrounds the National Park Service is perhaps less frequently recognized for its preservation of paleontological resources at the original localities from which many of our museums have amassed their collections. By an Act of March 1, 1872, Congress established Yellowstone National Park as "a public park or pleasuring ground for the benefit and enjoyment of the people" (Kieley, 1940). More than 130 years later, today the National Park System is composed of 388 areas extending nearly 84.5 million acres in 49 states, the District of Columbia, American Samoa, Guam, Puerto Rico, Saipan and the Virgin Islands (National Park Service, 2005). By the very nature of its mission statement, which reads "to preserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations" (Kieley, 1940), the National Park Service works hard to preserve the American legacy, from pre-human America at Triassic aged Petrified Forest National Park in Arizona to our nation's birth at Independence National Historical Park in Philadelphia. Many of our national parks and monuments, located primarily in the western interior of our continent, pay special tribute to a time before man, when our world was populated by many floral and faunal forms now long gone.

Unlike the great museums of the east, the National Park Service has preserved many of the original fossils *in situ*, rather than as cast replicas or in collection storage facilities. At these sites of discovery in the American West, where fossil relics are now preserved for the enjoyment and education of the public in their original location, they are also protected against theft, commercial collection, vandalism and, in some cases, even against the elements of erosion. In addition to the *in situ* preservation of these fossils, the National Park Service also has museum quality displays in park visitor centers, offers public interpretive programs, publishes educational materials and works closely with scientists who, by permit, can continue to study and collect data from these park

localities. Petrified Forest National Park, located in eastern Arizona, is an easily accessible outdoor classroom of natural history and a fine example of preservation stewardship. After a field investigation of the area in 1899, Lester Ward, paleobotanist to the United States Geological Survey recommended to Congress that the area be withdrawn from homesteading and placed under protection of the federal government (Tuttle, 1990). Then, after Congress passed the Antiquities Act in 1906, President Theodore Roosevelt declared the area as a national monument until, after several additions of adjacent land areas, in 1962 the monument was redesignated as Petrified Forest National Park (Tuttle, 1990). Preserving the 93,493 acres of the park, the National Park Service enforces strict laws prohibiting the removal of petrified wood, fossils and all other artifacts from the park in order to preserve them for the enjoyment of future generations. In addition to law enforcement, the National Park Service works hard to preserve some of the park's other curiosities, such as at Agate Bridge, a petrified log over one hundred feet in length, straddling an eroded ravine. In an attempt to protect the log against erosional forces, the addition of support beams have been placed beneath the log so as to preserve the beauty and uniqueness of Agate Bridge for years to come (Tuttle, 1990). The Rainbow Forest Museum and Visitor's Center, located at the park's south entrance, displays petrified wood and dinosaur fossils from the park's Triassic Upper Chinle Formation. In addition there are a variety of ranger led interpretive programs such as the Triassic Park Program, a twenty-minute ranger guided walk along the park's Giant Log Trail. The Junior Ranger Program provides children an educational opportunity to learn about the park and its resources at leisure and is fun for the whole family. At Petrified Forest National Park, the National Park Service has taken another step in its education programs such as the Paleontology Module, a hands-on educational curriculum based activity for school field trips and other groups. The National Park Service Paleontology Program, in keeping with their mission statement, focuses its efforts on the preservation of fossils and other natural geologic processes in the parks. Fossils (invertebrate, plant, vertebrate and trace) have been found in over 180 units of the National Park System and together, provide a comprehensive history of life throughout geologic time, from the Precambrian to the Pleistocene.

In May of 2000, the Secretary of the Interior, reporting in Fossils on Federal and Indian Lands listed seven principles governing fossil management by the National Park Service and other federal land management agencies (Department of the Interior, 2000). They are as follows:

Principle #1- Fossils on federal lands are a part of America's heritage.

Principle #2- Most vertebrate fossils are rare.

Principle #3- Some invertebrate and plant fossils are rare.

Principle #4- Penalties for fossil theft should be strengthened.

Principle #5- Effective stewardship requires accurate information.

Principle #6- Federal fossil collections should be preserved and available for research and public education.

Principle #7- Federal fossil management should emphasize opportunities for public involvement.

Such principles are essential to the care and management of Na-

tional Park paleontological resources. Principles 2 through 6 directly pertain to preserving such resources from damages of natural and human origin. Principles 1, 6 and 7 indicate the National Park System makes educational use of their protected resources (Paleontology Module at Petrified Forest National Park) and Principle 5 is the cornerstone of preservation. With the modern technological support of Global Positioning Systems and Geographic Information Systems (GIS) software, the National Park Service can now keep detailed accurate information on the locations of fossil localities within the parks and can rely on visitors and volunteers to provide such information, thus reducing the cost of park service manpower to collect such data. With such accurate electronic and digital models, the National Park Service can better manage, and thus preserve, America's fossil heritage. The National Park Service

also publishes a wealth of information concerning park paleontology for any who are interested. Such publications as the newsletter *Park Paleontology* and *NPS Paleontological Research* volumes serve to communicate information on the preservation and resource management of fossils in the park system. The Paleontology Internship Program and Geoscientists-in-the-Parks Program serve to educate college students on the particulars of fossil preservation, education and scientific data collection ethics within the national parks. With such an abundance of fossil-bearing units and large diversity of fossils, the publications, law enforcement efforts, preservation techniques and educational programs, it is easy to see why, although unorthodox in a museological sense, the National Park Service is perhaps the largest and most diverse paleontological institution in the world.

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MIDDLE PROTEROZOIC PALEONTOLOGY OF THE BELT SUPERGROUP, GLACIER NATIONAL PARK

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Abstract—Glacier National Park in northwestern Montana holds significant geological and paleontological resources. The Middle Proterozoic sedimentary rocks exposed by the Lewis Overthrust span over 2,100 m of stratigraphic thickness, representing 800 million years of deposition. The glacial carving of the mountains and valleys that began 1.6 Ma left outcrops that are strangely unaltered. While the geological resources of the park have been substantially researched, the paleontological studies have been more sporadic. Precambrian formations of the Belt Supergroup hold a record of abundant ancient life, such as stromatolites and eucaryotes. Stromatolites within the parks were first recognized by Walcott in 1906. They have subsequently been studied in detail by Fenton and Fenton in the 1930s, Rezak and Ross in the 1950s and to a great extent by Horodyski from the mid-1970s to the 1990s. Current research conducted on the eukaryote *Horodyskia moniliformis*, from the Precambrian Appekunny Formation, and on the cone- and branching-shaped stromatolites of the Precambrian Siyeh Formation. These works yielded a great deal of knowledge about the paleontological history of the park but many more questions exist. Future explorations lie in the morphometric attributes, macrostructures and environmental conditions of the local stromatolites. Detailed study of the separate units within the park could also prove useful in the further search for fossils.

INTRODUCTION

The fossil resources of northwestern Montana's Glacier National Park (GLAC) are both renowned and yet obscure in the world of paleontology research (Fig. 1). When compared to other aspects of research within the park, it is apparent that fossils overall receive very little attention. However, the attention select fossils have received is considerable and thorough. The bulk of the research that has taken place has focused on the Precambrian algal mats, recording some of the earliest life on earth.

Known as the Belt Supergroup, the Middle Proterozoic rocks exposed in the park are 1.45 to 1.1 Ga (Fig. 2; Table 1). They were deposited in what is commonly referred to as the Belt Sea, a shallow, possibly inland sea, which covered much of the area during this time. The geological record for the Paleozoic and most of the Mesozoic is unknown in GLAC, with a small amount of Late Cretaceous (Campanian) and late Eocene to early Oligocene aged sediments being preserved within the park. On the eastern border of the park, Precambrian aged units overlie those of the Campanian due to faulting during the Tertiary. This is known as the Lewis Thrust Fault.

PALEONTOLOGISTS IN THE PARK: AN HISTORICAL BACKGROUND

Since before GLAC's establishment in 1910 as the tenth national park in the United States, there have been seven paleontologists who devoted research time to the paleontology of the park. The first major paleontological research was conducted during the summer of 1908 by Charles Doolittle Walcott (1906, 1908), who had been appointed the new Secretary of the Smithsonian Institution in 1907 (Yochelson, 2001). His panoramic photographs of the region from these excursions assisted George Bird Grinnell, who was a major player in the establishment of the park, to persuade congress to preserve the area. Walcott returned to the area in 1914, after his discovery of Cambrian fossils in the Burgess Shale of British Columbia, with his findings being published later that year (Walcott, 1914).

Two paleontologists, Carroll and Mildred Fenton, continued the work during the 1930s, publishing four papers on the area from 1931 to 1939 (Fenton and Fenton 1931, 1933, 1937; Fenton, 1939). In the 1950s,



FIGURE 1. Location of Glacier National Park, Montana. Scale = 200 km.

Richard Rezak (1953, 1954, 1957) conducted his dissertation research within the park and worked with Clyde P. Ross on a publication of the geology and paleontology of the park for the U.S. Geological Survey (Ross and Rezak, 1959). Rezak also wrote the first summary of stromatolites known from the Belt Series of GLAC.

The 1970s-1980s seem to be the peak of paleontological research within Glacier. During the 1970s to early 1980s, Brian White worked extensively on the columnar stromatolites found in the upper Altyn Formation. White published six reports (White, 1970, 1974a,b, 1979, 1984; White and Pedone, 1975) about these stromatolites, along with reports of microfossils from the Altyn Formation.

The 1970s also brought with it the man who would complete the bulk of the research done on the parks paleontological resources, to date. Robert J. Horodyski completed his dissertation on the stromatolites and paleoecology of the park in 1973 (Horodyski, 1973). From 1975 to 1994, he went on to publish and co-author over 15 reports on many aspects of the paleontology of the park from. In the mid-1990s, Horodyski began to work on pseudofossils from the Appekunny Formation with Mikhail A. Fedonkin of the Russian Academy of Science and Ellis L. Yochelson of the U.S. Geological Survey and Smithsonian Institution. Horodyski's untimely death in 1995 brought an abrupt end to his extensive research within the park. After Horodyski's death, Fedonkin and

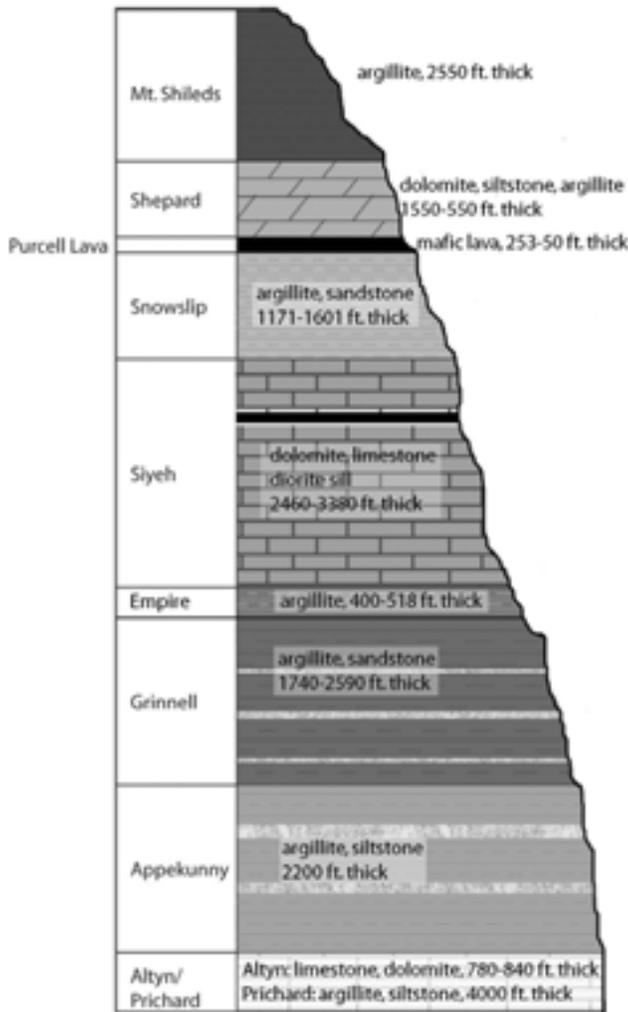


FIGURE 2. Stratigraphic column displaying the Precambrian Belt formations present in Glacier National Park, along with rock compositions and thickness.

Yochelson continued to work in the Appekunny Formation within the park. They have since published their findings on *Horodyskia moniliformis* (Yochelson and Fedonkin, 2000; Fedonkin and Yochelson, 2002), possibly one of the oldest known eucaryotes.

THE PRICHARD AND ALTYN FORMATIONS

The Prichard Formation, 1.375 to 1.4 Ga sandstone and siltstones, is only found on the western side of the park and is believed to be the age equivalent of the Altny Formation, found in the eastern portion of GLAC. This formation has been reported to contain microfossils and pseudomicrofossils (Horodyski, 1981). The microfossils found in the dark gray mudstones of the Prichard Formation are of interest due to the fact that they demonstrate the effects of burial metamorphism on organic-walled microfossils. The fossils, which consist of black carbonaceous films, are very rare and poorly preserved, with only 12 known thus far. Due to the extent of their altered state, these fossils cannot be identified to the genus level and are therefore not useful for biostratigraphic correlations. The pseudomicrofossils from the formation occur as spheroids and filaments and illustrate an occurrence of non-biogenic carbonaceous microstructures that could be mistaken as authentic fossils (Horodyski 1981, 1993a).

The Altny Formation, found in the eastern portion of Glacier National Park, is composed predominantly of 1.350 to 1.450 Ga limestones and dolomite. When the park was studied by paleontologists such as Charles Walcott around 1914, this formation was often referred to as

TABLE 1. Precambrian fossils and formations listed in chronological order (rather than stratigraphic placement) within Glacier National Park, Montana.

Geologic Period	Type of Formation/Location	Reported Fossils in Glacier
Precambrian, Mid-Proterozoic	Altny/Waterton Formations: dolomite, limestone, and arenite; Located in eastern portions of the park, Appekunny Falls.	Stromatolites, microfossils
	Prichard Formation: argillite, sandstone, limestone, breccia and arenite; Located in western portions of the park.	Microfossils
	Appekunny Formation: argillite, siltstone, arenite; Abundant outcrops throughout the park, Altny, Apikuni, Running Wolf and Otokomi Mountains.	Microfossils, Eucaryotes
	Grinnell Formation: argillite and sandstone; well exposed throughout the park, Mt. Henkel.	Stromatolites
	Empire Formation: argillite, siltstone and sandstone.	None
	Siyeh (Helena) Formation: dolomite, limestone, arenite; Going-to-the-Sun Road, Grinnell Glacier and Logan Pass.	Stromatolites, microfossils
	Snowslip Formation: argillite, sandstone, siltstone, and breccia; exposed at higher elevations, Swiftcurrent Glacier, Piegan Mountain and Highway 2 near the Walton Ranger Station.	Stromatolites, microfossils
	Purcell Lava: mafic lava flows, altered basalt.	None
	Shepard Formation: dolomite, siltstone, argillite, sandstone, and limestone; Boulder Pass, Akamina Pass, Grinnell Glacier, Reynolds Mountain.	Stromatolites

the "Newland Limestone," a formation known from the Big Belt and Little Belt Mountains. The Fentons noted a stratigraphic error made by Walcott in assigning *Weedia tuberosa* to the Altny Formation. They reassigned this genus to the Siyeh Formation and also identified *Beltina* cf. *danaii* in the park (Fenton and Fenton, 1931, 1937; Horodyski, 1985a, 1993b). However, this remains an important discovery in that it is one of the earliest published reports of fossils from the park.

One of the significant contributions to the park's paleontology in the 1930s was the description of a massive bed of stromatolites located near Apikuni Falls (also known as Appekunny Falls) in the upper Altny Limestone (Fenton and Fenton, 1931). These columnar stromatolites are located in a light gray to tan limestone that is some 6 m thick at the foot of Apikuni Mountain. They were named *Collenia columnaris* by Fenton and Fenton, with two other locations containing *C. columnaris* identified from within the park (Fig. 3; Fenton and Fenton, 1931, 1937; Horodyski, 1977). Another stromatolite group occurring above the *C. columnaris* zone was assigned to *Baicalia* by White (1970). Ross (1959) notes that the zones are well developed on both Apikuni ("Appekunny") and Divide Mountains, but poorly developed or absent in other areas,

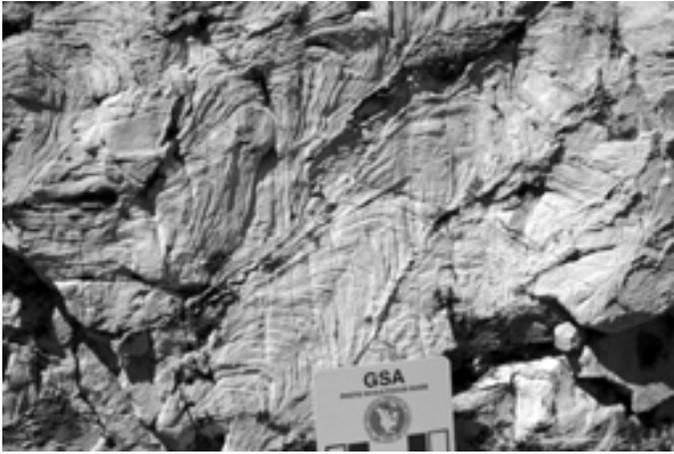


FIGURE 3. Altn Formation columnar stromatolites “*Collenia columnaris*” found near Apikuni Falls, Many Glacier, Glacier National Park, Montana.

making it a discontinuous zone in the Altn Formation. Horodyski (1976a) studied these stromatolites in great detail, describing three macrostructural varieties that occur in this horizon. In 1957, Rezak reassigned *Collenia columnaris* to *Collenia frequens* without explanation, assigning it as a “zone” due to its presence in two new locations (Ross and Rezak, 1959). Horodyski (1985a) took this a step further and referred to these stromatolites as “highly elongated, inclined stromatolites,” rather than referring to them by a genus name. However, Horodyski still referred to the group *Baicalia* interchangeably with “branching stromatolite” (Horodyski, 1985a).

Baicalia is a branching columnar stromatolite forming in subtidal areas, where *C. columnaris* is a highly elongated, unbranched, columnar stromatolite living in quiet waters below the tidal zone. These stromatolites are tightly packed next to one another and would have formed reef-like masses similar to those seen in the vicinity of the contemporary Bahamas.

During their time in the park Fenton and Fenton (1931, 1937) also identified three new species from the Altn Formation: *Newlandia sarcinula*, *Collenia albertensis* and *Morania antique*, although Rezak (1957) reassigns *Collenia albertensis* to *Collenia frequens*. White (1974a,b, 1979) also reports on an assemblage of microfossils that are comparable to modern blue-green algae and unicellular green algae from black chert found within the Altn Formation (Horodyski, 1993b). Unidentified circular trace fossils found in the 1960s from the Altn Formation are also still awaiting study (Fig. 4).

THE APPEKUNNY AND GRINNELL FORMATIONS

The Appekunny Formation is a 1.375 to 1.4 Ga mudstone, and is often referred to as the Appekunny argillite. This formation is the approximate temporal counterpart of the Grayson Shale in the Big Belt Mountains (Fedonkin and Yochelson, 2002) and can appear green in color, due to the large amount of chlorite minerals. Stromatolites were reported from the upper Appekunny Formation (Earhart et al., 1989), although no other reports have been made of stromatolites from the Appekunny argillite (Horodyski, 1985b). Authentic microfossils and pseudomicrofossils are also known from this formation, first reported by Horodyski (1981, 1993b) from dark gray to black fine-grained muddy sandstone, sandy mudstone and mudstones. The pseudomicrofossils appear to be organic envelopes and spiral impressions, while the authentic microfossils appear to be poorly preserved sphaeromorphs (Horodyski, 1993b). These sphaeromorphs are too poorly developed for general assignment, but are within the size range of prokaryotes (Fedonkin and Yochelson, 2002). Fedonkin et al. (1994) describe several types of sphaeromorphs, dubiofossils and pseudofossils from the Appekunny Formation. They conclude that some pseudofossils found



FIGURE 4. Trace fossil from Altn Formation (GLAC 5749; photograph by Casey Wollschlaeger). Scale = 7 cm.

in this formation could be the result of sedimentary processes that are unknown today. However, they note that several of the surfaces were once “alive” and merit further study.

In 1972, Horodyski discovered a fossil he referred to as “problematic bedding-plane markings, each resembling a string of flat beads” near Apikuni Mountain (formerly Appekunny Mountain; Fig. 5; Horodyski, 1982a, 1983a, 1985a, 1993a,b). The validity and taxonomy of these markings were questioned for years by Horodyski and others. Often referred to as dubiofossils, in 1991 they were interpreted for the first time, as fossils of a megascopic organism. Yochelson et al. (1993) interpreted the remains to be “metaphyte or metazoan body fossils and/or trace fossils, although evidence of their organic origin is still not conclusive.” After the death of Horodyski, Fedonkin and Yochelson (2002) continued to work on the “string-of-bead” fossils. Together they concluded that the remains belonged to a new type of eucaryote, which they named *Horodyskia moniliformis* (Fedonkin and Yochelson, 2002), in honor of the contributions of Horodyski to Precambrian paleontology. Similar fossils have also been recognized from rocks of comparable age in western Australia. Growth stages have been recognized for *Horodyskia* and its presence in an argillite signifies that it would have possessed a highly specialized mode of life. These fossil organisms are considerably older than other accepted multicellular organisms, making this a significant discovery.

The Precambrian Grinnell Formation is composed of an argillite, similar to the Appekunny Formation. The Grinnell argillite is rich in hematite, with occasional green banding due to the presence of chlorite. Fossils from this formation are rare, with only three areas documented

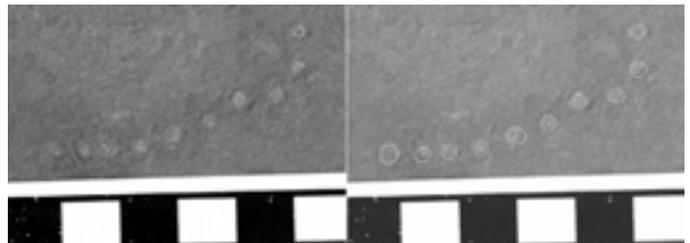


FIGURE 5. *Horodyskia moniliformis*, with “beads” traced to right (scale = 6 cm; photographs by Casey Wollschlaeger).

thus far. One occurrence of mound-shaped stromatolites was discovered in the summer of 1953 along Going-to-the-Sun Road in the St. Mary Valley (Fig. 6). These stromatolites were identified as *Collenia symmetrica*, *Cryptozoon occidentale* and *Collenia undosa* (Rezák, 1957). Mound-shaped stromatolites are also found in two locations on Mt. Henkel (Horodyski, 1983a, 1989). The scarcity of these fossils is most likely due to the high rate of deposition of terrigenous sediment that would have clouded the waters where these fossils attempted to survive. The algal components of stromatolites require clear waters in order to utilize photosynthesis. A high content of silt in the water would likely have halted this process.

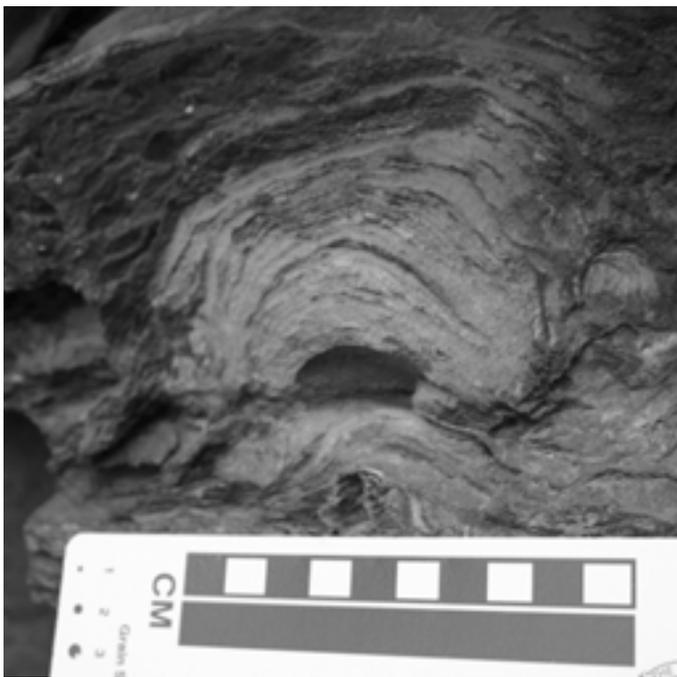


FIGURE 6. Small, mound-shaped stromatolite from the Grinnell Formation along Going-to-the-Sun Road.

THE HELENA (SIYEH) FORMATION

The Helena Formation (also known as the Siyeh Formation) is by far the best exposed formation in the park. This formation outcrops as one drives along the Going-to-the-Sun Road alongside the Garden Wall, up to the western flank of Going-to-the-Sun Mountain in the Saint Mary Valley and in several other locations within the park, particularly in Two Medicine and the Many Glacier areas. This 1.1 Ga limestone formation also contains numerous fossils. Seven species of stromatolites have been described from the formation, along with filamentous microfossils and puzzling “molar-tooth structures.”

Mound-, conical- and dome-shaped stromatolites are so abundant in the Helena (Siyeh) Formation that they are now often grouped in zones. These zones are typically somewhat continuous and have a general similar thickness. The Fentons worked extensively in the Helena (Siyeh) and first described four subdivisions and stromatolite zones within the park. Some of these zones are so persistent that they are often called bioherms (Fenton and Fenton, 1933). Some of these well exposed zones can be seen at the foot of Grinnell Glacier, along the trail leading to Granite Park chalet, and near Hole-in-the-Wall. Rezák (1957), and later with Ross (Ross and Rezák, 1959), redefine these into three zones. Afterward Horodyski (1985b, 1989) redefined the zones into cycles, specifically the *Jacutophyton* and *Baicalia-Conophyton* cycles. The *Baicalia-Conophyton* cycle is subdivided into six distinct units by Horodyski and composes 70% of the actual volume of stromatolites from within the Helena (Siyeh) Formation (Fig. 7). Horodyski con-

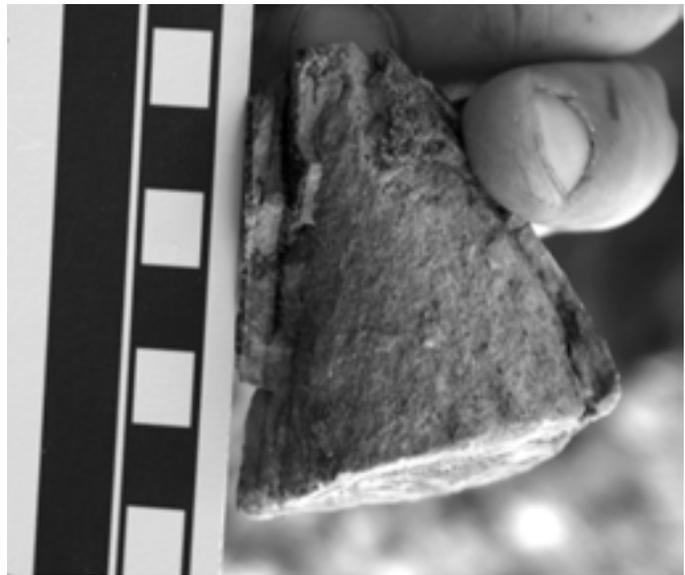


FIGURE 7. The conical stromatolite, *Conophyton*, from the Siyeh Formation, Glacier National Park. Scale=7 cm.

ducted thorough research on the Siyeh stromatolites, resulting in eight publications. Isolated stromatolite occurrences not associated with these cycles are also known from within the park.

Sedimentary structures, such as mud cracks, scour marks and load-casts are common in the Helena (Siyeh) Formation. Fenton and Fenton (1937) describe pelecypod burrows and trails near Dawson Pass. It is commonly believed that the remains described by Fenton and Fenton (1937) can be attributed to these non-organic remains. Microfossils have also been described from chert in the lower portions of the *Baicalia-Conophyton* cycles (Horodyski, 1985a).

The Helena (Siyeh) Formation also contains one of the strangest pseudofossils to be described from the park – the molar-tooth structure (Fig. 8). These irregular patterns were first described by Bauerman (1885) and are thought to resemble the grinding surface on the molar teeth of elephants. They have been considered to be organic in origin by several authors; an idea often contested. Daly hypothesized that these structures were the result of “secondary tectonic segregation” (Daly, 1912; O’Connor, 1972). Walcott (1914) described these structures as organic

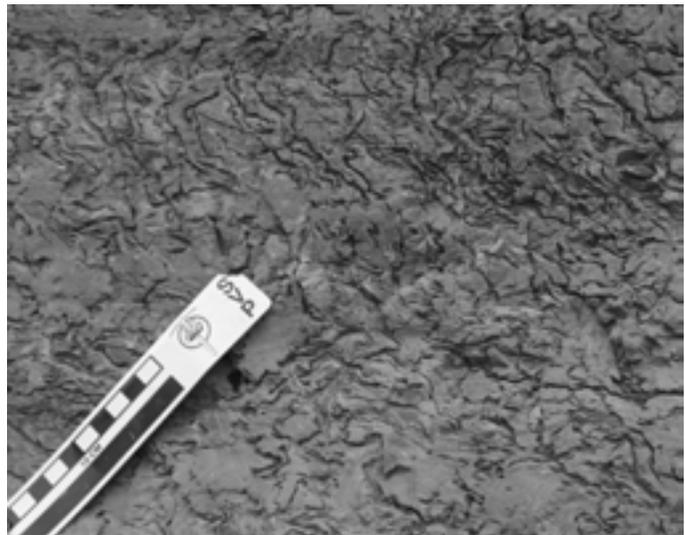


FIGURE 8. Molar tooth Structure, Siyeh Formation, Going-to-the-Sun Road, Glacier National Park. Scale = 10 cm.

remains, believing them to be algal, and named three types, *Greysonia*, *Copperia* and *Weedia*. Fenton and Fenton (1937) and Rezak (1957) concur with Daly's hypothesis, where O'Connor (1972) and Smith (1968) interpret them as having a syndepositional origin, as a direct result of algal activity (Horodyski, 1993b). However, Ross (1959) also attributed the structures to an organic source. Horodyski (1976b, 1983b, 1985a,b, 1989) interprets them as being produced as a result of calcite infill of open-space structures. Overall, the prevailing opinion regards these molar-tooth structures as inorganic remains.

THE SNOWSLIP AND SHEPARD FORMATION

In publications from the 1930s to 1976, the Snowslip and Shepard Formations are often grouped together and referred to as the Missoula Group. In 1977, the current formation names were proposed. The Snowslip Formation is exposed locally at high elevations within the park and forms the base of the Missoula Group. This one billion year old formation contains calcitic or dolomitic red and green argillites, siltstones and sandstones and represents a subtidal to intertidal setting with occasional subaerial exposure. Pseudocolumnar and mound-shaped stromatolites, or stromatoloids, are known from five locations, with filamentous and pillar-shaped microfossils detected from a stromatolite (or stromatoloid) in the lower part of the Snowslip Formation (Horodyski, 1977, 1983a, 1985a, 1993a,b). Rezak (1957) describes the stromatolites *Collenia undosa*, *Collenia symmetrica* and *Cryptozoon occidentale* from locations along Highway 2 on the southern border of the park (Fig. 9).

The Shepard Formation is highly eroded, existing only in higher



FIGURE 9. "*Collenia undosa*" from the Snowslip Formation near the along Highway 2, Glacier National Park. Scale = 10 cm.

elevations within the park. It is predominantly composed of dolomite, siltstones, argillite and quartzite and overlies the 1.5 to 1.845 Ga Purcell Lava (Aleinikoff et al., 1996). Fenton and Fenton (1931) report several species of stromatolites from the Shepard Formation: *Collenia parva*, *Collenia clappii* and *Collenia undosa*. They also describe "problematic structures" from the base of the Shepard, later known as "molar-tooth structures," also noted by Horodyski (Fenton and Fenton, 1931; Horodyski, 1985a). Mound-shaped stromatolites were also located in this formation by Horodyski (1982a) on Reynolds Mountain.

SUMMARY

The fossil remains of Glacier National Park comprise one of the richest accumulations of Precambrian life in the northwestern United States. While these fossils are often overlooked, the amount of knowledge that can still be gained from them is immense. Future explorations may include morphometric attributes, macrostructures and environmental conditions of the local stromatolites. Still lacking is a detailed correlation of the Belt Supergroup rocks present in the park with those found to the south, north and west. Microscopic study of the preserved sedimentary Belt rocks of GLAC, investigations of the erosion difference between *Conophyton* and *Baicalia* stromatolites and the origins of Altn circular trace fossils are all possible research topics to be addressed within the park. Overall GLAC holds a wealth of Middle Proterozoic, well preserved fossil remains from which researchers, park staff and visitors alike can learn much. The opportunity to learn more about the Precambrian fauna and environmental conditions offers a glimpse into a wider ecological and biological window of an immense time span on the North American continent.

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A PRELIMINARY INVENTORY OF FOSSIL FISH FROM NATIONAL PARK SERVICE UNITS

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Abstract—Fossilized fish remains are widespread throughout the continental United States. At this time 42 park units are identified to contain these remains, although this number will surely increase as further investigations are conducted. The stratigraphic record of these remains range from Silurian to Holocene ages and preserves both marine and freshwater forms. Large concentrations and varieties of these remains are found in Fossil Butte National Monument, Grand Canyon National Park, Death Valley National Park, Petrified Forest National Park, Santa Monica Mountains National Recreation Area and Big Bend National Park. The diversity, record and availability of these fish remains in national park units emphasizes future research needs while also informing both park staff and visitors of these important resources for stewardship and interpretation of the past.

INTRODUCTION

At least 180 units of the National Park Service (NPS) preserve paleontological resources. A number of these units preserve a wide array of fossil fish resources, possibly larger than ever thought before. A comprehensive look at the park service units containing the remains of fish has not been previously undertaken and currently 42 of 180 NPS units preserving fossils have been identified with fossil fish remains (Fig. 1). These parks contain fish remains spanning the Silurian to Holocene and tell of the ecological history that existed during these times. While parks such as Fossil Butte and Florissant Fossil Beds National Monuments are very well known for the fossilized fish remains, many other parks also contain a great diversity. The purpose of this report is to review the records of these fossil fish remains, identify their occurrence, distribution and scientific importance, report on new findings, inform park staff and highlight possible research opportunities.

PALEOZOIC FISH FOSSILS

The oldest known fish fossils from within an NPS unit are contained in the Silurian and Devonian rocks of Death Valley National Park, California and Delaware Water Gap National Recreation Area of Pennsylvania and New Jersey.

Death Valley National Park

A comprehensive survey of the paleontological resources of Death Valley National Park (DEVA) was completed by Nyborg and Santucci (1999). The Lippincott Member of the Hidden Valley Dolomite Formation (Silurian/Devonian) has produced the remains of *Panamintaspis snowi* and *Blieckaspis priscillae*, together with other agnathan fishes and a small arthrodire (placoderm; Elliot & Ilyes, 1993, 1996a, 1996b). The placoderm, *Dunkeleosteus terrelli*, a small cladodont shark and a cochliodont crushing tooth were also reported from within the Lost Burro Formation (Middle to Upper Devonian; Dunkle and Lane, 1971).

Delaware Water Gap National Recreation Area

The Late Silurian Bloomsburg Formation of the Delaware Water Gap National Recreation Area (DEWA) has been reported to contain the remains of the agnathan fish *Vernonaspis* and *Americaspis* (Epstein, 2001; Monteverde, 2001). Beerbower and Hait (1959) reported two fish localities near the recreation area that produced significant specimens of *Vernonaspis vaningeni* (Denison, 1964; Koch and Santucci, 2004). The Middle Devonian Mahantango Formation has been noted to contain a wide array of fossils within the park area, including plant impressions and carbonized fragments, four coral species, three bryozoan species,



FIGURE 1. Distribution of fossil fish in National Park Service areas: 1. John Day Fossil Beds, Oregon; 2. Hagerman Fossil Beds National Monument, Idaho; 3. Death Valley National Park, California; 4. Santa Monica Mountains National Recreation Area, California; 5. Point Reyes National Seashore, California; 6. Cabrillo National Monument, California; 7. Lake Mead National Recreation Area, Nevada and Arizona; 8. Glacier National Park, Montana; 9. Bighorn Canyon National Recreation Area, Montana and Wyoming; 10. Yellowstone National Park, Wyoming and Montana; 11. Grand Teton National Park, Wyoming; 12. Fossil Butte National Monument, Wyoming; 13. Dinosaur National Monument, Utah and Colorado; 14. Arches National Park, Utah; 15. Canyonlands National Park, Utah; 16. Capitol Reef National Park, Utah; 17. Glen Canyon National Recreation Area, Utah; 18. Bryce Canyon National Park, Utah; 19. Cedar Breaks National Monument, Utah; 20. Zion National Park, Utah; 21. Curecanti National Recreation Area, Colorado; 22. Florissant Fossil Beds National Monument, Colorado; 23. Mesa Verde National Park, Colorado; 24. Grand Canyon National Park, Arizona; 25. Parashant National Monument, Arizona; 26. Chaco Culture National Historical Park, New Mexico; 27. Petrified Forest National Park, Arizona; 28. Lake Meredith National Recreation Area, Texas; 29. Guadalupe Mountains National Park, Texas; 30. Big Bend National Park, Texas; 31. Theodore Roosevelt National Park, North Dakota; 32. Badlands National Park, South Dakota; 33. Tall Grass Prairie National Park, Kansas; 34. Buffalo National River, Arkansas; 35. Petersburg National Battlefield, Virginia; 36. Colonial National Historical Park, Virginia; 37. George Washington Birthplace National Monument, Virginia; 38. Manassas National Battlefield Park, Virginia; 39. Fort Washington Park, Maryland; 40. Piscataway Park, Maryland; 41. Delaware Water Gap National Recreation Area, New Jersey and Pennsylvania; 42. Gateway National Recreation Area, New Jersey and New York.

crinoid columnals and trace fossils (burrows, tracks and trails). While no fish remains have been discovered from this formation within the park, fish remains are known from this formation outside of the park, leading to the plausibility of similar fossils within the park (Parris and Albright, 1979a). Fish specimens have also been recovered from the Trimmers Rock Formation (Upper Devonian; Parris and Albright, 1979b).

Lake Mead National Recreation Area and Parashant National Monument

Paleozoic rocks are extensively exposed in northwestern Arizona. Lake Mead National Recreation Area (LAME) and Grand Canyon-Parashant National Monument (PARA) contain bony plates of freshwater fish, including *Bothriolepis*, along with “placogonoid” fish, which are recognized from the eastern facies of the Middle to Upper Devonian Temple Butte Formation (Beus, 1990). The remains of placoderm fish (both antiarchs and arthrodiros) have been discovered in the Devonian Mountain Springs Formation (Johnson, personal commun., 2003).

Grand Canyon National Park

Of the many geologic formations exposed in the Grand Canyon National Park (GRCA) area, three formations of Paleozoic age are known to contain fish remains. The Temple Butte (Late Devonian; Frasnian) and the Redwall (Late Mississippian; Chesterian) formations are reported to contain marine fish remains, such as bony plates. The Permian Kaibab Limestone is well known for its shark teeth, some of which have been assigned to *Cladodus* sp. and *Deltodus mercurii*. The remains of other chondrichthyans such as *Coolyella peculiaris*, *Cooperella striatula* and *Mooreyella typicalis*, along with phylloodont tooth plates are also reported (Hunt et al., 2005).

Bighorn Canyon National Recreation Area, Dinosaur National Monument and Buffalo National River (additional Mississippian fossil fish)

Parks containing additional Mississippian fish remains, other than Grand Canyon National Park, include Bighorn Canyon National Recreation Area (BICA), Dinosaur National Monument (DINO) and Buffalo National River (BUFF). Santucci et al. (1999) notes the presence of crushing teeth belonging to the cochlodont *Hybodus* in the Madison Limestone (Mississippian) of BICA, which sits on the Wyoming-Montana border. DINO, which lies on the border of Colorado and Utah, preserves fishes in the shales of the Upper Mississippian Doughnut Formation (Hansen et al., 1983; Scott et al., 2001). The Boone Formation (Mississippian) of northwestern Arkansas, is highly fossiliferous and occasionally preserves the remains of sharks’ teeth in outcrops along BUFF (Bitting, personal commun., 2001; Santucci et al., 2001).

Yellowstone National Park and Grand Teton National Park

While Yellowstone National Park (YELL) and Grand Teton National Park (GRTE) national parks are more often observed for their modern megafauna and scenic beauty, several fossiliferous units are exposed within these parks. The Mississippian Madison Group of YELL was reported to contain a cochlodont (primitive holocephalian chondrichthyes) along with a crushing tooth plate, while the Permian Phosphoria Formations is known to yield the shark *Helicoprion* in YELL and the possible dentical of a undetermined Paleozoic fishes in GRTE. Unidentified phosphatized fish remains are also known from the Permian Shedhorn Sandstone outcrops of YELL (Santucci, 1998; Tracy, 2003).

Tall Grass Prairie National Preserve

Tall Grass Prairie National Preserve (TAGR) was established in 1996 and contains 10,894 acres of land situated in the center of the Flint

Hills region of Kansas. Fossils have yet to be reported from the Pennsylvanian and Permian limestones that underlie the grasses. However, Mike Everhart collected a *Ctenacanthus* from the Grant Member of the Winfield Formation, 48 km to the northwest of the park (Lower Permian; Everhart, personal commun., 2006).

Guadalupe Mountains National Park

The Permian formations of Guadalupe Mountains National Park, Texas (GUMO) are renowned for the well-preserved Capitan Reef complex. The middle Permian submarine fan sandstones of the Brushy Canyon and Cherry Canyon Formations within the park contain hundreds of fish remains, including shark’s teeth, in small phosphatic nodules. The younger Lamar Limestone Member of the Bell Canyon Formation has also preserved the dentition of a holocephalan (Bell, personal commun., 2005).

MESOZOIC FOSSIL FISH

The Mesozoic formations hold the widest array of fossilized fish remains known in national park units. Much of this is due to the presence of the Cretaceous Western Interior Seaway in the middle of North America and to fluvial drainage during the Triassic and Jurassic (Heckert, personal commun., 2006).

Petrified Forest National Park

The fossils of Petrified Forest National Park (PEFO) are well known from the Chinle Formation (Upper Triassic). During this time, large fluvial systems were draining the area towards the western coast of Pangea. The Blue Mesa Member contains the chondrichthyes “*Xenacanthus*” *moorei*, *Lissodus humblei* and “*Acrodus*” sp., along with the osteichthyans *Arganodus dorotheae*, redfieldiid indet., Actinopterygii indet. and Paleoniscidae indet. aff. *Turseodus*. The Painted Desert Member preserves the chondrichthyan *Reticulodus synergus* and the osteichthyans *Arganodus dorotheae*, Redfieldiidae indet., Paleoniscidae indet. aff. *Turseodus* and Semionotidae indet. (Heckert, 2004, personal commun., 2006; Heckert et al., 2005; Irmis, 2005; Kirby, 1993; Murry, 1989; Murry and Kirby, 2002; Murry and Long, 1989).

Canyonlands National Park and Glen Canyon National Recreation Area (Chinle Formation)

The Chinle Formation is also exposed in Canyonlands National Park (CANY) and Glen Canyon National Recreation Area (GLCA). The Rocky Point Member of the Chinle Formation within GLCA contains unidentified fish remains, while in CANY, the remains of semionotid and redfieldiid fishes, along with lungfish burrows are reported (Santucci, 2000).

Manassas National Battlefield Park

On the opposite side of the United States, Manassas National Battlefield Park, Virginia (MANA), contains the remains of Triassic aged fish. The Culpeper Basin, one of the Newark Supergroup’s Triassic rift basins, which frames the eastern front of the Appalachian Mountains from Culpeper County, Virginia into Maryland, exposes the Triassic Groveton Member of the Bull Run Formation. This formation has produced disarticulated fishes, including scales and isolated bones (Gore, 1988; Garland, 1997; Kenworthy and Santucci, 2004).

Zion National Park

In Zion National Park (ZION), a large amount of semionotid and coelacanth remains are represented in the Whitmore Point Member of the lower Jurassic Moenave Formation (Hettangian). In the same member, to the southwest of ZION, *Ceratodus* n. sp., along with the *Chinlea*-like coelacanth, *Semionotus* n. sp. and a hybodont shark, *Lissodus* n. sp., have been discovered at the Saint George Dinosaur Discovery Site at

Johnson Farm in Saint George, Utah (Milner et al., 2005, in review). The holostean fish, *Semionotus kanabensis*, is also known from skeletal remains and scales within the Whitmore Point Member (Schaeffer and Dunkle, 1950; DeBlieux et al., 2004; Milner et al., in press) and in the Kayenta Formation (DeBlieux et al., 2004; Milner et al., in press).

Bighorn Canyon National Recreation Area, Yellowstone National Park and Grand Teton National Park (Cretaceous Mowry Shale)

The Cretaceous Mowry Shale (Cenomanian) is exposed in several parks and contains a wide array of remains. Santucci et al. (1999) note that Bighorn Canyon National Recreation Area (BICA) includes unidentified fish scales from the Mowry Shale, the Niobrara Shale Member and the Shale Member (equivalent to the Eagle Sandstone) of the Cody Shale (Richards, 1955; Santucci et al., 1999). The Mowry Shale is also present in Yellowstone National Park (YELL) and Grand Teton National Park (GRTE), along with the Frontier Sandstone (Cenomanian), which reportedly contains unidentified fish scales and teeth (Santucci, 1998).

Dinosaur National Monument, Currecanti National Recreation Area, Capitol Reef National Park and Cedar Breaks National Monument (Cretaceous Mancos Shale)

Similar to the Mowry Shale, the Upper Cretaceous Mancos Shale (middle to upper Turonian) is also present in several parks. Dinosaur National Monument contains shark teeth in this formation (Mowry Shale "member"; Hansen et al., 1983; Scott et al., 2001). According to Koch (personal commun., 2006), fish scales were also recently discovered in the Mancos Shale (Late Turonian) of Currecanti National Recreation Area (CURE). Both the Tununk Shale and Blue Gate members of the Mancos Shale in Capitol Reef National Park (CARE) are known to contain sharks teeth, while the Straight Cliffs Formation (Turonian) of Cedar Breaks National Monument (CEBR) is reported to contain unidentified fish remains (Santucci, 2000).

Bryce Canyon National Park

While no fish fossils have been reported from within Bryce Canyon National Park (BRCA) at this time, the Cretaceous Dakota Formation and Cretaceous Tropic Shale from outside of the park have yielded many different varieties. The Dakota Formation is known to contain sharks, rays and other fish, along with the last known North American lungfish (Kirkland, 1987; Eaton, personal commun., 1999; Santucci, 2000).

Glen Canyon National Recreation Area

Shark teeth and the extinct skate *Ptychodus* sp. have been recovered from within the upper Tropic Shale (Cenomanian/Turonian) outside of Glen Canyon National Recreation Area (GLCA; Santucci, 2000).

Mesa Verde National Park

The Cretaceous (late Campanian) Cliff House Formation within Mesa Verde National Park (MEVE) has been noted to contain shark teeth along with jaws, fins and isolated teeth from the teleost fish *Enchodus*. To the north of the park, the Mancos Shale has been reported to contain shark teeth in the Graneros Shale and Fairport Shale members (Scott et al., 2001).

Fort Washington Park

In Maryland, the Cretaceous (Campanian) Severn Formation of Fort Washington Park (FOWA) contains the fossil teeth from the mako shark *Isurus?* and the snaggletooth shark *Hemipristis serra*, along with other shark, ray and sawfish teeth, bones and otoliths, the calcareous concretions in the internal ear of some fish (Kenworthy and Santucci, 2004).

Glacier National Park

The Cretaceous (Campanian) Two Medicine Formation is known from the eastern border of Glacier National Park, Montana (GLAC), on the Blackfoot Indian Reservation, and contains the remains of fish scales, possibly lepisosteid fish scales. While this formation has yet to be mapped within the park, there is a high probability that it exists there and could yield similar fossils (Rice and Cobban, 1977; Whipple, 1992; Hunt, 2005a).

Cabrillo National Monument

Cabrillo National Monument, California, is known to contain a single tooth of the chondrichthyan *Squalicorax* sp. in the Cretaceous (Maastrichtian) Cabrillo Formation of the Rosario Group (Koch and Santucci, 2003).

Big Bend National Park

The Cretaceous units of Big Bend National Park, Texas (BIBE) have been known to yield abundant remains of fish. The Boquillas Formation (Turonian) is noted to contain the remains of fish bones and shark teeth (Maxwell et al., 1967). The remains of the giant teleost fish *Xiphactinus* and the ray *Ptychotrygon*, along with gar, are noted from the Campanian Pen Formation (Standhardt, 1986; Wick, personal commun., 2006). Sharks are well known from both the Pen and the Aguja Formation, with known species including *Lissodus selachos*, *Squalicorax kaupi*, *Cretorectolobus olsoni*, *Ischyrrhiza mira*, *Scapanorhynchus texanus*, *S. raphidon*, *Cretolamna appendiculata*, *Odontaspis*, *Anomotodon angustidens* and *Lamna appendiculata* (Fig. 2; Standhardt, 1986; Lehman, 1985). The sawfish *Ochopristis*, the rays *Squatirrhina americana*, *Myledaphus bipartitus*, *Ptychotrygon agujaensis*, along with the bowfin *Melivius thomasi* and the gars *Lepisosteus* and *Atractosteus* are also known from the Aguja Formation (Late Campanian/Early Maastrichtian; McNulty and Slaughter, 1972; Boreske, 1974; Davis, 1983; Lehman, 1985; Standhardt, 1986; Mosley, 1993; Wick, personal commun., 2006). The Javelina (Maastrichtian) and Black Peaks formations (Maastrichtian/Paleocene) are also contain a local abundance of gar scales and a contain the rays *Rhombodus* and *Dasyatis* (Hunt, 2005b; Schmidt, personal commun., 2006).

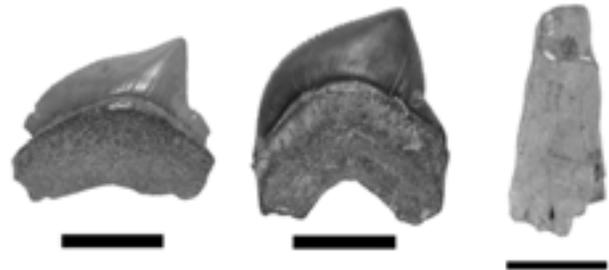


FIGURE 2. Shark teeth from the Aguja Formation: *Squalicorax kaupi*, (left: TTU-P11558; center: TTU-P11557) and *Ischyrrhiza mira* (right: TTU-P10992). All collected and photographed by Bill Mueller in 1977, repositied and used with permission from the Museum of Texas Tech University.

CENOZOIC FOSSIL FISH

At the end of the Mesozoic, the Cretaceous Western Interior Seaway began its final regression from the North American continent. Within the continent, Cenozoic fossil fish are limited to lacustrine and fluvial dwellers, while marine forms are limited to the formations deposited by the former extents of the Atlantic and Pacific Oceans.

Fort Washington Park and Piscataway Park

The Paleocene Aquia Formation of Fort Washington Park (FOWA) and neighboring Piscataway Park (PISC) in Maryland, has been known

to produce sharks teeth, assigned to the genus *Odontaspis*, according to a 1901 summary (Clark and Martin, 1901; Kenworthy and Santucci, 2004). The lower Piscataway Member of this same formation could be the setting for numerous ray teeth and crushing plates, identified as belonging to the cow nosed ray *Rhinoptera* sp. These fossils are accessioned into PISC museum collections (Kenworthy and Santucci, 2006).

Big Bend National Park

The Black Peaks Formations (Maastrichtian/Paleocene) of Big Bend National Park, Texas (BIBE) are locally abundant in gar scales and are known to contain the rays *Rhombodus* and *Dasyatis*. The Eocene Hannold Hill Formation also contains the ray *Myliobatis* and gar (Hunt, 2005b; Schmidt, personal commun., 2006).

Death Valley National Park

Death Valley National Park, California (DEVA) preserves the remains of the Eocene osteichthyan fishes *Fundulus* and *Cyprinodon*. These were collected by H. Donald Curry from the Titus Canyon Formation and first reported by R.R. Miller (1945). Curry also collected three type specimens of osteichthyan teleost fish from Titus Canyon: *Fundulus curryi*, *Fundulus euepis* and *Cyprinodon breviradius* (R.R. Miller, 1945; Nyborg and Santucci, 1999).

Fossil Butte National Monument

Fossil Butte National Monument, Wyoming (FOBU) was established to preserve spectacular geologic exposures and fossils of the Eocene Green River Formation in Fossil Basin. The Green River Formation is world renowned for the extraordinary abundance, diversity and preservation of fossils found in the lacustrine sediments of ancient Fossil Lake. These fossils include many invertebrates, reptiles, birds and plants in addition to a number of terrestrial reptiles, birds, mammals and plants, typical of a subtropical environment. However the formation is probably most famous for its abundant fossil fish. The Green River fish fauna (summarized here by Aase, personal commun., 2006) from Fossil Basin include 14 genera and 21 valid species: *Amia* and *Cyclurus* (bowfin), *Amhiplaga* (trout-perch), *Asineops* (pirate perch), "*Atracosteus*" and "*Lepisosteus*" (gar), *Crossopholis* (paddlefish), *Diplomystus* ("herring"/shad), *Knightia* (herring), *Eohiodon* (mooneye), *Esox* (pike), *Mioplosus* (perch), *Notogoneus* (sand fish), *Phareodous* ("arawana") and *Priscacara* (superficially resembles sunfish, but is not related). Freshwater stingrays (*Asterotrygon* and *Heliobatis*) are also spectacularly preserved. Many of these fish are found in sometimes unusual taphonomic conditions such as immense mass death layers or aspirations, where one fish chokes and dies while eating another fish.

Knightia eocaena is by far the most abundant and may in fact be the most common articulated vertebrate fossil in the world. Its abundance in Fossil Basin led to the declaration of *Knightia eocaena* as the Wyoming official state fossil. FOBU is the only NPS unit established to steward primarily fish fossils. However, the park preserves less than 2% of the former area covered by Fossil Lake and as such the diversity of fish found within park boundaries is considerably smaller than the fauna found outside the park. Fish species found within the park are limited to *Knightia eocaena* (most common), *K. alta*, *Diplomystus dentatus*, *Mioplosus labracoides*, *Phareodus encaustus*, *P. testis*, *Priscacara liops* and *P. serrata* (Aase, personal commun., 2006).

Information on the fish of Fossil Basin, which have been scientifically studied since the 1870s (E.D. Cope), can be found in numerous scientific publications including the first comprehensive review (Grande, 1984, and references therein) and other papers such as McGrew and Casilliano (1974), Grande (1982a,b) and Loewen and Buchheim (1998). Dr. Lance Grande of Chicago's Field Museum has studied the fish of Fossil Basin for nearly three decades.

The park has a unique visitor accessible interpretive quarry where fossil fish can be excavated, with assistance from park staff and collected

scientifically for use in the park's museum or study collections (no fish are removed from the park). A large number of commercial quarries are found outside of the park in Fossil Basin. Cooperative efforts between the park and local quarriers seek to raise scientific awareness of the incredible fish fossils excavated in Fossil Basin.

Florissant Fossil Beds National Monument

The most abundant fish fossils known from Colorado are from Florissant Fossil Beds National Monument (FLFO), which includes varieties of bowfin, catfish, pirate perch and sucker. These fish were preserved in the Oligocene Florissant Formation and described originally by E.D. Cope during the 1870s. The most primitive of the fish known from the park belongs to the bowfin, *Amia scutata*. The catfish are known from only two incomplete specimens, both assigned to *Ictalurus pectinatus*. The suckers represent a poorly studied and larger, more diverse group, containing three species: *Amyzon commune*, *A. fusiforme* and *A. pandatum*. The pirate perches are represented by one species, *Trichophanes foliarum* (Meyer, 2003).

Glacier National Park

Glacier National Park, Montana (GLAC) has limited exposures of the Coal Creek Member of the Late Paleogene Kishenehn Formation, which is reported to contain the fossil remains of amiiiforms and a variety of teleost fishes (Constenius et al., 1989).

Badlands National Park

The Oligocene Brule Formation (White River Group) of Badlands National Park, South Dakota (BADL), contains catfish and sunfish remains (Benton, personal commun., 2006; Foss, personal commun., 2006).

George Washington Birthplace National Monument

Within the George Washington Birthplace National Monument, Virginia (GEWA) the Miocene Calvert Formation is exposed. This formation is very well known in the eastern United States for its marine fossils and has produced abundant shark teeth of *Hemipristis serra*, *Oxyrhina desorii* and *Otodus obliquus* from within the monument (Fig. 3; McLennan, 1971; Morawe, personal commun., 1999). Additionally, teeth from sand, mako, silky and white sharks have been recovered from the beaches of GEWA (Morawe, personal commun., 1999, 2003). Excavations of marine mammals from within the Calvert Formation in the park has resulted in the recovery of shark teeth belonging to the tiger



FIGURE 3. *Hemipristis serra* (left) and *Isurus hastalis* (right) from the Calvert Formation of George Washington Birthplace National Monument (Photo by Rijk Morawe).

shark *Galeocerdo contortus*, the white shark *Carcharodon* and the snaggletooth shark *Hemipristis* (Bohaska, unpubl., 1989; Kenworthy and Santucci, 2003). Interestingly, some of the shark's teeth have been found in direct association with archeological sites, suggesting their use as "scrapers" (Morawe, personal commun., 2005; Kenworthy and Santucci, this volume).

Santa Monica Mountains National Recreation Area

A large amount of the fossil resources preserved within California's Santa Monica Mountains National Recreation Area (SAMO) are those of fish. The middle Miocene Calabasas (and/or Upper Topanga Formation?) contains fish scales, while the middle to Late Miocene Modelo Formation (and/or Monterey Formation?) contains shark's teeth and several well-preserved fish (Fig. 4; Hoots, 1930; David, 1943; Yerkes and Campbell, 1979). These include fish scales and skeletons, often representing mass death assemblages, with seven genera of chondrichthyans and 41 genera of osteichthyans known from these Miocene units. The Pliocene Repetto, Pico and Fernando formations contain shark teeth (Koch et al., 2004).

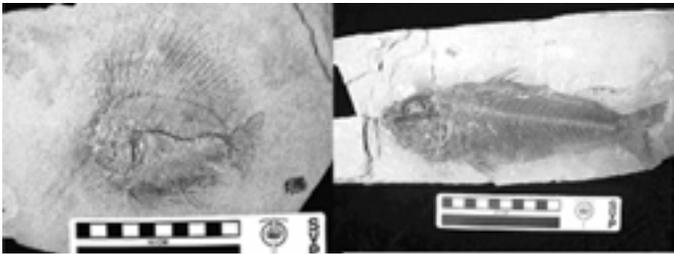


FIGURE 4. *Chalcidichthys malacopterygius* (left; LACM (CIT) 317/10228 Holotype) and *Scorpaena ensiger* (right; LACM (CIT) 317/10226 Figured). Photos by Alison Koch.

Lake Meredith National Recreation Area

Lake Meredith National Recreation Area, Texas (LAMR) has outcrops of the Ogallala Formation (Miocene-Pliocene, dating from approximately 5-12 Ma), which are reported to contain the remains of fish (Phillips, unpubl. report to LAMR, 2000; Hunt and Santucci, 2001). Similar remains may be found in the same formation at nearby Alibates Flint Quarry National Monument, Texas.

Hagerman Fossil Beds National Monument

The Glens Ferry Formation (Pliocene) of Hagerman Fossil Beds National Monument, Idaho (HAFO) contains seven fish species, five of which are now extinct (Malde, 1972). These include the teleosts, *Mylopharodon hagermanensis*, *Sigmopharyngodon idahoensis* and

Ptychochilus oregonensis, the catfish *Ameiurus vespertinus* and the sunfish, *Archoplites taylori* (Uyeno, 1961; Miller and Smith, 1967; Smith et al., 1982). A nearly complete skull of the catfish, *Ameiurus vespertinus* was recovered in 2001 from the wall of the Smithsonian Horse Quarry (Gensler, 2002).

Colonial National Historical Park

The Pliocene Yorktown Formation of the Colonial National Historical Park (COLO) yields the remains of shark teeth and fish vertebrae (Johnson, 1972). Burns (1991) listed the sharks found locally as *Isurus hastalis*, the sand tiger shark *Eugomphodus* sp., the cow shark *Notorhynchus primigenius*, the tiger shark *Galeocerdo aduncus* and the gray shark *Carcharinus egertoni*. Teleost fish bones are largely unidentified, although a dental plate belonging to the parrot fish *Diodon* is reported. Rays are also known from unidentified dermal and dental plates (Burns, 1991).

Petersburg National Battlefield

Two undiagnosed shark teeth were also discovered in the lower Yorktown Formation of Petersburg National Battlefield in a core sample (Pranger, unpubl. report to PETE, 2000).

Point Reyes National Seashore

During a 1993 excavation in the Drake Bay Formation (Pliocene) of Point Reyes National Seashore, California (PORE) fish vertebrae, possibly belonging to a giant salmon and sharks teeth were found associated with the remains of a whale skeleton (Galloway, 1977).

Gateway National Recreation Area

Gateway National Recreation Area (GATE), situated on the New York-New Jersey border, contains exposures of the Gardiner's Clay (Pleistocene), noted to hold the remains of fish vertebrae and teeth (Stoffer, 1996; Kenworthy and Santucci, 2003).

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A PRELIMINARY INVENTORY OF NATIONAL PARK SERVICE PALEONTOLOGICAL RESOURCES IN CULTURAL RESOURCE CONTEXTS, PART 1: GENERAL OVERVIEW

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Abstract—At least 180 National Park Service areas preserve paleontological resources. While most of these fossils are found *in situ*, some are “exposed” in cultural resource contexts. This paper serves as the first in a series that, together, will form a preliminary inventory of National Park Service fossils found in cultural resource contexts. These contexts include archeological resources, ethnographic stories and legends, prehistoric and historic structures and other documented historical occurrences. Fossils are found as tools, jewelry or other spiritual items in National Park Service archeological sites. Ethnographic stories and legends told by American Indians and “mountain men” of the American West also incorporate fossils found within areas now administered by the National Park Service. Many building stones found in prehistoric and historic structures of the National Park Service display fossils including body fossils, trace fossils and petrified wood. In addition, various archives, journals, memoirs and photographs include numerous other historical accounts of fossils in areas of the National Park Service. This paper introduces the concept for an inventory of such occurrences, highlights a few examples and aims to encourage park staff and researchers to view paleontological resources with regards to the cultural resource contexts where they may occur.

INTRODUCTION

Inventory efforts throughout the National Park Service (NPS) currently identify at least 180 NPS areas known to preserve paleontological resources. Increased awareness of paleontological resources has broadened awareness of the contexts in which those resources are found. Most NPS fossils are found *in situ* in the exposed bedrock of a park. However, fossils found in some parks are not found *in situ*, but “exposed” in a variety of cultural resource contexts. Fossils, or references to them, are found in archeological sites, ethnographic stories and legends, prehistoric and historic structures and other documented historic occurrences.

This paper, as a general overview, is the first in a series that will form a preliminary inventory of such paleontological resources found in cultural resource contexts throughout the NPS. This effort is very much a work in progress. With this paper we aim to summarize the various cultural resource contexts that include fossils, highlight a small cross section of known examples and promote interest and awareness of such occurrences. Future papers will delve deeper into the subject and present additional examples. We encourage paleontologists, archeologists, historians and other park personnel to see how the stories told in their park’s paleontology, archeology and history intertwine. As awareness of paleontological resources grows throughout the NPS, and other land management agencies, so too will an appreciation for those fossils found in cultural resource contexts.

CULTURAL RESOURCE CATEGORIES

As outlined in the 2001 NPS Management Policies, cultural resources in the National Park Service are broadly categorized as: archeological resources, cultural landscapes, ethnographic resources, historic and prehistoric structures and museum collections. Fossils are found in all of these cultural resource categories, however, not all are applicable to the current discussion. For instance, cultural landscapes include primarily large-scale physical attributes, biotic systems and viewsheds. As such, they are not typically relevant to discussions on paleontological resources. Also, while many parks have paleontological specimens in their museum collections, a separate discussion on them is generally beyond the scope of this inventory. In addition to archeological resources, ethnographic resources and prehistoric and historic structures, we will

also consider other historically significant occurrences of fossils within NPS areas. Such occurrences are found in historical archives or other documents such as journals, memoirs or photographs.

ARCHEOLOGICAL RESOURCES

As defined by the NPS Archeology Program, archeological resources are any physical evidences of past human activity at least 100 years old. This includes artifacts such as tools, pottery, jewelry or spiritual objects. Human interest in paleontological resources is not a recent phenomenon. Many American Indians utilized fossils as tools or incorporated them into spiritual objects or jewelry. Examples date back a few hundred to thousands of years. Several NPS areas preserve such resources, including those below.

Petrified Forest National Park, Arizona (PEFO)

In a “textbook” example of a paleontological resource recognized as a cultural resource, archeologists at Petrified Forest National Park uncovered projectile points (arrowheads) fashioned from the park’s namesake Triassic petrified wood (primarily *Araucarioxylon arizonicum*) (Fig. 1). Mayor (2005, p. 159) reported that John Wesley Powell visited what

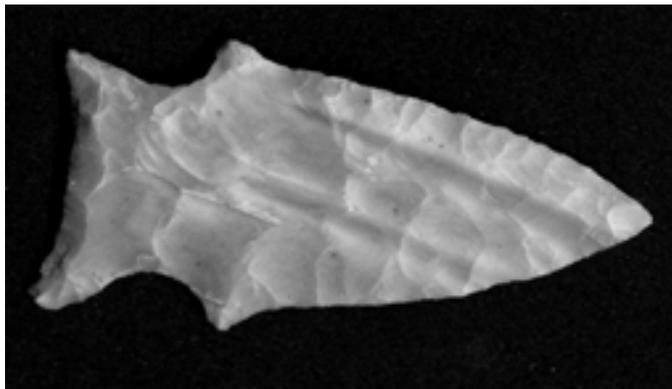


FIGURE 1. Petrified wood shaped into a projectile point, Petrified Forest National Park, Arizona. Size of projectile: 5.75 cm x 3.2 cm. NPS Photo/T. Scott Williams.

is now PEFO in the late 19th century and observed American Indians chipping arrowheads and axes from the petrified wood.

George Washington Birthplace National Monument, Virginia (GEWA)

Fossil sharks teeth, typical of the Miocene Calvert Formation, have been found within the park in direct association with shell middens dating back to the Late Archaic (5,000-3,200 years before present, ybp), Middle Woodland (2,500-1,100 ybp) and Late Woodland (1,100-400 ybp) periods. The serrated sharks teeth (one tentatively identified as a snaggletooth shark) are up to about one inch in length and are still quite sharp. Their association with the shell middens is thought to suggest their use as “scrapers” for removing meat from the bivalves, although there is not yet definitive evidence of this practice. (R. Morawe, personal commun., 2003, 2005).

Grand Canyon National Park, Arizona (GRCA)

The many rock shelters, alcoves and caves within Grand Canyon National Park contain exceptionally well-preserved archeological resources. Occasionally these archeological resources are associated with much older paleontological resources. For example, some cairns include packrat middens, probably of Late Pleistocene age (Emslie et al., 1987; Santucci et al., 2001). A number of the well-known split-twig figurines found within the park have dung pellets (potentially from the bighorn sheep, *Ovis canadensis*) wrapped inside of them (Emslie et al., 1987, 1995). Apparently, some GRCA caves with abundant paleontological resources seemed to attract prehistoric peoples. In turn, these peoples left offerings of split twig figures and grass bundles (Mayor 2005, p. 163 referencing Paul Martin).

Hopewell Culture National Historical Park, Ohio (HOCU)

Sharks teeth and other fossils discovered in the mortuary offerings of American Indians in Ohio, date back approximately 2000 years (M. Lynott, personal commun., 2005). Museum collections at HOCU include 13 shark teeth that, according to their catalog description, may have originally been part of a necklace (J. Pederson, personal commun., 2005). Further investigation may identify the age of the sharks teeth and their original source, as well as their connection to the Hopewell Indians.

ETHNOGRAPHIC STORIES AND LEGENDS

According to current NPS Management Policies (2001), a park’s ethnographic resources are the cultural and natural features of a park that are of traditional significance to traditionally associated peoples. In the context of this paper, we are interested in those stories and legends that mention paleontological resources associated with NPS areas. While paleontologists generally focus on the scientific significance of specimens, ethnographic stories and legends, primarily told by American Indians, offer a unique perspective into the traditional cultural or spiritual significance of fossils. Such cultural or spiritual significance can be above and beyond any associated scientific significance. Adrienne Mayor’s (2005) recently published book describes many such stories and legends throughout the country. A number of these legends are tied either directly or indirectly with fossils found in NPS areas, especially in the Great Plains and Southwest. In addition to the stories of the American Indians, the “mountain men” of the American West also told stories of fantastic landscapes and natural features before the subsequent scientific surveys of the West in the late 1800s. Their frequently colorful descriptions occasionally mention fossils, including some found within NPS areas. Ethnographic stories and legends present exceptional interpretive opportunities as they illustrate direct human connections with paleontological resources. Below is a sample of ethnographic stories and legends connected with NPS paleontological resources

Big Bend National Park, Texas (BIBE)

The largest known flying creature was the pterosaur *Quetzalcoatlus northropi*, with an estimated 11 meter wingspan. *Quetzalcoatlus* was originally described from a specimen discovered in BIBE (Lawson, 1975). The pterosaur is named after the Aztec Feathered Serpent god Quetzalcoatl. Similar fossils have been found in the traditional Aztec homeland in northern Mexico and the southwest United States. The bones of this giant pterosaur may have influenced the image of mythic figures such as Quetzalcoatl although there is currently no definitive evidence of such a connection (Mayor, 2005).

Agate Fossil Beds National Monument, Nebraska (AGFO)

Agate Fossil Beds National Monument was originally authorized in 1965 to preserve the abundant and diverse fossils found primarily in the Miocene Marsland and Harrison formations (Kiver and Harris, 1999). The Miocene mammalian fossils from the monument include bones of *Menoceras* (rhinoceros), *Moropus* (chalicothere), *Daphoenodon* (beardog), *Dinohyus* (pig-like scavenger) and *Stenomylus* (gazelle-like ungulate) among many other genera (National Park Service, 1980). Paleontologists recognized the significance of the site in the early 1900s and collected hundreds of specimens from localities known as Carnegie and University Hills (National Park Service, 1980). The Lakota Sioux, however, know those localities as A’bekiya Wama’kaskan s’e (“Animal Bones Brutally Scattered About”) (Mayor, 2005). As reported by Mayor (2005) these bones found at Agate Springs were considered “bad medicine” originating from the malevolent Unktehi monsters. Conversely, the fossils of the beaver *Paleocastor* and its distinctive spiral burrow, *Daemonelix*, were thought to protect people from the “evil” fossils. According to the Lakota legend, the beaver volunteered to sacrifice themselves, becoming stone to offset the “bad medicine” of the Unktehi bones (Mayor, 2005). A traditional buffalo hide wintercount calendar is on display in the park’s Visitor Center and includes a number of paleontology-related pictographs. The wintercount was created in 1997 by a Lakota artist working with park staff and is a modern attempt to link the fossil resources and American Indian cultural resource collection of AGFO through a traditional Indian method of recording history (M. Hertig, personal commun., 2006).

Yellowstone National Park, Wyoming, Idaho, Montana (YELL)

Jim Bridger is one of the better known and colorful mountain men. Although his “tall tales”, particularly of the area that would become Yellowstone National Park, were embellished over the years, they are generally based in genuine observations. Haines (1974) recounts a mid-late 1800s exchange (originally published in Miles, 1897, p. 137) between General Nelson A. Miles and Jim Bridger. Miles tells Bridger of the “great trees with limbs and bark all turned to stone” he saw when visiting what would become Petrified Forest National Park. Bridger responded “O, that’s peetrification. Come with me to Yellowstone next summer, and I’ll show you peetrified trees a-growing, with peetrified birds on ‘em a-signing peetrified songs”. According to Haines (1974), Bridger’s story may be a rehashing of a story told by fellow mountain man Moses “Black” Harris in 1823. Nevertheless, the petrified forests of Yellowstone National Park include numerous upright *in situ* trees as well as 27 successive layers of fossil forests as summarized by Santucci (1998). The volcaniclastic sediments of the early-middle Eocene Sepulcher and Lamar River Formations of the Absaroka Volcanic Supergroup (Smedes and Protska, 1972) preserve these exceptional paleontological resources.

PREHISTORIC AND HISTORIC STRUCTURES

Throughout the National Park Service are literally tens of thou-

sands of prehistoric and historic structures including American Indian dwellings and structures, visitor centers, lodges, houses, schools, churches, courthouses, stores, factories and mills, monuments and memorials, tunnels and roads, dams, bridges, military facilities and innumerable out-buildings and other structures. Many of these structures are constructed, faced or ornamented with natural stone either found locally or imported from other parts of the country or world. Paleontological resources are found in some of these limestones, sandstones, or shales, creating unique occurrences of fossils in at least 19 NPS areas. Six examples of fossils in association with NPS structures are described below. Prehistoric and historic structures therefore are the most common cultural resource to display fossils, and likely the most visible to visitors.

Fossil occurrences in these structures may be a result of happenstance (e.g., suitable local material happened to be fossiliferous) or by design (e.g., a particular fossiliferous stone was desired). Fossils in prehistoric and historic structures include body fossils, petrified wood and trace fossils as summarized below. Body fossils represent actual physical morphological elements of the organism such as shells, bones, teeth and leaves or molds/casts of such parts. For example, limestones, which can be almost entirely composed of body fossils or fragments of marine organisms, are commonly used as building stones. Petrified wood is particularly well suited as a “building stone” due to its aesthetic properties and durability and is highlighted here. Trace fossils, such as burrows, tracks/trackways or coprolites, represent evidence of an organism’s activity without preserving any part of the actual organism.

BODY FOSSILS

Lincoln Memorial and Capitol Reflecting Pool, Washington, D.C. (NAMA)

Located at opposite ends of the National Mall, both the Lincoln Memorial (interior walls and columns) and Capitol Reflecting Pool (border stones and steps) were constructed with the extraordinarily fossiliferous Mississippian Salem Limestone. This rock is commonly referred to by the trade name Indiana Limestone. Indiana Limestone is an extensively quarried building stone (Patton and Carr, 1982) utilized in numerous buildings across the United States including the Pentagon, the Department of the Interior building and dozens of other federal buildings in Washington, D.C. The Empire State Building in New York City is also constructed with Indiana Limestone. Nearly 190 species have been identified in the Salem Limestone of Indiana including: foraminifera, sponges, coral, bryozoans, brachiopods, bivalves, gastropods, cephalopods, ostracods, crinoids and fish, all indicative of a shallow water environment (Cumings et al., 1906). At the Lincoln Memorial and the Capitol Reflecting Pool, fragmented corals, crinoid columnals, bryozoan fronds and mollusk shells are easily visible. At the Capitol Reflecting Pool, the surrounding limestone matrix weathers away more rapidly than the fossils, creating a unique surface relief where the fossils appear to be coming out of the rock (Fig. 2).

Castillo de San Marcos National Monument, Florida (CASA)

The walls of Castillo de San Marcos, completed in 1695, were constructed of coquina from the Pleistocene Anastasia Formation (Schroeder and Klein, 1954). The coquina was quarried on Anastasia Island, now part of Anastasia State Park. The park actively interprets the coquina quarries (Florida State Parks, 2006). The clam *Donax variabilis* is the primary shell of the CASA coquina. The coquina was relatively soft and easy to quarry, and was found to absorb the impact of cannon balls with minimal damage to the walls of the fortification (Florida State Parks, 2006). Coquina (Spanish for “tiny shell”), is geologically defined as “any detrital limestone composed of weakly to moderately cemented broken and abraded shell fragments” (Bates and Jackson, 1984). Interestingly, this general geologic definition of the word coquina originated from the Donacidae family of clams (which includes *D. variabilis*),

which are commonly called coquinas. Therefore, the building stones of CASA are literally the archetypal coquina.

TRACE FOSSILS

Gettysburg National Military Park, Pennsylvania (GETT)

Building stones quarried from the Late Triassic–Early Jurassic Gettysburg Formation at the Trostle Quarry (York Springs, Pa. 24 km northeast of GETT) were utilized in the construction of bridges within GETT during the mid 1930s. Fossils are not common within the Gettysburg Formation; however vertebrate trackways, including those of dinosaurs, are known from the formation as first reported by Wanner (1889). Two well-preserved dinosaur tracks are visible in the parapets of one such bridge within the park. These tracks have been identified as *Atreipus milfordensis* and *Anchisauripus sp.* (Santucci and Hunt, 1995; J. Jones, personal commun., 2006; A. Hunt, personal commun., 2006). In 1937, more than 50 additional track-bearing slabs were recovered from the Trostle Quarry (Cleaves 1937). While many of these tracks were interpreted by the park and distributed to various museums by park administration, it is unclear who (aside from the original stone masons) first noticed the tracks in the park’s bridge (W. Peterson, personal commun., 2006).

Valley Forge National Historical Park, Pennsylvania (VAFO)

The early Cambrian Chickies Quartzite is the “type formation” for the ubiquitous worm burrow trace fossil *Skolithos* (Wise, 1960; Alpert, 1974). Exposures of the Chickies Quartzite within VAFO are known to display abundant *Skolithos* burrows (Wiswall, 1993). The Chickies Quartzite was used in the façade of the lower visitor center restroom building. Blocks displaying both vertical and horizontal cross sections of *Skolithos* burrows are visible (M. Carfioli, personal commun., 2005).

PETRIFIED WOOD

Petrified Forest National Park, Arizona (PEFO)

The Painted Desert’s exceptional abundance and preservation of petrified wood (primarily *Araucarioxylon arizonicum*) from the Late Triassic Chinle Formation led to the creation of Petrified Forest National Monument (now a national park) in 1906. Petrified wood was utilized in the construction of two structures within the park, the Painted Desert Inn and the Agate House Pueblo.

The Painted Desert Inn was originally constructed in 1924 as the Stone Tree House, referring to the extensive amount of local petrified wood used in its construction. Much of this petrified wood is now concealed under a stucco finish. The Civilian Conservation Corps (CCC) applied the stucco during remodeling of the structure to pueblo revival



FIGURE 2. Capitol Reflecting Pool, Washington, D.C. **A.** Overview, showing fossiliferous Mississippian Salem Limestone blocks. **B.** Close up, showing fossil detail and crinoid columnals (width of photo approximately 4 cm). NPS Photo.



FIGURE 3. Agate House, constructed of petrified wood (primarily *Araucarioxylon arizonicum*), Petrified Forest National Park, Arizona. NPS Photo.

style, following the 1936 NPS acquisition of the inn (Livingston, 1992).

The Agate House Pueblo is a much older structure dating back to the Pueblo II-III period (approximately 900-1200 AD). Petrified wood was used almost exclusively for the construction of Agate House, and apparently a few other prehistoric pueblos within the park as well (Reed, 1940). The CCC partially reconstructed Agate House to its present appearance in 1934 (Fig. 3).

Washington Monument Commemorative Stones, Washington, D.C. (WAMO)

Petrified wood obtained in the Chalcedony Forest outside of Petrified Forest National Park was incorporated into the Washington Monument as the Arizona Stone in 1924. This striking stone (Fig. 4) consists of nearly 6,000 pounds of an *Araucarioxylon arizonicum* log, cut into three sections (National Park Service, 2003). The state's name is engraved across the logs and painted with gold leaf. Apparently a copy of



FIGURE 4. Petrified wood (*Araucarioxylon arizonicum*) in the Arizona Stone, Washington Monument, Washington, D.C. NPS Photo.

F. H. Knowlton's (1889) publication on the petrified wood of Arizona and a photograph of petrified trees near Holbrook are also incorporated into the state stone (Author unknown 1924). At least a half dozen of WAMO's commemorative stones display fossils (Kenworthy and Santucci 2004), although the Arizona Stone is the most dramatic of the fossiliferous stones. National Park Service (2003) and Jacob (2005) summarize all 193 commemorative stones, from every state, many countries and dozens of organizations, within the monument.

HISTORICAL OCCURRENCES

A rich history of paleontological resource research and collection dating back to the early or middle 1800s and 1900s exists in many NPS areas. Many of the specimens collected during those research efforts

represent extraordinarily significant finds. In this section, however, we look beyond those well-documented examples and share just a few of the perhaps more obscure historic occurrences of fossils, or references to them, in NPS areas. There are undoubtedly numerous others, and we certainly welcome any additions or comments. Some specimens mentioned below are themselves historically significant. In other cases, a specimen's significance is derived more from the who, when, where or why they were collected rather than what was collected.

Colonial National Historical Park, Virginia (COLO)

While many parks have a record of fossil collection that extends back even as far as the early 1800s, the area surrounding what is now Colonial National Historical Park has been the site of fossil collecting for nearly 320 years! Ward and Blackwelder (1975) tell the fascinating story behind the first described and figured fossil from America (Fig. 5), found in Martin Lister's 1687 *Historiae Conchyliorum, Liber III* ("History of the Mollusks, Volume 3"). Lister did not name the scallop-like shell in his description. Unfortunately, as he did not actually collect the specimen, he misinterpreted the collecting locality as the Virgin Islands, rather than Virginia. Thomas Say (1824) recognized that the fossil described by Lister came from the Atlantic Coastal Plain rather than the Virgin Islands. No fossil or living pectinids are known from the Virgin Islands according to Ward and Blackwelder (1975). Say (1824) subsequently named the species *Pecten jeffersonius*, (renamed *Chesapecten jeffersonius*, Ward and Blackwelder, 1975). Like Lister though, Say misinterpreted the original collecting locality, identifying the fossil as coming from Miocene deposits in Maryland. Based on many subsequent collections that include *Chesapecten jeffersonius* near Yorktown, Virginia, the Pliocene Yorktown Formation appears to be the likely source of Lister's original

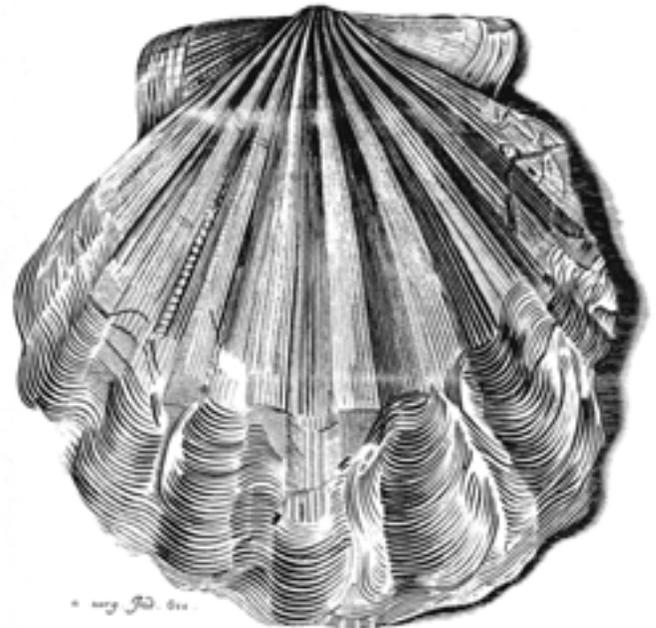


FIGURE 5. Copy of Martin Lister's 1687 figure of *Chesapecten jeffersonius*, the first figured and described fossil from North America, likely collected near Colonial National Historical Park, Virginia. Ward and Blackwelder (1975, pl. 1).

material (Ward and Blackwelder, 1975). The Yorktown Formation is famous for its extraordinary fossil diversity and many fossils have been found within COLO (Ward and Blackwelder, 1980). While the exact collection locality of Lister's specimen is not known, it is likely near, perhaps even within, the current boundaries of COLO (G. Johnson and L. Ward, personal commun., 2003). The Virginia General Assembly, rec-

ognizing the historical significance and abundance of the fossil, named *Chesapecten jeffersonius* the official state fossil in 1993 (Kenworthy and Santucci, 2003).

Ulysses S. Grant National Historic Site, Missouri (ULSG)

Julia Dent Grant, wife of Ulysses S. Grant, grew up outside of St. Louis, Missouri on a farm named White Haven, now the site of ULSG. Greg McDonald, senior curator of natural history for the NPS, visited the site in 2005 and noticed a large chunk of fossil coral sitting just outside the house (Fig. 6). Inquiring with park staff, McDonald learned the piece of coral was entwined in the roots of a tree that blew over in a storm (G. McDonald, personal commun., 2005). Interestingly, Pam Sanfilippo, ULSG historian, recalled a passage, below, in Julia Grant's memoirs (published posthumously in 1975) mentioning "petrified honeycomb", very likely a similar piece of fossil coral.

"Once, when I was about nine years old, I, with my dusky train, had wandered far up the brook and deeper than usual into the woods when we came upon a beautiful, shad-ow, moss-covered nook. My little maids exclaimed: 'Oh! Miss Julia! Have this for your playhouse, and we will mark it out with all the pretty stones we can find.' Hastening to the brook, they gathered all the 'petrified honeycomb' and round boulders they could find, placing these so as to mark the supposed walls of my mansion." (Grant, 1975, p. 36).



FIGURE 6. Large block of coral from Ulysses S. Grant National Historic Site, Missouri. NPS Photo/Pam Sanfilippo.

Grant is probably referring to Gravois Creek, which flows east of ULSG. Thompson (1928) described exposures along Gravois Creek and measured a section at Grant Road quarry, just outside of ULSG. The abundantly fossiliferous limestone found there was identified as the Mississippian St. Louis Limestone near the contact with the underlying Salem Limestone ("Spergen formation") by Thompson (1928). The tabulate coral *Syringopora* is a common fossil in the St. Louis Limestone (Thompson 1928).

Lewis and Clark National Historic Trail (LECL)

The 5955 km (3700 mile) Lewis and Clark National Historic Trail commemorates the famous three-year voyage of discovery led by Meriwether Lewis and William Clark beginning in 1804. The journey was for the most part the dream of President Thomas Jefferson who was curious about the far western frontier. Jefferson, in fact wrote to French naturalist Bernard Lacépède in 1803, stating his hope that "this voyage of discovery will procure us further information of the Mammoth, & of the Megatherium...and an enormous animal incognitum [*Megalonyx*]" (Jefferson, 1803). Among the numerous discoveries credited to Lewis and Clark, reports of fossils occur in their journals and through other historic accounts. For example, during their travel in western Iowa during 1804, near the confluence of the Missouri River and Soldier Creek, Lewis and Clark discovered in a cave a petrified jawbone of some large, unknown creature (Simpson, 1942). The fossil was later identified and described as an enormous lizard-headed fish named *Saurocephalus lanciformis*. Today the specimen is in the collections of Natural Academy of Sciences in Philadelphia. This discovery has been a mystery to paleontologists including Simpson because this fossil specimen is known only from the Cretaceous Niobrara Chalk of western Nebraska or Kansas. The cave from which the specimen was collected is near Council Bluffs, Iowa, and the area surrounding Soldier's Creek is covered by Pleistocene loess deposits. Mayor (2005) hypothesized that the Cretaceous fish fossil may have been transported from Nebraska or Kansas to the cave by American Indians.

Vicksburg National Military Park, Mississippi (VICK)

John Wesley Powell is certainly one of the most well known figures in North American geology. Before his explorations of the west in the 1870s, he served in the U.S. Army during the Civil War. In 1863, he was stationed at Vicksburg. There are many accounts (e.g. Dellenbaugh, 1902; Moring, 2002) of John Wesley Powell collecting fossils from around the Federal earthworks during the siege of Vicksburg (D. Dockery, personal commun., 2005). According to Moring (2002) John Stewart, an amateur geologist and paleontologist who accompanied Powell on his second Colorado River expedition, first met Powell at Vicksburg as both were looking for fossils. There is no shortage of paleontological resources in the Vicksburg area. Most of the earthworks were probably excavated into the extensive Pleistocene loess deposits that blanket the area. This loess contains an abundant gastropod fauna and has even produced mastodon remains south of Vicksburg (Mellen, 1941; Kolb et al., 1976). Exposures of the Oligocene Vicksburg Group near Mint Spring Bayou within the park have produced an extraordinary diversity of marine invertebrates (e.g. Mellen, 1941; Kolb et al., 1976; Dockery 1982; McNeil and Dockery, 1984). Powell's Vicksburg collection may have been housed in the Illinois State Natural History Society where he served as curator in the late 1860s (Dellenbaugh, 1902). Further investigation may yield additional information regarding the whereabouts and extent of this collection.

Florissant Fossil Beds National Monument, Colorado (FLFO)

The world-renowned paleontological resources of FLFO are extraordinarily diverse and well preserved (see Meyer 2003). Fossils from the late Eocene Florissant Formation include nearly 2,000 known species of fossils, three-quarters of which are insects. Fossil spiders, fish, birds and mammals are also found in the formation in addition to a significant floral assemblage and large pieces of petrified wood. The petrified wood, primarily *Sequoia affinis* (redwood), attracted the attention of a seemingly unlikely paleontological resource "manager", Walt Disney. In 1956, Disney visited the privately owned Pike Petrified Forest; now a part of FLFO (established 1969). He personally purchased a large petrified stump 2.3 m in diameter and weighing some five tons from the owners (Meyer 2003; D. Smith, personal commun., 1999) appar-

INTERPRETATION AND RESOURCE MANAGEMENT

The NPS generally makes a distinction between natural resources (including fossils) and cultural resources. Indeed, paleontologists and archeologists have all spent time explaining the differences in their respective disciplines. However, fossils found in cultural resource contexts, such as those summarized in this paper, reinforce the interconnectivity of humans and their natural surroundings. This interconnectivity of these “cultural resource fossils” creates incredible interpretive opportunities. Awareness of this interconnectivity and, in some cases, sacred values associated with some paleontological resources or localities, should be considered in interpretation and paleontological resource management decisions.

Paleontological resource management policy in the NPS generally focuses on *in situ* occurrences (1998 NPS Omnibus Management Act Section 207, NPS 2001 Management Policies Section 4.8.2.1, and NPS DO 77 (Natural Resource Management)). Therefore, fossils found in cultural resource contexts may be subject to the legislative protection and management/preservation guidance found in the 1979 Archeological Resources Protection Act (ARPA), 1990 Native American Graves Protection and Repatriation Act (NAGPRA), NPS 2001 Management Policies Section 5.3, and NPS Directors Orders (DO) 28 (Cultural Resources Management) and DO 29 (in development, Ethnography Program).

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FIGURE 7. Petrified wood from what is now Florissant Fossil Beds National Monument, Colorado, on display at Disneyland's Frontierland (Anaheim, California). NPS Photo.

ently as a gift to his wife, Lillian. Disney later displayed the stump in Disneyland's (Anaheim, Calif.) Frontierland area, where it can be seen today (Fig. 7).

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UTAH GEOLOGICAL SURVEY: A VALUABLE PARTNER IN THE MANAGEMENT OF FEDERAL FOSSIL RESOURCES

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Abstract—The Utah Geological Survey has a legislative mandate to insure that Utah's paleontological heritage benefits its citizens. One of the largest state geological surveys, the Utah Geological Survey has a depth of expertise and facilities that it can bring to bear as it works with various federal, state, local, educational, and private agencies to document and manage important paleontological resources for the maximum public scientific and educational benefit.

INTRODUCTION

The extraordinary sedimentary geology of Utah is reflected in its many geological state and federal parks and monuments (Stokes, 1986; Hintze, 1993, 2005; Sprinkel et al., 2003; Hamblin, 2004). Contained within these rocks is a remarkable fossil record that ranges from common invertebrate and plant fossils to unique vertebrate fossils (e.g. Kirkland, 2005). The American people have a proven interest in these fossil resources; both for the opportunities to make their own discoveries and to learn more about the history of life on Earth. As land managers and scientists, we have obligations to protect this important scientific and educational resource and to learn from and interpret the resource for the maximum public benefit. The Utah Geological Survey (UGS) is charged by the State of Utah with providing timely, independent information and advice to federal, state, and local governments, and to the general public about Utah's geologic resources (e.g. oil, gas, coal and minerals), hazards (e.g. earthquakes, landslides, debris flows and rock falls) and the geologic environment (e.g. ground water and fossils) to promote economic development and assist with wise land-use decisions. Within the Utah Code regarding the mission of the UGS under Title 63 State Affairs in General, Chapter 73 Geological Survey, sections 63-73-1 (3)-(6), (9)-(12), (15)-(17), 63-73-6 (1) (l)-(p), and 63-73-11-20 all relate to paleontology (http://www.le.state.ut.us/~code/TITLE63/63_2D.htm). To facilitate these responsibilities, the State Geologist assigns certain tasks to a State Paleontologist and his/her staff. These mandated tasks include: (1) maintaining a paleontological locality database; (2) issuing permits for paleontological studies on state lands; (3) commenting on issues and development projects affecting paleontological resources in Utah; (4) promoting the significance of Utah's paleontological resources and heritage; (5) monitoring activities involving paleontology in Utah; (6) serving as partner with federal, state, and local agencies and educational organizations regarding paleontology in Utah; (7) advising, overseeing training programs, and providing opportunities for involvement for Utah's statewide paleontological volunteer organization, the Utah Friends of Paleontology; and (8) conducting research on Utah's paleontological resources.

UTAH PALEONTOLOGICAL LOCALITY DATABASE

The office of the State Paleontologist at the UGS has been working for the past 20 years to develop a comprehensive digital paleontological locality database for all fossil sites in the state of Utah. The Bureau of Land Management (BLM) has helped fund this endeavor over the last several years through a memorandum of understanding with the UGS, as part the BLM's mandate under the Antiquities Act of 1906 and BLM Organic Act of 1977. The information in the database can be queried and sorted in a multitude of ways to address specific research and management questions, and maps can be created using Geographic Information Systems (GIS) software. Following federal guidelines, the UGS considers significant fossils sites to be: (1) all sites preserving

vertebrate fossils and their traces; (2) sites of exceptional fossil occurrence; (3) sites of exceptional fossil preservation; and (4) sites preserving rare fossils. Fossils that are not considered to be significant include: (1) common invertebrates; (2) common fossil plants; and (3) microfossils. The Utah Code restricts access to these data to qualified agencies and researchers.

UGS PALEONTOLOGICAL SENSITIVITY MAPS

The office of the State Paleontologist at the UGS has also been using GIS to integrate existing digital geologic maps produced by the UGS with the UGS Paleontological Locality Database to generate paleontological sensitivity maps. We have developed these maps for public lands in Utah, assigning sensitivity levels to the different geologic units based on the type and distribution of fossils. These maps can serve as a basis for paleontological resource management by aiding land managers in making decisions regarding the protection of fossil resources (DeBlieux et al., 2003; 2004).

The office of the State Paleontologist has defined six levels of sensitivity for map units for the purpose of developing paleontological sensitivity maps. This sensitivity scale starts at five for the most sensitive rock units and decreases to zero for rock units that do not preserve fossil resources. This scale is as follows:

- (5) Significant fossils are abundant and widespread (e.g. Morrison and Uinta formations).
- (4) Significant fossils are present (e.g. Chinle and Cedar Mountain formations).
- (3) Significant fossil sites are known (e.g. Mancos Shale, Wahweap and Green River formations).
- (2) Common fossils may be abundant, but significant fossils are rare. This category includes most Paleozoic formations and Pleistocene deposits.
- (1) Significant fossils are rare (e.g. Navajo Sandstone and Uinta Mountain Group).
- (0) Map units represent rocks in which fossils are not preserved, such as igneous and high-grade metamorphic rocks.

The BLM has 1-3 paleontological sensitivity scale that would translate as follows:

- (1) Most sensitive = UGS 5 & 4
- (2) Moderately sensitive = UGS 3 & 2
- (3) Low sensitivity = UGS 1 & 0

The quality of the paleontological sensitivity maps is directly related to the level of detail in the geological map. The statewide Utah Paleontological Sensitivity Map (Fig. 1) was developed from the Digital Geological Map of Utah (Hintze et al., 2000). A significant weakness of this map, beyond its small scale (1:500,000), is that most formations are mapped together in groups. The UGS is in the process of completing 30' X 60' (1:100,000 scale) digital geological maps for Utah that will facilitate improved resolution of the state paleontological sensitivity map. On the 7.5' (1:24,000 scale) quadrangle maps being produced by the UGS,



FIGURE 1. Paleontological Sensitivity Map of Utah.

rock units at the member level are mapped and dozens of types of superficial deposits are recognized, providing greater resolution in the resulting paleontological sensitivity maps. Letters from outside agencies requesting the UGS to produce specific 7.5' geologic quadrangle maps are very effective in helping the UGS Geological Mapping Program obtain funds from STATEMAP, a cooperative federal/state geological mapping effort for specific mapping projects of high priority to land managers.

In addition, it is critical that field investigations be conducted because fossils are never uniformly distributed through any rock unit. Field investigations provide an essential test of paleontological sensitivity maps developed from reviewing the paleontological literature.

RECENT UGS PALEONTOLOGY PROJECTS

A number of our recent cooperative projects are described below. These projects all include several components that are generally common to each project: (1) literature search; (2) search of Utah Paleontological Locality Database; (3) acquisition of detailed geological hard copy and/or digital map for the area under investigation; (4) identification of areas of highest potential paleontological significance; (5) field investigations to secure ground truth; (6) data compilation in GIS compatible formats; and (7) compilation of maps, databases and final reports.

St. George Tracksite

In the winter of 2000, landowner Sheldon Johnson discovered a significant fossil locality in the Lower Jurassic Moenave Formation on his land in St. George, Utah. The UGS worked closely with the landowners, the City of St. George, and other agencies to ensure that this important fossil discovery was protected for the good of the citizens of Utah and the nation (e.g. Kirkland et al., 2002b). Today, the City of St. George manages the St. George Dinosaur Discovery Site at Johnson Farm. St. George's Dixie State College of Utah now has a paleontology program, and has hosted a conference on the Triassic/Jurassic boundary as a direct result of this discovery (Harris, 2005).

Flaming Gorge Project

The UGS was recently asked by the U.S. Bureau of Reclamation to evaluate the potential impacts of varying water levels at Flaming Gorge National Recreation Area (managed by the National Forest Service) in Utah and along the Green River downstream in Utah (Mathews et al., this volume, fig. 5). Wave action along the shoreline is an active agent of fossil destruction in dammed water bodies, and fluctuations in water depth expand this detrimental effect over a much wider area. Preliminary examination of the most sensitive formations along the shoreline resulted in the discovery of several significant fossil localities (Hayden, 2002; Bilbey et al., 2005). Combining these new data with the state geological map (1:500,000 scale) permitted a reasonable preliminary paleontological sensitivity map to be developed for this area. However, if geological mapping at the 7.5-minute quadrangle scale were undertaken, a much more detailed paleontological sensitivity map would be possible.

Zion National Park Paleontological Survey

The spectacular rocks exposed in Zion National Park, Utah, include many fossiliferous units ranging in age from Permian through Holocene. Important vertebrate fossil-bearing formations include the Triassic Chinle Formation and the Jurassic Moenave and Kayenta formations, among others. In cooperation with the UGS, several National Park Service interns conducted a comprehensive inventory of paleontological resources located within the park (DeBlieux and Kirkland, 2003). The goal of this work was to identify new fossil localities, assess the distribution of fossils within formations and establish baseline paleontological resource data to support the management and protection of fossils.

We identified over 100 new sites as a result of this project. Terrestrial vertebrate body fossils were found in the Shinarump and Petrified

Forest members of the Chinle Formation, these included the remains of phytosaurs, aetosaurs, metoposaurs and a possible ornithischian dinosaur. Dozens of new dinosaur tracksites were discovered in the Whitmore Point Member of the Moenave Formation and the Kayenta Formation. These include numerous *Eubrontes* and *Grallator* trackways as well as probable swim tracks.

We used GIS programs to not only record site localities, but also to create paleontological sensitivity maps from recently completed UGS 7.5-minute geologic quadrangle maps (1:24,000 scale) of the park. Because of the vast size of parks such as Zion accurate detailed geologic maps are essential for focusing field assessments on the formations and deposits that have the highest potential for containing important paleontological resources. Modern geologic maps provide several advantages over older maps, including greater detail, more accurate placement of geologic contacts, better division into members and even sub-members, and much more detailed mapping of surficial deposits that cover fossil-bearing strata (Willis et al., 2004). The identification of scientifically important new localities illustrates the value of cooperative projects in the National Parks.

Grand Staircase–Escalante National Monument Wahweap Survey

Over the past four years, the UGS has been funded by the BLM to conduct a paleontological inventory of the lower sandstone and middle shale members of the Wahweap Formation in the southern Kaiparowits Basin in the Grand Staircase – Escalante National Monument (GSENM) within a mile of open roads in the area. In addition to providing data on the distribution of paleontological resources, this study has identified and recovered specimens that are adding to our knowledge of large terrestrial animals during a time interval from which they are poorly known.

The Wahweap Formation preserves the most diverse early-middle Campanian terrestrial fauna in North America, based largely on information gained by the study of microvertebrate fossils collected by wet screenwashing. These studies have documented four freshwater shark species, three freshwater ray species, seven bony fish species, two amphibian species, six turtle genera, two lizard taxa, three crocodylian taxa, eight dinosaur taxa and 23 mammal species (Eaton et al., 1999; Eaton and Kirkland, 2003). However, the turtles, crocodylians, and dinosaurs require more complete skeletal material for specific identification (Kirkland, 2001).

Although no significant crocodylian specimens have been found during the UGS's field investigations, both trionychid and baenid turtle shells have been recovered and are presently under study. Only two dinosaurs have been identified to species-level from rocks of this age in North America (Montana). At GSENM, cranial remains of a new species of long-horned centrosaurine ceratopsian (horned dinosaur) are the most significant dinosaur fossils to be identified so far (Kirkland, 2001; Kirkland and DeBlieux, 2005; Kirkland et al., 2002a; 2005a; 2005b; Titus et al., 2005). A number of associated hadrosaurid (duck-billed dinosaur) skeletons have been identified in the field, although taxonomically critical cranial remains have yet to be identified in these preliminary excavations. The isolated skull roof of a juvenile pachycephalosaur (dome-headed dinosaur) has been collected. Additionally, carnivorous dinosaur remains have been identified at a number of sites, although nothing diagnostic has come to light.

Sevier River Formation Project

We should note that the absence of recorded fossil localities does not equate with an absence of fossils. Prior to the mid-1990s no vertebrate fossil localities were known from the Miocene Sevier River Formation in Fish Lake National Forest of central Utah. Recent discoveries indicate that these rocks preserve the richest Miocene fauna known from Utah or its immediate vicinity (DeBlieux et al., 2002). Ground truth is critical to understanding the distribution of important fossil resources,

so field research and inventories by qualified paleontologists need to be encouraged. In this way, the public will have its fossil resources protected and will gain most from this compelling resource.

CONCLUSIONS

The UGS is particularly well suited to developing management tools for paleontology. As one of the largest state surveys, it employs an experienced paleontological staff, a sizable geological mapping program and a large support staff of experts in GIS software. Not being a federal or state repository, the UGS is free to work with all the repositories in Utah as needs of specific projects warrant. Additionally, the UGS pub-

lishes a variety of products from limited runs of reports restricted to specific clients to mass-produced public documents intended for general distribution to libraries and the public.

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INNOVATIVE STRATEGIES TO DEVELOP INTERPRETIVE MEDIA FOR PALEONTOLOGICAL SITES AT CURECANTI NATIONAL RECREATION AREA, COLORADO

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Abstract—Curecanti National Recreation Area preserves three significant fossil localities along the shoreline of Blue Mesa Reservoir, primarily containing dinosaur fossils. Once resource management concerns are addressed to protect these paleontological resources, the park will provide interpretive resources to educate the visiting public. Due to the subject matter, location and physical conditions of the sites, traditional forms of interpretation are not adequate to meet the park’s interpretive goals. The proliferation and sophistication of mobile technology in recent years provides an excellent opportunity for visitors to explore the sites, learn at their own pace and access interpretive information and activities on a variety of personal or government owned devices.

INTRODUCTION

Curecanti National Recreation Area (CURE) is located in south-western Colorado (Fig. 1). Colorado’s largest body of water, Blue Mesa Reservoir, is within the boundaries of the park. The majority of visitors come to the area for boating and fishing opportunities. Several paleontological localities are found exposed along the fluctuating shoreline within the Jurassic Morrison Formation. Invertebrate and vertebrate burrows, plant material, reptile and dinosaur fossils are known from the park.

PALEONTOLOGICAL LOCALITIES

Three significant fossil localities are found along the Blue Mesa Reservoir shoreline in the Upper Jurassic Morrison Formation. The sites contain reptile and dinosaur body fossils and termite burrow fossils. *Apatosaurus* and *Allosaurus* dinosaur fossils were excavated from the Dino Cove locality in the 1990s and currently no bone material is exposed (Trujillo, 2000). A large collection of several hundred bone fragments was made in 2005 from the Northern Dinosaur Beach locality and resulted in expanding the paleofaunal list of the area to include six dinosaurs: *Apatosaurus*, *Allosaurus*, *Ceratosaurus*, *Camarasaurus*, *Diplodocus* or *Barosaurus* and *Stegosaurus* (Koch et al., in press) (Fig. 2). Limited collections exist for the Dinosaur Beach locality including crocodylian, turtle, theropod (*Allosaurus*) and sauropod (*Camarasaurus*) dinosaurs (Trujillo, 2001; Koch et al., in press).

RESOURCE MANAGEMENT

Human and natural activities currently threaten the stability of these paleontological sites. The endangerment of the scientific and educational potential of the localities must be addressed. Wave actions of Blue Mesa reservoir are constantly eroding and undercutting the sites. Unpredictable water level fluctuations increase the erosion rate and threaten to seasonally submerge several exposed bones. Colorado’s climate produces freeze/thaw events that crack both the exposed bone and the rock matrix that stabilizes the fossils. Additionally, the reservoir seasonally freezes and creates ice heaving on beach surfaces. All three fossil sites are accessible to visitors by recreational boating. Campers, fishermen and day users visit these fossil beaches.

Resource management will address the impairment concerns by collecting all scientifically valuable specimens, determining rates of new fossil exposures and creating and implementing a monitoring strategy. Once these actions are completed, the park will provide interpretive services to educate visitors about the important fossil resources that exist on the shores of Blue Mesa Reservoir.

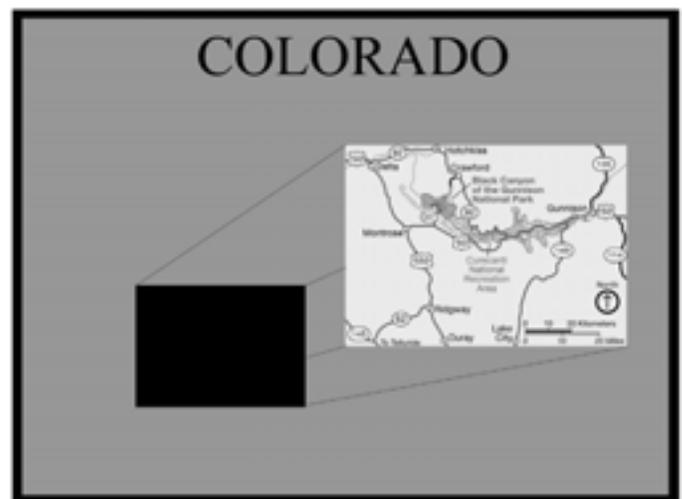


FIGURE 1. Location map of Curecanti National Recreation Area.

INTERPRETATION AND TECHNOLOGY

The Balance of Information and Protection

If the public knew more about the importance of preserving paleontological resources, would they protect them? The balance of on-location interpretation of precious resources and greater visitor understanding is a struggle for interpretive management. Remote and obscure locations in national parks, far from the visitor crowd could go unnoticed and untouched for generations. Researchers know where the “best” fossils are at Curecanti National Recreation Area. The one million annual visitors could go on boating, fishing and camping with little knowledge or appreciation of what surrounds them in the rock record. Worse, a handful of fossil-savvy collectors could go unnoticed by the watchful general public, removing significant fossil evidence. The resources must have a value in the public’s collective mind in order for protection to occur.

Few Will Visit, Many Can Learn

With 10,000 acres of water surface surrounded by 30,000 acres of essentially trail-free land at CURE, most visitors won’t explore the Morrison Formation. Even though the recreation area captures the highest tourism in Colorado west of the Continental Divide, few will partake in personal contact with an interpretive ranger. Previously, CURE relied heavily on visitors reading ten-year-old wayside exhibit signage located at various highway rest areas. Nothing was available for the average of

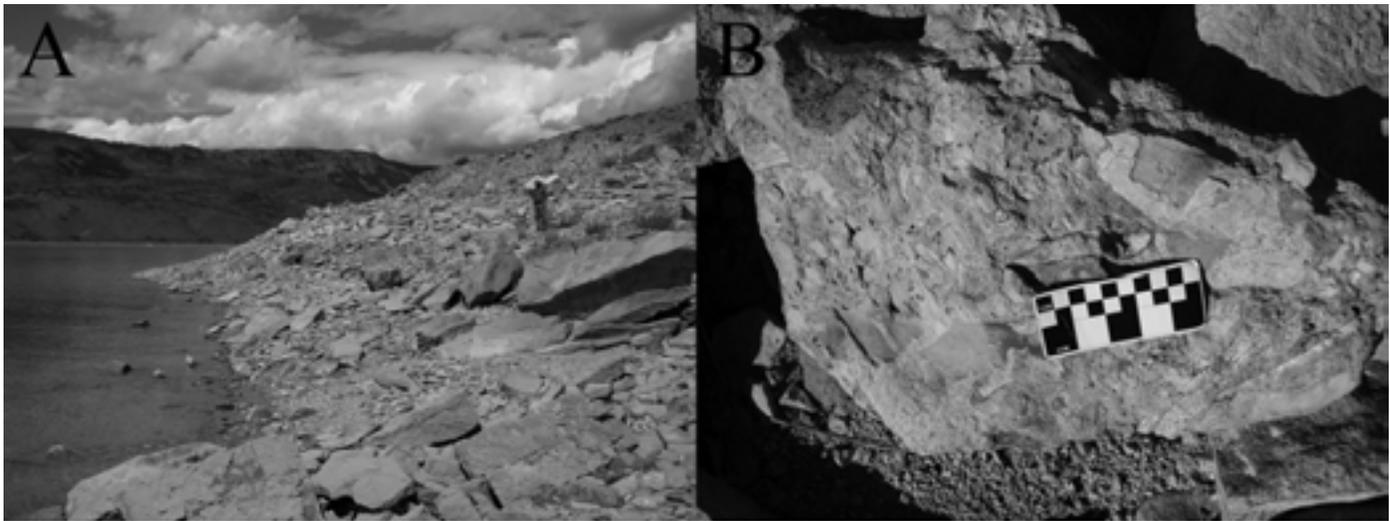


FIGURE 2. A, Northern Dinosaur Beach locality with archeologist for scale. B, Typical block of float at Northern Dinosaur Beach littered with fossil bone fragments.

two hundred daily boaters on Blue Mesa Reservoir. A two-minute safety message broadcasting night and day, inside a two-mile range along U.S. Highway 50 could be heard on AM radio. Interestingly, three times the number of on-site visitors to Black Canyon of the Gunnison National Park in 2005 visited the park's website last year. Most spent nearly an hour cruising through the two hundred pages of information. Visitors to the website came from every state of the United States and far more countries outside of our borders. Within seconds, and a few clicks of a mouse, visitors who had never seen Colorado were learning about dinosaurs inside a national park and a national recreation area.

The Newest Internet Frontier

The internet has been around for a long time with its early exchange of information in the academic community in the 1940s. Its popularity after the boom of the World Wide Web is unprecedented. Enter podcasting, a portable, time-shifting means of hearing the spoken word of radio disc jockeys, standup comedians and readers of periodicals. A new free subscription of information or entertainment, a podcast or broadcast deliverable by the internet and heard on an MP3 player (particularly the popular Apple iPod), became a new industry. On September 28th, 2004 a Google search for the word podcast would reveal 24 hits. On September 30th, the same search found 526, then 2,750 only three days later. A year later, Google finds more than 100 million hits for the word "podcast." In the summer of 2005, a new frontier of video-on-demand (VOD) was pioneered and marketed in the Netherlands (www.vodcast.nl). Not surprisingly, the Dutch had the largest demand for Internet-based video broadcast, since over 60% of the population has 1 Mbps or faster broadband connections. Asia followed suit in August 2005 with a Philippine-based infotainment "vodcast" called HIT. By winter, portable video devices (PVDs) appeared on the world market. Apple's video iPod was challenged within a month by more than ten affordable devices.

The Saturation and Time-shift Stories in MP3

Not unlike television and the internet, MP3 and video player popularity in the US market has soared. According to new research from the Pew Internet and American Life Project, over 22 million Americans own an MP3 or iPod player and 6 million of these owners have listened to podcasts (Madden and Rainie, 2005). Pew also determined MP3/iPod players were owned by the more affluent at this time. Thirty-one percent of those with annual incomes over \$50,000 owned the devices. In

households with incomes under \$50,000 only 16% have the players. Broadband access is strongly associated with ownership of iPods and MP3 players, with 23% of broadband-enabled households owning music players, compared to nine percent of those on dial-up connections. Consumers with broadband at home and at work are the most likely of all to have iPods or MP3 players, with one in three owning the devices (Horrihan, 2005). Two-thirds of United Kingdom teenagers know the price of an iPod, but three-quarters have no idea about the price of a pint of milk, according to a separate 2005 study by ICM Research (ICM Research, 2005).

All of the portable devices allow the user to subscribe to an internet download and listen and/or view the broadcast at a later time. The service is now popularized by Apple's iTunes free software, allowing viewers to time-shift last night's most popular television shows for less than two dollars. Listeners in the United States downloaded 5 million podcasts in 2005, but that activity is projected to grow to over 62.8 million by 2010, according to a study by Bridge Ratings (2006).

Moving Compelling Interpretation into the Portable World

Capturing the attention of new audiences and keeping them interested is a challenge all interpretive managers and educators face. Teachers are facing the paradigm shift of required reading becoming required listening. National parks already get a great deal of travel planning, safety information and pre-site learning to visitors through the popular National Park Service (www.nps.gov) website. Rather than placing expensive location-based wayside exhibits, well-done interpretation can be loaded into visitor-owned portable devices. Interpreting geology stories through images, timelines, graphics and video can be far more compelling than written text. The viewer or listener can steer their own learning by navigating, like many do through the World Wide Web, in a non-linear fashion. Learners gain knowledge on their own schedule, at their own pace and when it's most important to them. For managers, the market saturation of this technology has made information management inexpensive, easy to edit and easy to broadcast. The interpretive materials are far easier to produce in multiple languages, at different education levels and distribute to wide-ranging audiences.

Interpretive Strategies for Curecanti National Recreation Area

Due to the location and environmental conditions of the three dinosaur sites, traditional forms of site interpretation do not seem feasible or appropriate. Waysides are too permanent a structure for an area that sees fluctuating water levels, high rates of erosion and may require



FIGURE 3. Visitor using a mobile device while exploring the park.

further digging in the future. Brochures do not seem sufficient to explain the geological and paleontological resources at the sites, create a connection for the visitor with the paleolandscape or provide information on the processes and techniques of paleontological science. The park believes that video presentations for mobile devices will better meet these interpretive goals. Visitors will have the opportunity to have a video presentation and/or interactive displays on hand while they explore the fossil sites along the beaches (Fig. 3).

Content will be created by park staff to include video footage, photographs, graphics and narrations. The park's visual information specialist will assemble all this information into one or several edited

video products. Topics may include reconstructing the paleoenvironment, animations to describe the paleolandscape, video and graphics describing the life of a fossil bone, footage showing scientists working on the site from collection to curation and a visual gallery of specimens collected from the site. Due to the ever-expanding marketplace for mobile devices and a desire for proprietorship, it can be difficult to determine the final file format in which to create video products. Fortunately, by using professional grade editing systems, the park can easily export content to an array of file formats to accommodate the growing mobile device market. Therefore, the park is not giving preferential treatment for interpretive content to any company, brand, device or file format.

There are several possible ways to provide the video content to visitors. First, content can be provided on the internet for viewing and for downloading for input into the visitor's personal mobile device. Second, the park visitor center may have a "downloading kiosk" or computer available for direct download of content into the visitor's device. Third, interpretive rangers can carry a flash drive, flash card or memory stick that contains the video files that can be copied to a visitor's device in the field during roving and visitor contact activities. Fourth, using Bluetooth technology, visitors can download the content virtually out of the air while inside the park. Finally, the park can invest in a few mobile devices to be rented to visitors who did not bring a device themselves but would like to have content on hand while at the fossil sites.

ACKNOWLEDGMENTS

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EARLY PALEOCENE (PUERCAN AND TORREJONIAN) ARCHAIC UNGULATES (CONDYLARTHRA, PROCREODI AND ACREODI) OF THE SAN JUAN BASIN, NEW MEXICO

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Abstract—We present the first comprehensive revision of all San Juan Basin Paleocene archaic ungulates, which are known from fossils collected primarily on BLM-administered lands. A brief description is given of each species of archaic ungulate found in the Puercan and Torrejonian strata of San Juan Basin. The description includes holotype information, revised diagnosis and distribution information. Taxonomic status, temporal ranges of archaic ungulate species and their importance for biostratigraphy are discussed in detail.

INTRODUCTION

The San Juan Basin, New Mexico, has produced more Paleocene mammalian fossils than any other location in North America. Most of these fossils come from BLM-administered lands. Many articles have been published on different groups of Paleocene vertebrates from this area, but surprisingly there were very few comprehensive studies of San Juan Basin Paleocene mammalian faunas. The only comprehensive detailed revision of San Juan Basin Paleocene mammals was undertaken by William D. Matthew (1937). Williamson and Lucas (1992, 1993) described the Paleocene biostratigraphy and vertebrate paleontology of the San Juan Basin. Williamson (1996) studied the geology of the Nacimiento Formation of San Juan Basin and briefly discussed its mammalian fauna, placing it into a detailed biostratigraphic framework. We present a comprehensive revision of all San Juan Basin Paleocene archaic ungulates and briefly discuss their biostratigraphic distribution.

Institutional abbreviations: AMNH = American Museum of Natural History, New York; KUVF = University of Kansas, Museum of Vertebrate Paleontology, Lawrence; NMMNH = New Mexico Museum of Natural History, Albuquerque; UCMP = University of California, Museum of Paleontology, Berkeley; USNM = National Museum of Natural History, Smithsonian Institution, Washington, D.C. **Other abbreviations:** P – upper premolars; M – upper molars; p – lower premolars, m – lower molars.

SYSTEMATIC PALEONTOLOGY

ORDER PROCREODI MATTHEW, 1909

Family Arctocyonidae Giebel, 1855

Subfamily Arctocyoninae Giebel, 1855

Arctocyon ferox (Cope, 1883)

Figs. 1, 2

Lectotype—AMNH 3268, right m2.

Diagnosis—A species of *Arctocyon* that differs from *A. corrugatus* by its larger size (15-20%) and from *A. acrogenius* by its smaller size (25%); also differs from *A. corrugatus* by its more robust lower jaw and shorter postorbital constriction.

Distribution—Lower Paleocene (Torrejonian) of New Mexico (Nacimiento Formation) and Montana (Lebo Formation).

Comments—Taxonomy of North American species of *Arctocyon* was discussed in detail by Kondrashov and Lucas (2004).

Arctocyon corrugatus (COPE, 1883)

Fig. 3

Holotype—AMNH 3258, right maxillary fragment with P4-M3.

Revised diagnosis—Smallest North American *Arctocyon*: 15-



FIGURE 1. Skull of *Arctocyon ferox*, NMMNH P-8627, dorsal stereophotograph (a), right lateral (b) and left lateral (c) views.

20% smaller than *A. ferox* and 40% smaller than *A. acrogenius*.

Distribution—Lower Paleocene (Torrejonian) of New Mexico and Paleocene (Torrejonian-Tiffanian) of Montana.

Colpoclaenus procyonoides (Matthew, 1937)

Holotype—AMNH 16554, left maxillary fragment with P1-M3, left dentary fragment with c, p4-m3.

Diagnosis—Differs from *C. silberlingi* and *C. keeferi* in having a

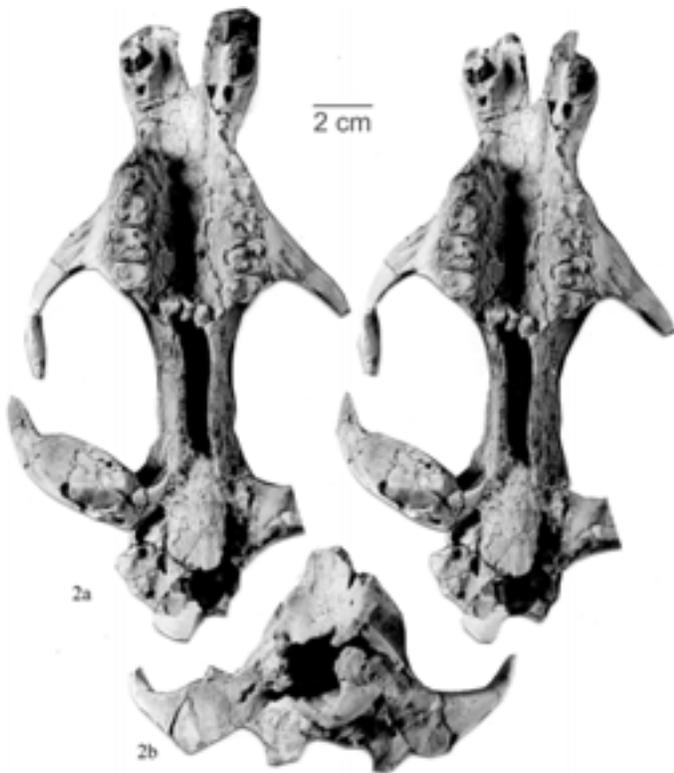


FIGURE 2. Skull of *Arctocyon ferox*, NMMNH P-8627, ventral stereophotograph (a) and occipital view (b).



FIGURE 3. *Arctocyon corrugatus*, AMNH 3258 (holotype), right P4-M3, occlusal view (a); USNM 407535, right mandibular fragment with p4-m3, occlusal view (b).

relatively well-developed M1-2 hypocone. Also differs from the other two species in being smaller.

Distribution—Lower Paleocene (Torrejonian) of New Mexico and Wyoming.

Subfamily Chriacinae Osborn et Earle, 1895

Chriacus pelvidens (Cope, 1881)

Fig. 4

Holotype—AMNH 3097, left dentary fragment with p4-m3.

Diagnosis—Differs from *Ch. baldwini* and *Ch. badgleyi* in being larger. Also differs from *Ch. badgleyi* in having better-developed conules and hypocone, in having a more molarized p4 with a metaconid and by the presence of a hypoconulid on m1. Differs from *Ch. orthogonius* in having rounded subtriangular upper molars. Differs from *Ch. gallinae* in having very well developed, complete upper molar cingula.



FIGURE 4. *Chriacus pelvidens*, KUPV 9519, right maxillary fragment with P4-M3, occlusal view (a); NMMNH 19780, left mandibular fragment with p4-m3, occlusal (b) and labial (c) views.

Distribution—Lower Paleocene (Torrejonian) of New Mexico and Wyoming.

Chriacus baldwini (Cope, 1882)

Fig. 5

Holotype—AMNH 3114, left dentary fragment with dp2-4.

Diagnosis—Slightly smaller than *Ch. pelvidens*, but larger than *Ch. badgleyi*. Differs from *Ch. orthogonius* in having rounded subtriangular upper molars. Differs from *Ch. gallinae* in having very well developed cingulum on upper molars.

Distribution—Lower Paleocene (Torrejonian) of New Mexico, Montana, Utah and Wyoming.

Comments—Van Valen (1978) described *Ch. calenancus* and differentiated it from *Ch. baldwini* in having a “more vertical posterior



FIGURE 5. *Chriacus baldwini*, KUPV 7787, right dentary fragment with p4-m3, occlusal (a) and labial (b) views; KUPV 9519, right maxillary fragment with P3-M3, occlusal view (c).

trigonid wall and smaller entoconid." Existing intraspecific variation of lower teeth of *Ch. baldwini* does not support the integrity of *Ch. calenancus*, so we consider it a junior subjective synonym of *Ch. baldwini*. Williamson (1996) suggested that *Ch. calenancus* is a subspecies of *Ch. baldwini*.

***Prothryptacodon ambiguus* (Van Valen, 1967)**

Holotype—AMNH 16591, left dentary fragment with c, p4, m2, right humerus, one lumbar and three caudal vertebrae.

Diagnosis—Differs from *P. furens* and *P. yalensis* in being 20% smaller and in having a shorter p4 protoconid.

Distribution—Lower Paleocene (Torrejonian) of New Mexico, Wyoming and Canada.

Comment—Van Valen (1967) initially referred this species to a new genus *Pantinomia*, which he tentatively placed in Pantolestidae. Van Valen (1978) later synonymized *Pantinomia* and *Prothryptacodon* and so referred *P. ambigua* to Arctocyonidae. Fox (1968) described *Prothryptacodon albertensis* from the early Paleocene of Canada. Van Valen (1978) placed this species in *Oxyprimus* and synonymized *P. albertensis* and *Carcinodon aquilonius* Russell, 1974. The synonymy was later questioned by Johnston and Fox (1984), who also suggested that *P. albertensis* should be placed in *Prothryptacodon*. After Van Valen (1978) referred *Pantinomia ambigua* to *Prothryptacodon*, *P. albertensis* became inseparable from *P. ambiguus*, which was described a year earlier, and so has priority. Rigby (1980) described *Prothryptacodon* cf. *P. furens* from Wyoming, which is identical to *P. ambiguus* in size and morphology.

Subfamily Oxycloeninae Scott, 1892

Tribe Oxycloenini Scott, 1892

***Oxycloenus cuspidatus* (Cope, 1884)**

Fig. 6

Lectotype—AMNH 3252, left maxillary fragment with P4-M3.

Diagnosis—A species of *Oxycloenus* that differs from *O. simplex* in weak development of the M1-2 hypocone, lingually projecting M2 parastyle and larger size (15-20%). Differs from *O. antiquus* in being much smaller (30%).

Distribution—Lower Paleocene (Puercan) of New Mexico and Wyoming.

Comment—Van Valen (1978) mentioned that the type specimen is atypical, but it is within the range of intraspecific variability of this species. We restrict the holotype of *O. cuspidatus* to a maxillary fragment with P4-M3. Williamson and Carr (2004) suggested that the holotype specimen of *Oxycloenus cuspidatus* belongs to *Microclaenodon*, which might alter the taxonomy of oxycloenid arctocyonids if documented.

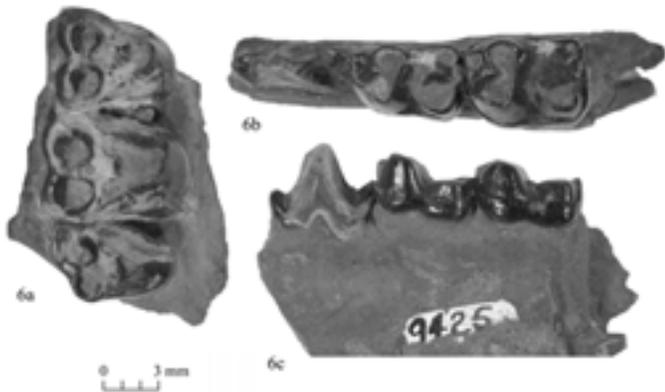


FIGURE 6. *Oxycloenus cuspidatus*, KU 9435, right maxillary fragment with m1-3, occlusal view (a); KU 9425, left dentary fragment with p4-m2, occlusal (b) and labial (c) views.

***Oxycloenus simplex* (Cope, 1884)**

Fig. 7

Lectotype—AMNH 3107, right maxillary fragment with M1-3.

Diagnosis—A small species of *Oxycloenus* that differs from *O. cuspidatus* in having a more developed cingulum on M1-2 and being smaller (15-20%). Differs from *O. antiquus* in being much smaller (40-45%).

Distribution—Lower Paleocene (Puercan) of North America.

Comment—Van Valen (1978) synonymized *Carcinodon filholianus* Cope, 1884 with *O. simplex*; this synonymy was later questioned by Johnston and Fox (1984), but Williamson (1996) concluded that it was justified and we concur.

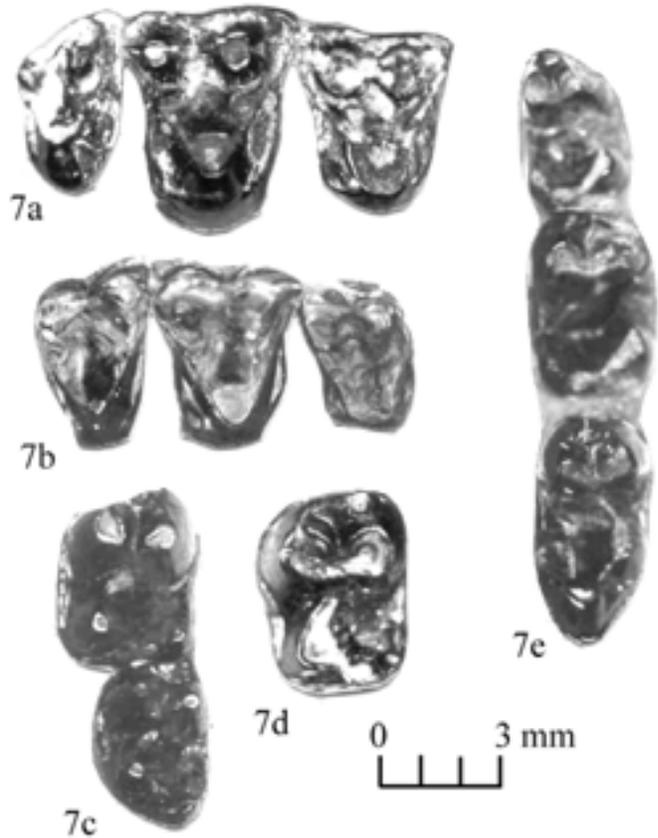


FIGURE 7. *Oxycloenus simplex*, AMNH 3107, right M1-3 (*O. simplex* lectotype), occlusal view (a); AMNH 16415, right M1-3, occlusal view (b); AMNH 16347, left m2-3, occlusal view (c); AMNH 3107, left m2, occlusal view (d); AMNH 3205, right m1-3 ("*Carcinodon filholianus*" holotype), occlusal view (e).

***Oxycloenus antiquus* (Simpson, 1936)**

Fig. 8

Holotype—AMNH 27714, maxillary fragment with P3-M3.

Diagnosis—The largest species of *Oxycloenus*; larger than *O. cuspidatus* (30%) and *O. simplex* (45%).

Distribution—Lower Paleocene (Puercan) of the San Juan Basin, New Mexico.

Comments—Simpson (1936) described this species as *Chriacus antiquus* and Van Valen and Sloan (1965) assigned it to *Oxycloenus*. Later, Van Valen (1978), following E. Manning's opinion (collection notes), referred this species to the genus *Baioconodon*. Williamson (1996) referred the species to *Oxycloenus*. This species is almost identical in tooth morphology to *O. cuspidatus* but differs in its much larger size, so we agree with Williamson and treat *O. antiquus* as the largest species of the genus *Oxycloenus*.



FIGURE 8. *Oxyclaenus antiquus*, KUVP 13364, left dentary fragment with p4-m3, occlusal (a) and labial (b) views.

Tribe Loxolophini Van Valen, 1978

***Loxolophus hyattianus* (Cope, 1885)**

Fig. 9

Holotype—AMNH 3121, left maxillary fragment with M1-3.

Diagnosis—The smallest species of *Loxolophus*; also differs from *L. priscus* in having relatively narrower lower molars, a considerably reduced m3 and an anteriorly-projecting m1 paraconid, shifted medially. Differs from *L. pentacus* in its much smaller size.

Distribution—Lower Paleocene (Puercan) of New Mexico and Wyoming.

***Loxolophus priscus* (Cope, 1888)**

Fig. 10

Holotype—AMNH 3108, incomplete skull with left P3-M3, right M2-M3 and dentary fragment with m1-2.

Diagnosis—Slightly larger than *L. hyattianus* and has relatively broader lower molars. Also differs from *L. hyattianus* in having an unreduced m3 and in the lingual position of the m1 paraconid. Differs from *L. pentacus* in being significantly smaller.

Distribution—Lower Paleocene (Puercan-Torrejonian) of New Mexico, Montana, Utah and Wyoming.

***Loxolophus pentacus* (Cope, 1888)**

Fig. 11

Holotype—AMNH 3192, right dentary with p2-m3.

Diagnosis—Species of *Loxolophus* that differs from both *L. hyattianus* and *L. priscus* in being significantly larger.

Distribution—Lower Paleocene (Puercan) of New Mexico and Wyoming.

***Tricentes subtrigonus* (Cope, 1881)**

Fig. 12

Holotype—AMNH 3227, skull fragment with right P4-M2.

Diagnosis—Morphologically similar to *Loxolophus*, differs in having three premolars, in its more reduced, centrally placed lower molar paraconids and in its less robust dentition.

Distribution—Early Paleocene (Torrejonian) of New Mexico.

Comment—Van Valen (1978) placed *Tricentes subtrigonus* in *Mimotricentes* and synonymized the two genera. The diagnosis of *Mimotricentes* clearly indicated that its representatives have four premolars (Simpson, 1935, 1937) instead of three in *Tricentes* (the basis of the generic name). Van Valen (1978) indicated that the Montana sample is polymorphic in this character. We failed to find the variation in number

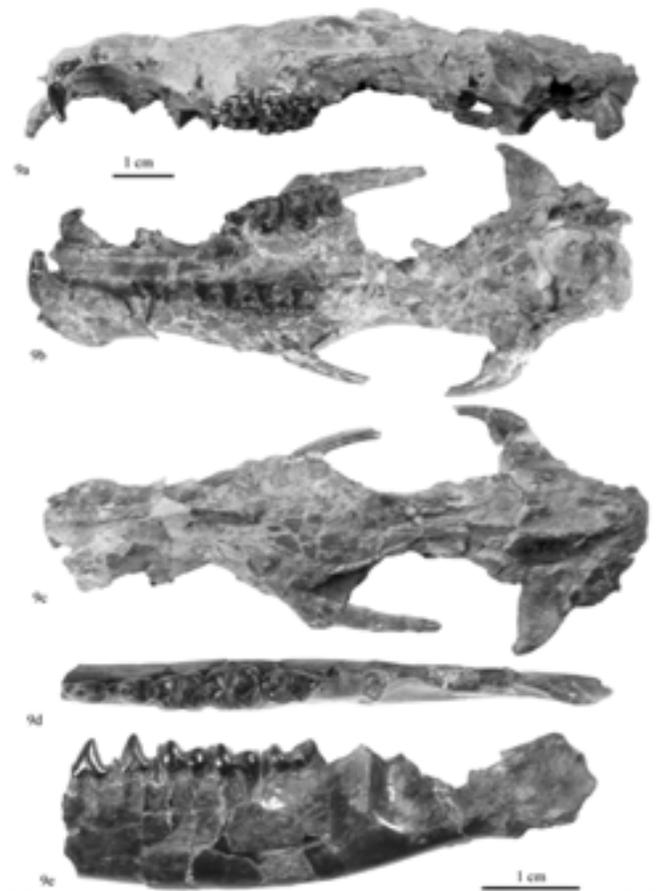


FIGURE 9. *Loxolophus hyattianus*, AMNH 16343: skull, lateral (a), ventral (b) and dorsal (c) views; left dentary with p3-m3, occlusal (d) and labial (e) views.

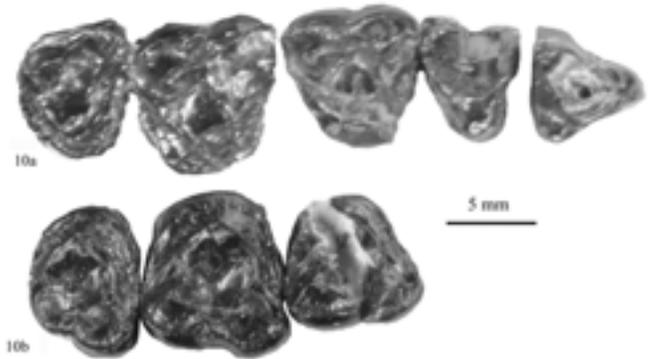


FIGURE 10. *Loxolophus priscus*, AMNH 3108, left P3-M3, occlusal view (a), right M1-3, occlusal view (b).

of premolars in the San Juan Basin sample, so we refer all New Mexico specimens to *Tricentes subtrigonus* and restrict *Mimotricentes* to the Fort Union sample.

***Desmatoclaenus protogonoides* (Cope, 1882)**

Fig. 13

Holotype—AMNH 3253, maxillary fragments with left and right M2-3.

Diagnosis—Differs from *D. diana* and *D. mearae* in having a weaker hypocone and parastyle; also differs from *D. hermaeus* in having a linguallly-placed M2 hypocone and being smaller.

Distribution—Lower Paleocene (Puercan) of New Mexico.



FIGURE 11. *Loxolophus pentacus*, AMNH 3192, right dentary with p3-m3 (holotype), occlusal (a) and labial (b) views.

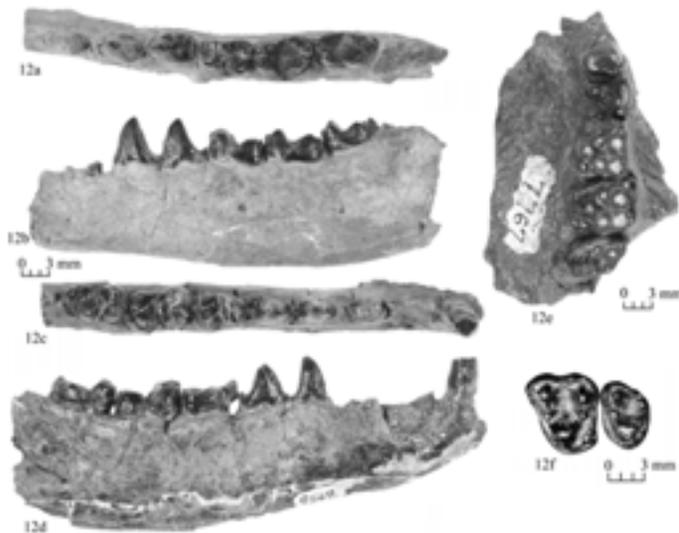


FIGURE 12. *Tricentes subtrigonus*, KUV 9569, left mandibular fragment with p3-m3, occlusal (a) and labial (b) views; KUV 7755, right mandibular fragment with p3-m3, occlusal (c) and labial (d) views; KUV 7767, left maxillary fragment with P3-M3, occlusal view (e); NMMNH 16372, left M2-3, occlusal view (f).

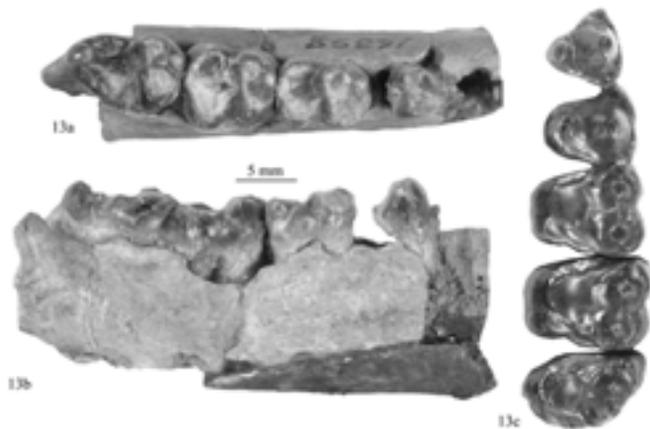


FIGURE 13. *Desmatoclaenus protogonoides*, AMNH 16398, right dentary fragment with p4-m3, occlusal (a) and labial (b) views; AMNH 16396, left P3-M3, occlusal view (c).

Desmatoclaenus diana Van Valen, 1978

Holotype—AMNH 2377, right M2.

Diagnosis—Differs from *D. hermaeus* and *D. mearae* in being smaller; also differs from *D. protogonoides* in having a better-developed upper molar hypocone.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Deuterogonodon montanus Gidley in Simpson, 1935

Fig. 14

Holotype—USNM 6061, right maxillary fragment with M3 and fragments of M1-2.

Diagnosis—The M1 and M3 hypocones are vestigial; the hypocone is better developed on the M2. The upper molar cingulum is well developed, and the mesostyle is usually present (at least on the M1). The parastyle is very large. Lower molar trigonid is taller than the talonid, the metaconid is smaller than the protoconid, the paraconid is reduced and median in position.

Distribution—Lower Paleocene (Torrejonian) of New Mexico and Montana.

Comments—Williamson (1996) pointed out that the difference between *D. montanus* and *D. "noletil"* is insignificant and cannot be used to differentiate the two species. The two species were not synonymized because of lack of specimens of *D. montanus*. However, the development of a mesostyle and slightly smaller size of *D. "noletil"* cannot be used to differentiate the two species, so we consider the latter to be a junior subjective synonym of *D. montanus*.

Van Valen (1978, 1988) suggested that *Deuterogonodon* is an ancestor of Dinocerata based on the comparison of *Deuterogonodon*, *Prodinoceras* and *Carodnia*. Lucas (1993) noted that characters used by Van Valen were insignificant because of existing morphological variability of the *Deuterogonodon* dentition.



FIGURE 14. *Deuterogonodon montanus*, AMNH 17078, right P4-M3 (holotype of *Deuterogonodon "noletil"*), occlusal view (a).

ORDER CONDYLARTHRA COPE, 1881

Suborder Taligrada Cope, 1881

Family Periptychidae Cope, 1882

Subfamily Periptychinae Cope, 1882

Periptychus carinidens Cope, 1881

Holotype—AMNH 3620, dentary fragments with dp3-4.

Diagnosis—Differs from *P. coarctatus* in having more laterally compressed posterior upper premolars and molars, a relatively larger paraconid and metaconid on the lower premolars, and protoconid and metaconid connected by a crest. Also differs from *P. coarctatus* in having a more complex talonid structure: the cristid obliqua begins from a small metaconulid, runs posteriorly and bifurcates before reaching the hypoconulid.

Distribution—Lower Paleocene (Torrejonian) of North America.

Comment—*P. rhabdodon* and *P. superstes* are junior subjective synonyms of *P. carinidens*. Specimens from Big Bend, Texas, that Schiebout (1974) referred to *P. superstes* are much larger than typical *P. carinidens* and do not possess the characteristics of *P. "superstes,"* such

as an enlarged m3 talonid. Therefore, it belongs to a new species of *Periptychus*. Similar large *Periptychus* was reported from the Animas Formation (Tiffanian) of Colorado (Burger, 2004), which may be conspecific with the Texas *Periptychus*.

***Periptychus coarctatus* Cope, 1883**

Holotype—AMNH 3775, isolated left c, p3, p4 and m1.

Diagnosis—A species of *Periptychus* that has the posterior premolars and molars relatively wider than in *P. carinidens*, has a relatively smaller paraconid and metaconid that are not connected by a crest and has a relatively simple structure of the talonid basin.

Distribution—Lower Paleocene (Puercan) of North America.

Comment—Van Valen (1978) suggested that *P. matthewi* is a subjective junior synonym of *P. coarctatus*, which was supported by Williamson (1996), and we concur. Also see the discussion of the generic status of *Periptychus coarctatus* in Williamson (1996).

***Ectoconus ditrigonus* (Cope, 1882)**

Holotype—AMNH 3798, right dentary fragment with m2.

Diagnosis—Large species of *Ectoconus* that differs from *E. symbolus* by its larger size (15-40%) and presence of the p4 paraconid.

Distribution—Lower Paleocene (Puercan) of New Mexico, Colorado, Utah and Wyoming.

Subfamily Anisonchinae Osborn et Earle, 1895

***Anisonchus sectorius* (Cope, 1881)**

Holotype—AMNH 3527, associated right maxillary fragment with P2-M2 and right dentary with p2-m2

Diagnosis—Differs from *A. athelas* in having square M1-2 and in lacking the anterior cingulum on upper molars. Differs from *A. willei* in having equally developed paracone and metacone on M2 and in having a small hypocone, which is directly posterior to the protocone. Differs from *A. oligistus* in having square M1-2, lacking the pericone on the upper molars and having the m1 trigonid wider than the talonid. Differs from *A. fortunatus* in having square M1-2, lacking the pericone on the upper molars and in the position of the hypocone, which has a base that is not shifted lingually; also differs in having equally developed M1-2 paracone and metacone.

Distribution—Lower Paleocene (Torrejonian) of New Mexico and Utah.

Comment—Williamson (1996) suggested that *A. dracus* is a junior subjective synonym of *A. sectorius*. Considering that the two species are very close in morphology and do not differ in size, we concur.

***Anisonchus gillianus* (Cope, 1882)**

Holotype—AMNH 3543, left maxillary fragment with P2-M2, left dentary fragment with p2-m3 and postcranial fragments.

Diagnosis—Differs from other *Anisonchus* species in having closely grouped trigonid cuspids; talonids relatively more robust. Upper molars relatively wider than in other species of *Anisonchus* and the premolars are more triangular. Differs from *Earendil* in having weak anterior cingulum on upper molars, well-developed hypocone and lacking the ectoflexus on upper molars.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Comment—Rigby (1981) placed *Anisonchus gillianus* in a new genus *Gillisonchus*. “*Gillisonchus*” *gillianus* is very similar to the representatives of the genus *Anisonchus*, so we return it to *Anisonchus*. Morphological distance between “*Gillisonchus*” *gillianus* and the type species of *Anisonchus* (*A. sectorius*) is not greater than morphological distances between the known species of *Anisonchus*.

***Haploconus angustus* (Cope, 1881)**

Holotype—AMNH 3477, right dentary fragment with p4-m3.

Diagnosis—Upper premolars robust, molars trapezoidal, with a small pericone and a well-developed hypocone. Mesostyle is not developed. Cusps of trigon and cuspids of trigonid are closely grouped. Hypoconulid is always developed. Differs from *Hemithlaeus* species in having greatly reduced lower molar paraconids, in lacking a mesostyle on the upper molars and in having a relatively small pericone.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Comments—Simpson (1959) noted that *H. angustus*, *H. inopinatus* and *H. corniculatus* are very close in morphology. Williamson (1996) suggested that *H. inopinatus* and *H. corniculatus* are junior subjective synonyms of *H. angustus*, and we concur.

***Hemithlaeus kowalewskianus* Cope, 1882**

Fig. 15

Holotype—AMNH 3587, right dentary fragment with p2-m2, left dentary fragments with p1-2, and m1-2.

Diagnosis—Upper molars are very wide, enamel is not wrinkled and pericone is well-developed. Paraconule and metaconule are present, as well as a small, but distinct mesostyle. Paraconid of lower molars is considerably reduced, but always present. Differs from *H. josephi* in having a larger pericone.

Distribution—Lower Paleocene (Puercan) of New Mexico and Montana.

Comments—Archibald (1998) placed *Hemithlaeus* in the subfamily Periptychinae, but noted significant distance between this genus and the other periptychines. However, *Hemithlaeus* does not possess the advanced features of this subfamily and should be referred to Anisonchinae.

Van Valen (1978) described a new genus *Tinuviel* with a single species *T. eurydice* and used characters such as large pericone and unreduced paraconid to differentiate *Tinuviel* from other periptychids. These characters are typical of *Hemithlaeus*. Considering the very similar morphology and close size of *Hemithlaeus kowalewskianus* and *Tinuviel eurydice*, we suggest that the latter is a junior subjective synonym of the former, and that *Tinuviel* is a junior subjective synonym of *Hemithlaeus*.

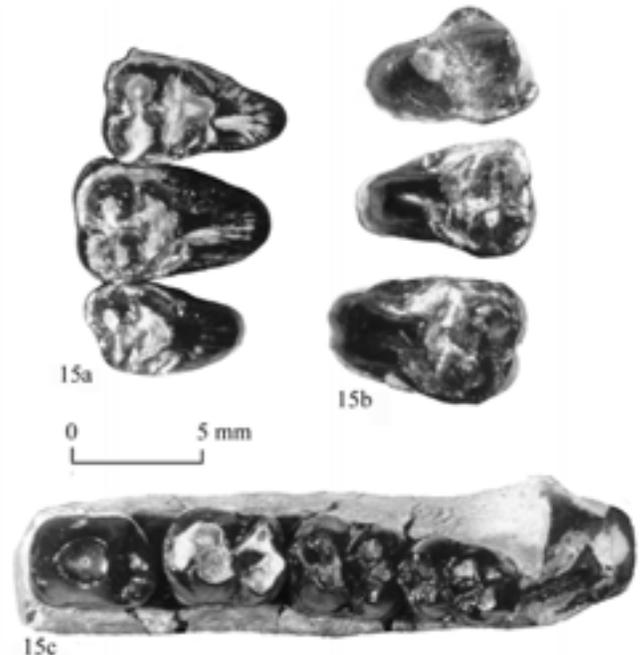


FIGURE 15. *Hemithlaeus kowalewskianus*, NMMNH 8828, right M1-3, occlusal view (a); NMMNH 8680, left P4-M2, occlusal view (b); NMMNH 15044, right dentary fragment with p4-m3.

Conacodon entoconus (Cope, 1882)

Fig. 16

Holotype—AMNH 3462, right dentary fragment with p3-m3.

Diagnosis—Differs from *C. kohlbergi* in being significantly larger (30%), in having a less developed upper molar metaconule and in lacking the parastyle on the P4. Differs from *C. cophater* in lacking the parastyle on the $\Delta 4$.

Distribution—Lower Paleocene (Puercan) of New Mexico.

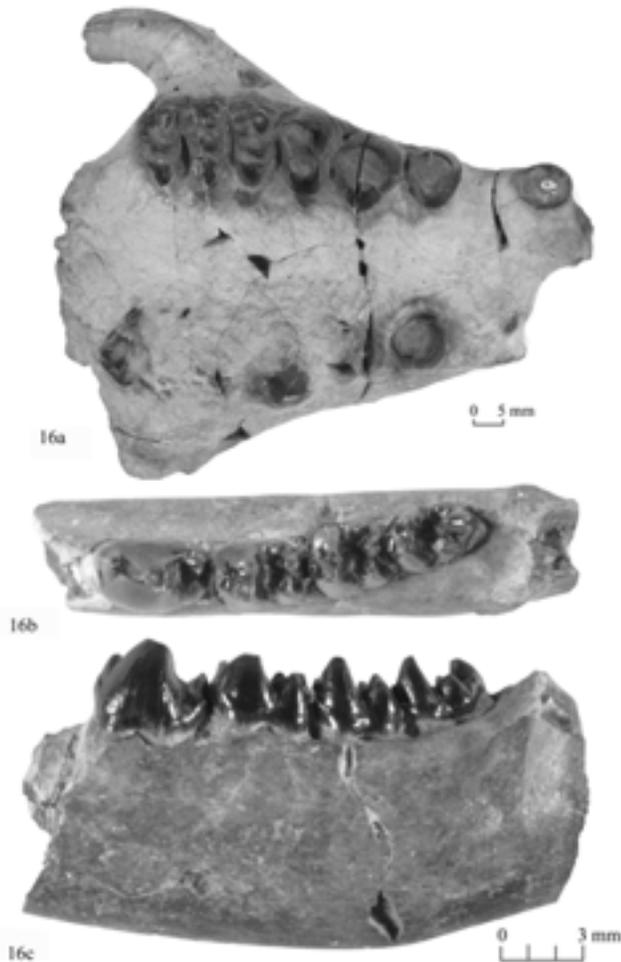


FIGURE 16. *Conacodon entoconus*, KUPV 1310, skull fragment with right P2-M2 and left P2, ventral view (a); NMMNH 21865, left dentary fragment with p4-m3.

Conacodon cophater (Cope, 1884)

Holotype—AMNH 3486, a skull fragment with left P4-M2 and right P3-M3.

Diagnosis—Differs from *C. kohlbergi* in being larger (20-30%). Differs from *C. entoconus* in having a well-developed P4 parastyle and slightly smaller size.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Comment—Matthew (1897, 1937) referred *Anisonchus cophater* Cope, 1884 to *Conacodon*. Van Valen (1978) argued that this species is closer to the genus *Oxyacodon*. Archibald (1982) and Archibald et al. (1983b) demonstrated that “*Anisonchus*” *cophater* belongs to the genus *Conacodon*.

Conacodon kohlbergi Archibald, Schoch and Rigby, 1983

Holotype—NMMNH 27707 (originally described under catalogue number UNM B1700), palate with right P4-M2, left P3-M2,

isolated right P2, bone fragment with right P3, right dentary with p4-m3, left dentary with p3-m1 and isolated right p2.

Diagnosis—Differs from *C. entoconus* and *C. cophater* in being smaller (20-30%); also differs from the former in having a well-developed upper molar metaconules and P4 parastyles.

Distribution—Lower Paleocene (Puercan) of New Mexico and Utah.

Comment—Robison (1986) described *C. utahensis* from Utah and compared the new species with *C. entoconus* and *C. cophater* but not with *C. kohlbergi*. Williamson (1996) pointed out that *C. utahensis* is a junior subjective synonym of *C. kohlbergi*. Both species are very close in size and in morphology, so we concur.

Oxyacodon apiculatus Osborn and Earle, 1895

Holotype—AMNH 816, damaged left dentary fragment with p4-m2.

Diagnosis—Differs from *O. agapetillus* in being slightly larger (15-20%) and in having different M1/P4 and m1/p4 ratios, where the M1 is almost the same length as the P4 and the m1 length is close to that of the p4. Differs from *O. priscilla* in being slightly larger (15-20%), in having an ectoflexus on the upper molars, reduced M3 metacone and large M3 parastyle.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Comment—Van Valen (1978) described *O. marshater* based on an isolated m2 with the following diagnosis: “m2 transverse, paraconid a small cusp, metacristid present, entoconid as large as relatively large hypoconulid.” Archibald et al. (1983a) noted that the validity of this species is dubious, but the large size (comparable to *O. apiculatus*) may prove its validity. *O. marshater* is indeed larger than *O. priscilla* but does not differ significantly in size from *O. apiculatus*. Such morphological features as enlarged entoconid and vestigial metacristid are found in both *O. marshater* and *O. apiculatus*, so they are conspecific, and *O. marshater* is a junior subjective synonym of *O. apiculatus*.

Oxyacodon agapetillus (Cope, 1884)

Lectotype—AMNH 3557, dentary fragment with m1-2.

Diagnosis—Differs from *O. apiculatus* in being slightly smaller (15-20%) and in having a different M1/P4 to m1/p4 ratio, where the M1 is longer and wider than the P4 and the m1 is longer than the p4. Differs from *O. priscilla* in having an ectoflexus on upper molars, reduced M3 metacone and large M3 parastyle.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Comment—Matthew (1937) designated two dentary fragments as the holotype of this species. Van Valen (1978) restricted the holotype to one fragment and described a new genus and species, *Fimbrethil ambaronae*, based on the other one. Archibald et al. (1983a) demonstrated that the two specimens belong to one species and synonymized *Fimbrethil ambaronae* with *Oxyacodon agapetillus*, but retained one specimen as a holotype for the latter species (AMNH 3557).

Oxyacodon priscilla Matthew, 1937

Fig. 17

Holotype—AMNH 3547, right dentary fragment with p2-m3.

Diagnosis—Differs from *O. apiculatus* in being slightly smaller (15-25%), in lacking the upper molar ectoflexus and in having an unreduced M3 metacone; also differs in the M1/P4 ratio, where the M1 is longer and wider than the P4. Differs from *O. agapetillus* in lacking the upper molar ectoflexus, in having an unreduced M3 metacone, and a weak M3 parastyle.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Comment—Van Valen (1978) suggested that *O. priscilla* and *Escatepos campi* are junior synonyms of *O. agapetillus*. Archibald et al. (1983a) argued that *O. priscilla* is a distinct species. They also described *O. ferronensis*, which is almost identical to *O. priscilla* in both size and

morphology. The only character that differentiates the two species is the length ratio between M1 and M2. This difference is only 2-3%, which may be due to intraspecific variation and does not warrant specific separation. In such features as lack of the ectoflexus on the upper molars and hypocone position, "*O. ferronensis*" is identical to *O. priscilla*, so we consider them synonymous.

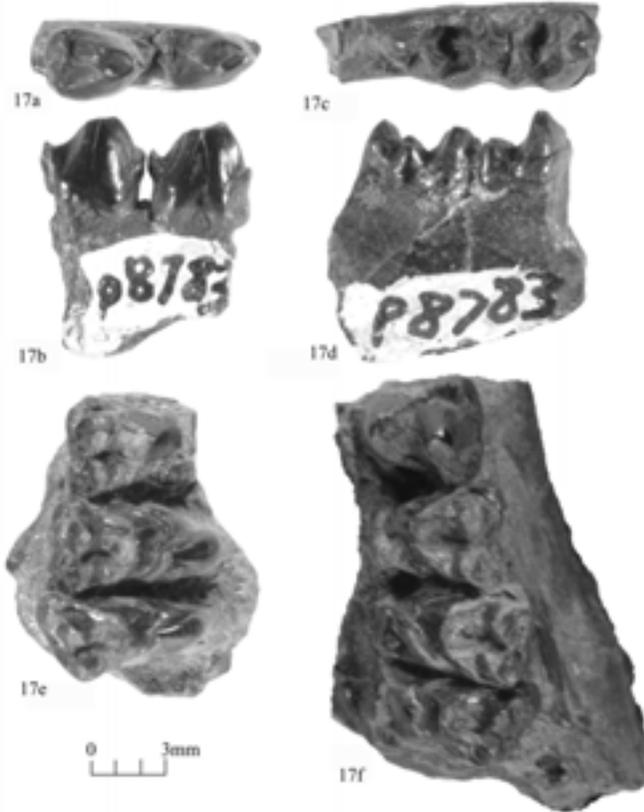


FIGURE 17. *Oxyacodon priscilla*, NMMNH 8783, right dentary fragment with p2-3, occlusal (a) and labial (b) views; right dentary fragment with m2-3, occlusal (c) and labial (d) views; right maxillary fragment with M1-3, occlusal view (e); left maxillary fragment with P4-M3, occlusal view (f).

Suborder Phenacodonta McKenna, 1975

Superfamily Hyopsodontoidea Trouessart, 1879

Family Hyopsodontidae Trouessart, 1879

Subfamily Hyopsodontinae Trouessart, 1879

***Litomylus osceolae* Van Valen, 1978**

Holotype—AMNH 16039, left dentary fragment with m1-3.

Diagnosis—Molars relatively and absolutely more elongate than in *L. dissentaneus*; m3 is much more elongate and the m2 talonid basin is open. Differs from *L. dissentaneus* in having rhomboid-shaped talonid basins.

Distribution—Lower Paleocene (Torrejonian) of New Mexico and Wyoming.

Comment—Rigby (1980) noted that the size differences between *L. osceolae* and *L. dissentaneus* are insignificant. Williamson (1996) pointed out that a rounded anterior margin of the p4 cannot be used to differentiate these two species and suggested that *L. osceoli* is a junior subjective synonym of *L. dissentaneus*. The difference in size is indeed minute, but the shape of the lower molars and especially of the m3 differs significantly in these two species, so we consider *L. osceoli* a valid species.

Superfamily Mioclaenoidea Osborn et Earle, 1895

Family Mioclaenidae Osborn et Earle, 1895

Subfamily Mioclaeninae Osborn et Earle, 1895

***Mioclaenus turgidus* Cope, 1881**

Fig. 18

Holotype—AMNH 3135, dentary fragments with left p4-m2, right p4-m1 and left maxillary fragment with P4-M2.

Diagnosis—Lower molar paraconids completely reduced, M3 and m3 extremely reduced and premolars inflated.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

Comment—One of the most advanced mioclaenids known.



FIGURE 18. *Mioclaenus turgidus*, NMMNH 18846, right dentary fragment with p3-m2, occlusal (a) and labial (b) views.

***Choeroclaenus turgidunculus* (Cope, 1888)**

Fig. 19

Holotype—AMNH 3291, maxillary fragment with P4-M2.

Diagnosis—Differs from *Litaletes* species in having reduced lower molar paraconids that are pressed onto the metaconids. Differs from *Mioclaenus turgidus* in retaining lower molar paraconids and less reduced M3/m3. Differs from *Promioclaenus* and *Ellipsodon* species in having differentiated entoconids and hypoconulids on m1-2. Differs from *Tiznatzinia prisca* in having closed talonid basins of lower molars.

Distribution—Lower Paleocene (Puercan) of New Mexico.

***Ellipsodon inaequidens* (Cope, 1884)**

Holotype—AMNH 3095, skull fragments with left P2-3, M1-3 and right P4, M2-3.

Diagnosis—Differs from *E. grangeri* in its smaller size (20%) and in having a weak lower molar precingulid that does not form additional cusps.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

***Ellipsodon grangeri* Wilson, 1956**

Fig. 20

Holotype—KUPV 7833, mandibular fragments with right m1-3 and left m3.

Diagnosis—Differs from *E. inaequidens* in being larger and in having a strong lower molar precingulid that often forms additional cusps.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

Comment—Our attempt to locate the holotype in the KUPV collection was unsuccessful.

***Promioclaenus acolytus* (Cope, 1882)**

Fig. 21

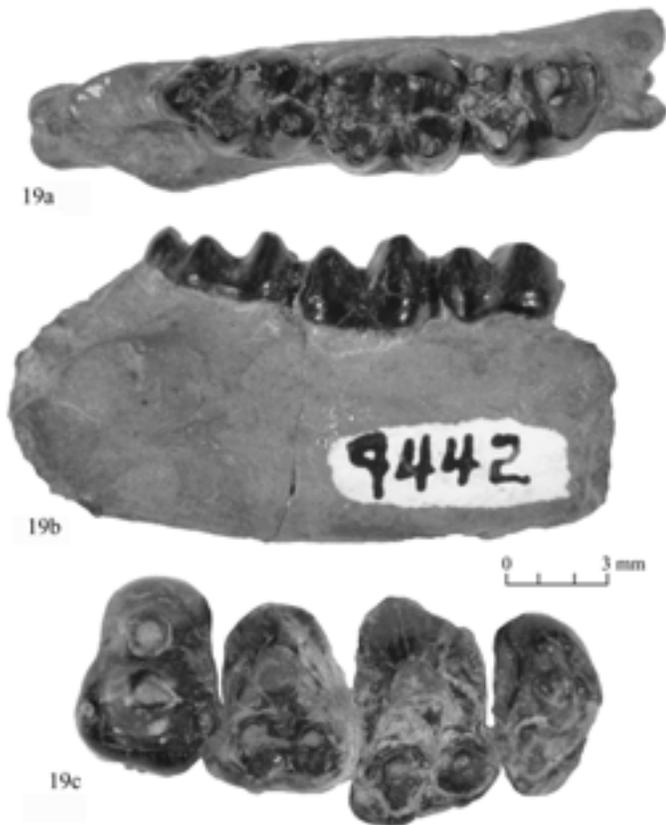


FIGURE 19. *Choeroclaenus turgidunculus*, KUVV 9442, right mandibular fragment with m1-3, occlusal (a) and labial (b) views; KUVV 9444, right P4-M3, occlusal view (c).

Holotype—AMNH 3208, left maxillary fragment with P3-M2 and left dentary fragment with p3-m3.

Diagnosis—Differs from *P. lemuroides* and *P. pipiringosi* in being 20% smaller; differs from *P. wilsoni* in having a less molarized p4 that does not have a metaconid.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

Comment—Rigby (1980) demonstrated that *Ellipsodon aquilonius* Simpson, 1935, which Wilson (1956) referred to *Promioclænus*, is a junior subjective synonym of *P. acolytus*.

***Promioclænus lemuroides* (Matthew, 1897)**

Fig. 22

Holotype—AMNH 16403, mandibular fragments with left p2-m3 and right p4-m2.

Diagnosis—The incisors are small and the canine is larger, about the size of the p1. The p1 is single-rooted and the other lower premolars are double-rooted. The molars are simple and flattened and the talonid basin is shallow. Differs from *P. acolytus* in being 20% larger; differs from *P. pipiringosi* in having more flattened premolars. Differs from *P. wilsoni* in having a less molarized p4 that does not have a metaconid.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

***Promioclænus wilsoni* Van Valen, 1978**

Holotype—KUVV 9446, skull fragment with left P4-M3 and right P3-M2, right dentary fragment with p1, p3-m2, left dentary fragment with p2-3.

Diagnosis—Teeth are less flattened than in other species of the genus and the posterior cingulum of the upper molars is interrupted by a labial cingulum. The p4 has a distinct metaconid and tall paraconid that is situated close to the protoconid.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

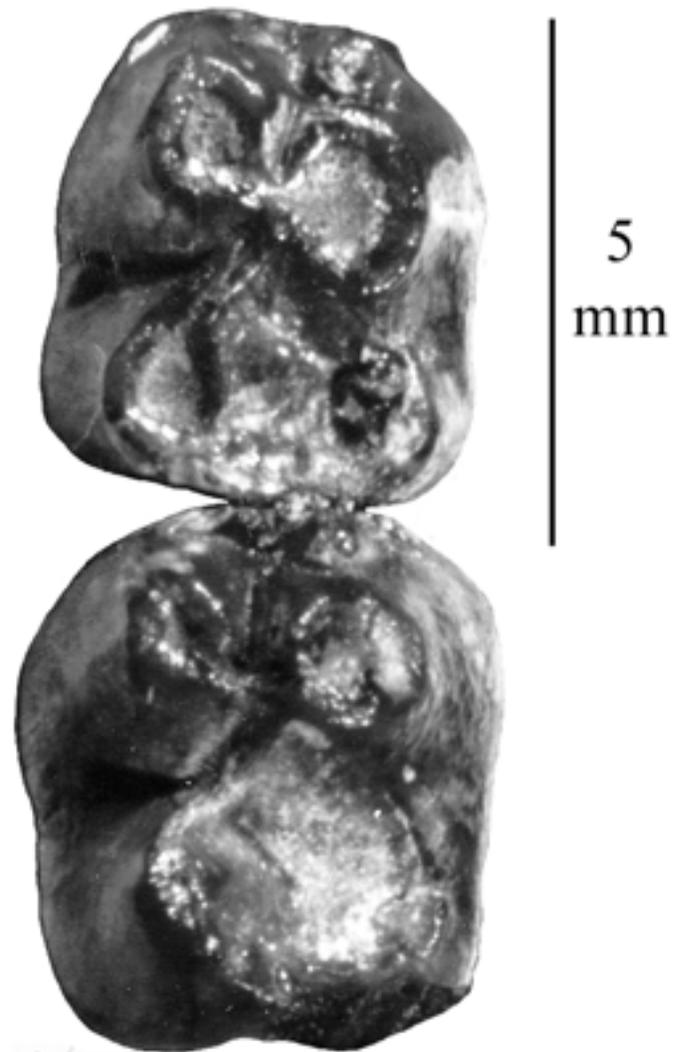


FIGURE 20. *Ellipsodon grangeri*, NMMNH 15852, left m1-2, occlusal view (a).

***Tiznatzinia vanderhoofi* Simpson, 1936**

Holotype—UCMP-31264, left dentary with p4-m2.

Diagnosis—Lower molar paraconids somewhat reduced, but always present. P4/p4 are elongate. The talonid basins of the lower molars are open. Differs from *Litaletes* species in having slightly reduced paraconids. Differs from *M. turgidus* in having less reduced M3/m3 and lower molar paraconids. Differs from *Ch. turgidunculus* in having open lower molar talonid basins. Differs from *T. prisca* in its much smaller size, more laterally compressed p4 and narrower lower molars.

Distribution—Lower Paleocene (Puercan) of New Mexico.

***Tiznatzinia prisca* (Matthew, 1937)**

Holotype—AMNH 16403, left dentary fragment with p2-m3 and right dentary fragment with p3-m3.

Diagnosis—The m3 is slightly reduced and m1-3 are very short and wide. The paraconids are distinct on all the lower molars. Differs from *T. vanderhoofi* in being significantly larger and in having a wider p4 and m1-2. The paraconid is more reduced than in *T. vanderhoofi*.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Comment—Simpson (1936) referred three species to his new genus *Tiznatzinia*: *T. vanderhoofi*, "*Mioclænus*" *turgidunculus* and

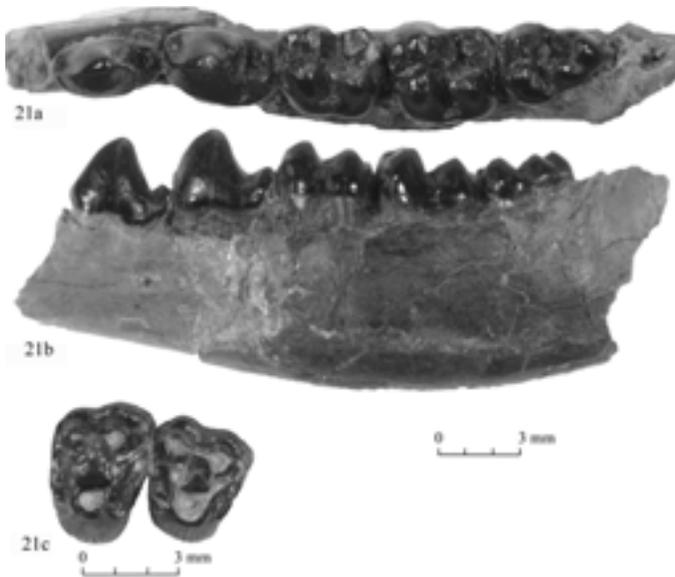


FIGURE 21. *Promioclæmus acolytus*, KUVV 9626, left dentary fragment with p3-m3, occlusal (a) and labial (b) views; KUVV 9623, right maxillary fragment with M1-2, occlusal view (c).

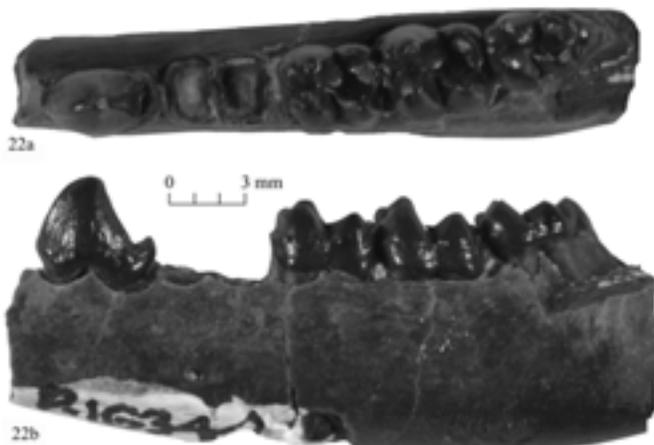


FIGURE 22. *Promioclæmus lemuroides*, NMMNH 16349, left mandibular fragment with p4, m1-3, occlusal (a) and labial (b) views.

“*Ellipsodon*” *priscus*. Later, “*Mioclæmus*” *turgidunculus* was referred to a new genus *Choeroclæmus* (Simpson, 1937). Van Valen (1978) synonymized *Tiznatzinia* with *Promioclæmus* and referred “*Ellipsodon*” *priscus* to a new genus, *Bomburia*. Cifelli (1983) resurrected the genus *Tiznatzinia* with a single species *T. vanderhoofi*, synonymized *Bomburia* with *Ellipsodon* and placed “*Bomburia*” *prisca* back in *Ellipsodon*. Williamson (1996) insisted on retaining the genus *Bomburia* based on the more archaic morphology of “*Bomburia*” *prisca* compared to *Ellipsodon* species. In the original diagnosis of *Tiznatzinia*, Simpson (1936) indicated that species of this genus are more primitive than the species of *Ellipsodon*. The morphology of “*Bomburia*” *prisca* fits the diagnosis of the genus *Tiznatzinia* well, so we suggest that “*Ellipsodon*” *priscus* should be placed in *Tiznatzinia* and *Bomburia* is a junior synonym of *Tiznatzinia*.

Subfamily Protoseleninae Rigby, 1980

Protoselene opisthacus (Cope, 1882)

Fig. 23

Holotype—AMNH 3275, left dentary with p4-m3, right dentary with m1-3.

Diagnosis—The premolars are not flattened and slightly inflated. The P4 has a well-developed protocone and a distinct metacone. The p4 has a well-developed talonid. Differs from *P. bombadili* in larger size and developed mesostyle. Differs from *P. novissimus* in deeper talonid basins, taller crests and more isolated lower molar paraconids. Differs from *P. griphus* in having a well-differentiated P4 protocone.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

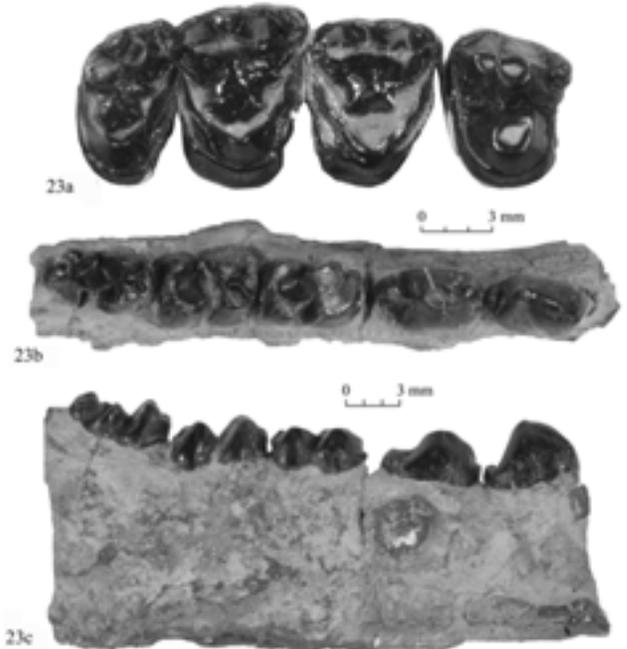


FIGURE 23. *Protoselene opisthacus*, KUVV 7851, right maxillary fragment with P4-M3, occlusal view (a); KUVV 14007, right dentary fragment with p3-m3, occlusal (b) and labial (c) views.

Protoselene bombadili Van Valen, 1978

Holotype—USNM 23285, left maxillary fragment with M2.

Diagnosis—The M2 is rounded, and the cingulum is extremely strong, interrupted at the lingual base of the protocone. There is a small parastyle on the upper molars and the mesostyle is not developed. Differs from other species of *Protoselene* in being much smaller. Differs from *P. opisthacus* in lacking the upper molar hypocones and mesostyles.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Superfamily Phenacodontoidea McKenna, 1975

Family Phenacodontidae Cope, 1881

Subfamily Phenacodontinae Cope, 1881

Tetraclaenodon puercensis (Cope, 1881)

Fig. 24

Holotype—AMNH 3832, left dentary with m2-3, right dentary with m1-3 and left maxillary fragment with M1-3.

Diagnosis—The tooth formula is complete. There are short diastemata between the C/c and P1/p1. P1/p1 simple, with a single cusp, P3/p3 is relatively molarized. M1-2 have six cusps and M3 is somewhat reduced. Lower molars are rectangular in shape. The lower molar paraconid is weak, but distinct. There is an entoconulid on all lower molars. Hypoconulid is large on all lower molars. Differs from *Phenacodus* and *Copecion* species in lacking the mesostyle on upper molars. Differs from *Copecion* species in having shorter premolars.

Distribution—Lower Paleocene (Torrejonian) of North America.

Comment—There are two size groups of Torrejonian *Tetraclaenodon*—the larger one that includes the type and the group that

includes smaller specimens that were referred to a different species, *T. symbolicus* by Simpson (1935). Thewissen (1990) doubted the validity of the latter species and synonymized it with *T. puercensis*. Williamson (1996) recognized two subspecies of *T. puercensis*: *T. puercensis puercensis* and *T. puercensis pliciferus*. A newly discovered specimen of a very small *Tetraclaenodon* from the San Juan Basin, represented by an almost complete skeleton, is currently under study. We hope that it will

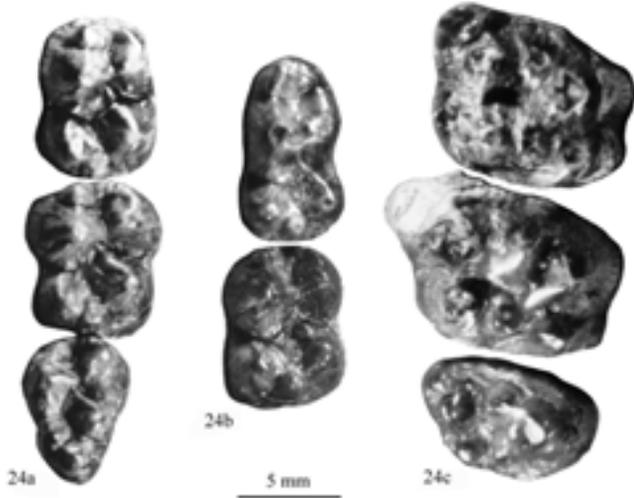


FIGURE 24. *Tetraclaenodon puercensis*, NMMNH 16136, right m1-3, occlusal view (a); NMMNH 15782, right dp4-m1, occlusal view (b); NMMNH 16221, right M1-3, occlusal view (c).

shed some light on the complex taxonomy of *Tetraclaenodon*.

Order Acrodi Matthew, 1909
Family Mesonychidae Cope, 1875
Dissacus navajovius (Cope, 1881)
Fig. 25

Holotype—AMNH 3356, mandibular fragments with left p4-m3 and right p3-m3.

Diagnosis—Differs from *Ankalagon saurognathus* in its much smaller size.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

Ankalagon saurognathus (Matthew, 1897)
Fig. 26

Holotype—AMNH 2454, left complete dentary with c, p1-4 and m1-3.

Diagnosis—Differs from *Dissacus navajovius* in being much larger.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

Comment—The species was originally described as *Dissacus*, but was placed in a new genus by Van Valen (1980).

Family Triisodontidae Scott, 1892
Triisodon quivirensis Cope, 1881
Fig. 27

Holotype—AMNH 3352, dentary fragments with canines, dp4-m2.

Diagnosis—Differs from *T. crassiscuspis* in much larger size. Differs from *Eoconodon* species in having somewhat reduced m3.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

Comment—Van Valen (1978) synonymized *Triisodon antiquus* with *T. quivirensis*. Tomida (1981) argued that *T. antiquus* is valid. Williamson (1996) evaluated a larger sample of *Triisodon* and stated that the synonymy was justified, and we concur.



FIGURE 25. *Dissacus navajovius*, AMNH 3356, mandible with left p4-m3 and right p2-m3 (holotype), occlusal (a), right labial (b) and left labial (c) views.



FIGURE 26. *Ankalagon saurognathus*, AMNH 2454, left dentary with c-m3 (holotype), occlusal (a) and labial (b) views; AMNH 776, left P2-M3 and right P3-M3, occlusal view (c).

Triisodon crassiscuspis (Cope, 1882)

Holotype—AMNH 3178, dentary with m2 talonid and m3.

Diagnosis—Differs from *T. quivirensis* in being significantly smaller and in having a more elongate P3. Differs from *Eoconodon* species in having somewhat reduced m3.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

Comment—Matthew (1937) referred “*Conoryctes*” *crassiscuspis* Cope, 1882 (= *Triisodon rusticus* Cope, 1884) to *Triisodon*. Van Valen (1978) placed this species in *Goniaconodon* following Scott’s (1892) referral of *T. rusticus* to that genus. Based on a new specimen, Williamson (1996) argued that “*Conoryctes*” *crassiscuspis* belongs to *Triisodon*, and we concur.

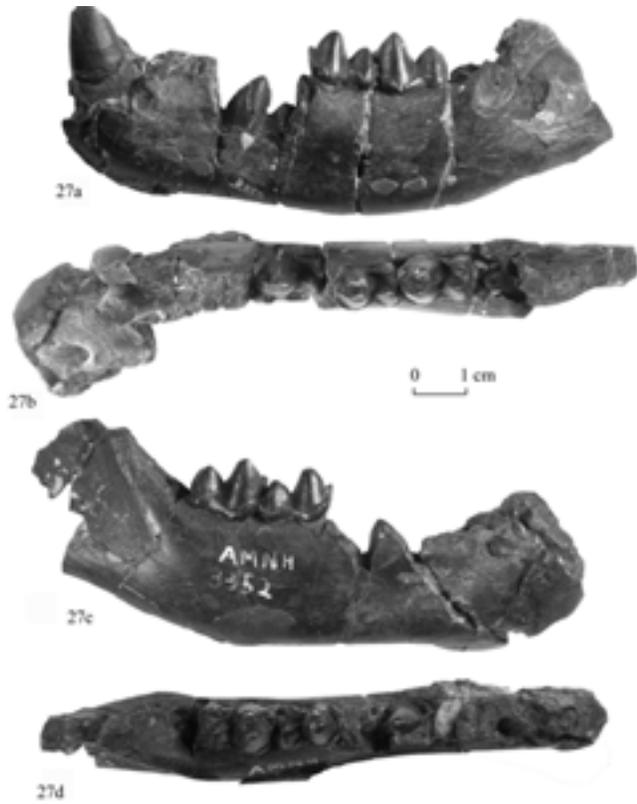


FIGURE 27. *Triisodon quivirens*, AMNH 3352, right dentary with c, p4-m2, and erupting m3, labial (a) and occlusal (b) views, right dentary with p4-m2, labial (c) and occlusal (d) views.

***Eoconodon gaudrianus* (Cope, 1888)**

Fig. 28

Holotype—AMNH 3200, dentary and maxillary fragments, calcanem.

Diagnosis—Intermediate in size between the other two San Juan Basin species. Differs from *Triisodon* species in having an unreduced m3.

Distribution—Lower Paleocene (Puercan) of New Mexico.



FIGURE 28. *Eoconodon gaudrianus*, AMNH 58116, right p4 talonid, m1-3, occlusal (a) and labial (b) views.

***Eoconodon coryphaeus* (Cope, 1885)**

Fig. 29

Lectotype—AMNH 3181, incomplete skull.

Diagnosis—Largest species of *Eoconodon*. Differs from *Triisodon* species in having an unreduced m3.

Distribution—Lower Paleocene (Puercan) of New Mexico.
Comment—Van Valen (1978) indicated that the holotype of *Triisodon heilprinianus* Cope, 1882 is “an unworn molar referable to the taeniodont *Conoryctes comma*.” Schoch and Lucas (1981) argued that the specimen belongs to *Huerfanodon*. Van Valen (1978) indicated that the next available name is “*Sarcothraustes*” *coryphaeus* and identified the skull (AMNH 3181) as the type specimen.



FIGURE 29. *Eoconodon coryphaeus*, AMNH 16329, left dentary with c-m3, occlusal (a) and labial (b) views; AMNH 764, right P4-M3, occlusal view (c).

***Eoconodon ginibitohia* Clemens and Williamson, 2005**

Holotype—NMMNH 21622, left dentary fragment with p4, m2-3.

Diagnosis—Differs from other species from San Juan Basin in being significantly smaller (Clemens and Williamson, 2005). Differs from *Triisodon* species in having an unreduced m3.

Distribution—Lower Paleocene (Puercan) of New Mexico.

Comment—The holotype specimen was provisionally identified as *Eoconodon* cf. *E. copanus* (Williamson and Lucas, 1993), and later as *Eoconodon* n. sp. (Williamson, 1996).

***Goniocodon levisanus* (Cope, 1883)**

Fig. 30

Holotype—AMNH 3217, right dentary fragment with p4 fragment and m1-2.

Diagnosis—Differs from *Eoconodon* species in having more triangular upper molars. Differs from *Triisodon* species in having more reduced M3 and in having a deep mandible with large symphysis.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

***Microclaenodon assurgens* (Cope, 1884)**

Holotype—AMNH 3215, left dentary fragment with m1-3.

Diagnosis—Differs from other triisodontids in its minute size, gracile lower jaw morphology and less robust dentition.

Distribution—Lower Paleocene (Torrejonian) of New Mexico.

Comment—Scott (1892) placed *Triisodon assurgens* Cope, 1884 in a new genus, *Microclaenodon*, which he referred to Triisodontidae.

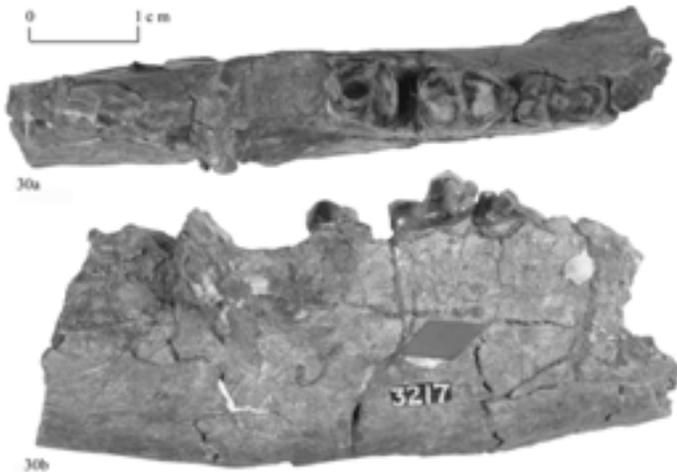


FIGURE 30. *Goniacodon levisanus*, AMNH 3217, right dentary with damaged m1-2, occlusal (a) and labial (b) views.

Matthew (1937) placed this genus in Mesonychidae, noting numerous differences from *Dissacus*. Gingerich (1981) argued against the inclusion of this genus in Mesonychidae. Williamson (1996), following Matthew (1937) and Szalay (1969), placed *M. assurgens* in Mesonychidae. In our opinion *Microclaeonodon* does not possess the distinctive morphological features of the dentition characteristic of mesonychids with extremely well pronounced shearing surfaces such as those of *Dissacus*. The more bunodont dentition of *Microclaeonodon* resembles the molars of triisodontids, such as *Eoconodon*. Because of that we tentatively place this species in Triisodontidae.

STRATIGRAPHIC DISTRIBUTION OF SAN JUAN BASIN ARCHAIC UNGULATES

The Paleocene mammal biostratigraphy of the San Juan Basin was thoroughly studied by various authors (Williamson and Lucas, 1992, 1993; Williamson, 1996), so we will concentrate on analyzing the distribution of archaic ungulates throughout the Paleocene faunal zones of the San Juan Basin. Wood et al. (1941) introduced the concepts of Puercan and Torrejonian North American land-mammal “ages” (NALMA). These concepts evolved for more than half a century, and the recent understanding of these two biochronological units and a brief history can be found in Lofgren et al. (2004). The Paleocene Nacimiento Formation of the San Juan Basin includes mammal assemblages that correspond to part of the Puercan and most of the Torrejonian NALMAs.

The Puercan NALMA is usually subdivided into three to five interval zones: Pu0, Pu1, Pu2, Pu3 and Pu4. In the latest revision of NALMAs, Lofgren et al. (2004) recognized three zones: Pu1 (*Protungulatum/Ectoconus*), Pu2 (*Ectoconus/Taeniolabis taoensis*) and Pu3 (*Taeniolabis taoensis/Periptychus carinidens*). Faunas that correspond to two of these zones (Pu2 and Pu3) are present in the San Juan Basin. Both interval zones are recognized by the appearance of archaic ungulate species.

Pu2 (*Ectoconus/Taeniolabis taoensis* interval zone) is recognized by the first appearance of the periptychid genus *Ectoconus*. In general this zone is characterized by the presence of archaic oxyclaenine arctocyonids of the genera *Oxyclaenus* and *Loxolophus*, archaic anisonchine periptychids of the genera *Conacodon*, *Oxyacodon* and *Hemithlaeus* and the appearance of the primitive mioclaenids *Tiznatzinia*, *Choeroclaenus* and *Bubogonia*.

Pu3 (*Taeniolabis taoensis/Periptychus carinidens* interval zone) is recognized as an interval between the first appearance of the multituberculate *Taeniolabis taoensis* and the first appearance of the archaic ungulate *Periptychus carinidens*, which is an index fossil of the Torrejonian NALMA. Although very similar in faunal composition to

Pu2, Pu3 is characterized by the wider diversity of oxyclaenine arctocyonids and triisodontids of the genus *Eoconodon*. A very distinctive change is observed in the archaic ungulate family Periptychidae. Most of the archaic representatives of the subfamily Anisonchinae are absent from the Pu3 interval zone, while the first *Periptychus* species — *P. coarctatus* — makes its appearance in this zone. There is no change in the mioclaenid faunas between the Pu2 and Pu3 zones.

As expected, there is a significant faunal change between the Puercan and Torrejonian archaic ungulate faunas. The Torrejonian NALMA is traditionally subdivided into three interval zones, To1, To2 and To3, which were redefined by Lofgren et al. (2004) as following: To1 (*Periptychus carinidens/Protoselene opisthacus* zone), To2 (*Protoselene opisthacus/Mixodectes pungens* zone) and To3 (*Mixodectes pungens/Plesiadapis praecursor* zone).

To1 (*Periptychus carinidens/Protoselene opisthacus* interval zone) is recognized by the first appearance of the archaic ungulate *Periptychus carinidens*. There are major changes in the archaic ungulate faunas between Pu3 and To1. These changes involve the disappearance of oxyclaenid arctocyonids and their replacement by such new genera as *Tricentes* and *Deuterogonodon*. *Periptychus* species change between Pu3-To1, from *P. coarctatus* to *P. carinidens*. Neither *Ectoconus* nor any of the “conacodontine” anisonchines (*Conacodon*, *Oxyacodon*) cross the Puercan-Torrejonian boundary. *Anisonchus sectorius* replaces *A. gillianus* in the Torrejonian faunas of the San Juan Basin. The diversity of Mioclaenidae changes dramatically in the Torrejonian with the extinction of three genera (*Bubogonia*, *Choeroclaenus* and *Tiznatzinia*) and appearance of two new genera, *Mioclaenus* and *Promioclaenus*. The first phenacodontid, *Tetraclaenodon puercensis*, makes its appearance in To1 and persists throughout the Torrejonian NALMA.

There are also numerous differences in faunal composition between To1 and To2. They involve mostly appearances of new taxa, rather than extinction of the existing species of archaic ungulates. Generally, To2 (*Protoselene opisthacus/Mixodectes pungens* interval zone) is characterized by the extensive radiation of chriacine and arctocyonine arctocyonids that replaced archaic Oxyclaenidae in the Torrejonian faunas. Two large species of *Artocyon* co-exist in To2 — *A. ferox* and *A. corrugatus*. *Chriacus* species along with *Tricentes* become some of the most abundant arctocyonids in To2. The only change in the periptychid family is the appearance of *Haploconus angustus* that is characteristic of this zone. Hyopsodontid condylarths make their first appearance in the San Juan Basin in To2, represented by a single species, *Litomylus osceolae*. Mioclaenids underwent further diversification during To2 with the appearance of five new species: *Protoselene opisthacus*, two species of *Ellipsodon* (*E. inaequidens* and *E. grangeri*) and two species of *Promioclaenus* (*P. acolytus* and *P. wilsoni*). One of the major changes between the To1 and To2 is the appearance of the family Mesonychidae and reappearance of triisodontids in To2, which were absent from To1. Mesonychids are represented by a single large species—*Angalagon saurognathus*. The radiation of triisodontids resulted in the appearance of three new genera, *Triisodon*, *Goniacodon* and *Microclaeonodon*.

The final zone of the Torrejonian in the San Juan Basin is To3 (*Mixodectes pungens/Plesiadapis praecursor* interval zone). There are only few differences in the archaic ungulate faunas of To2 and To3. Two more genera of arctocyonids appear in To3 of the San Juan Basin, *Colpoclaenus* and *Prothryptacodon*. Only two genera of periptychids make it into To3 — *Periptychus carinidens* and *Anisonchus sectorius*. Mioclaenid diversity dwindles to four species. *Triisodon* species do not extend into To3, while the mesonychids are represented by two species in this zone — *Ankalagon saurognathus* and *Dissacus navajovius*.

Archaic ungulates are abundant throughout the Paleocene deposits of the San Juan Basin and can be efficiently used for the biostratigraphy of the region. Several species of archaic ungulates, such as *Ectoconus ditrigonus*, *Periptychus coarctatus*, *Periptychus carinidens*, *Protoselene opisthacus* and several others are index fossils for certain interval zones within the Puercan and Torrejonian NALMAs.

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APPRAISAL OF FOSSIL RESOURCES AND SPECIMENS

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Abstract—Appraisal and assessment of paleontological resources and fossil specimens play important roles in the management of paleontological resources on federal lands. Appraisals are opinions of market value while assessments are estimates of value. The former are prepared by licensed or certified professional appraisers; the latter may be prepared by a professional, but not necessarily an appraiser. Valuations can include the appraisal of fossil specimens for litigation and museum property purposes; resource value estimates and damage assessments for fossil theft cases; and resource value estimates for lands actions. Paleontological resource values can be categorized into two types: natural resource value — scientific and heritage — and fair-market or commercial value. Natural resource values are intangible non-market values and may include scientific, museum and heritage values, as well as resource potential. Fair-market appraisals of fossil resources, whether as real or personal property, can be estimated using standard appraisal methods. The comparable sales method may work best in the appraisal of fossil specimens for litigation purposes. The approach is straightforward. It is tied to whatever price a buyer is willing to pay, and what the market will bare. In 1997, “Sue,” the most complete *Tyrannosaurus rex* fossil specimen at the time, sold at auction for \$8.36 million.

INTRODUCTION

Paleontological resources are important natural resources and national assets in the management of federal lands. The scientific value of paleontological resources is without question. Fossils are evidence of past life on Earth and are indispensable indicators of geologic time in the stratigraphic record. Fossils allow scientists to study changes in paleoecosystems and paleoclimates, both essential tools to understanding the history of life. Recognition by the Federal Accounting Standards Advisory Board (FASAB) of the importance of stewardship resources, including “heritage assets” and “stewardship lands,” and the government’s responsibility for and accountability of these resources has furthered the importance of paleontological resources as “uniquely governmental” assets. Such programs as “Preserve America” and “Save America’s Treasures” have brought additional recognition of paleontological resources as having heritage values in concert with the traditional cultural and historical resources. Fossil resources on federal lands, particularly fossils occurring on federal lands with protective mandates, such as the National Park Service, and multiple-use mandates, such as the Bureau of Land Management and the Forest Service, are important national treasures to be enjoyed by all. With the ever-increasing fascination of dinosaur fossil discoveries and the increasing popularity of participation in fossil digs, federal paleontological resources fall prey to the increased likelihood of fossil theft and vandalism. Therefore, the appraisal and assessment of paleontological resources become important tools in the management and accountability of this uniquely governmental asset.

APPRAISAL VS. ASSESSMENT

An appraisal is an opinion of market value of a specific type of property in a specific period of time by a professional appraiser. Professional appraisers are usually certified or licensed by a professional trade organization in a particular area of expertise, and issue opinions (appraisals) in accordance with the “Uniform Standards of Professional Appraisal Practice (USPAP).” An assessment is also an estimate of value of property, but the assessor need not be a professional appraiser.

When estimating the value of paleontological resources, it is important to enumerate the specific purpose for the evaluation, and the level of credibility and certainty required to support the intent and use of the evaluation. An appraisal or opinion of value for fossil specimens (personal property) or *in situ* paleontological resources (real property)

would have the highest level of credibility and certainty because it is prepared by and sworn to by a licensed or certified appraiser using uniform standards for appraisals. This level of certification may be required in litigation to satisfy evidentiary requirements and lands actions involving transfers of title. An assessment of value, whether for an estimate of value for fossil specimens (personal property) or *in situ* paleontological resources (real property), would have a lesser degree of credibility and certainty because it may be prepared by a resource specialist or other professional generally for management purposes.

REAL VS. PERSONAL PROPERTY

Real property is land (real estate) and any associated improvements or fixtures such as buildings and fences. Personal property is any property that is not real property and is usually movable and transportable. Intangible property, such as patents, stocks, and copyright (intellectual property), are also considered personal property. *In situ* paleontological resources are considered real property and part of the surface estate (real estate). Once the fossil specimen has been excavated and removed from the surface estate, it becomes personal property.

Appraisal and assessment of *in situ* paleontological resources may be associated with the evaluation of real property for federal lands actions, such as land sales or other land transfers, and evaluation of stewardship resources, or resource potential. Appraisals of fossil specimens (personal property) are usually associated with the need for certified value estimates for litigation involving fossil theft cases or resource damage assessments, and valuation of museum property.

APPRAISAL OF PROPERTY: STANDARD METHODS

There are three standard methods used for the appraisal of real and personal property: 1) the market-based or comparable sales method; 2) the cost approach; and 3) the income approach. In the comparable sales method, the opinion of fair-market value is based on the comparison of the subject property with other sales or transfers of property similar to the subject property. The cost approach uses the cost of replacement of the subject property with a similar property. In the income approach, the subject property’s ability to generate income is used to appraise its value when the subject property’s worth is the same as its income-producing potential. The comparable sales method may work best for the valuation of fossil specimens, especially in appraising

fossil specimens for litigation purposes or in estimating value of museum property. However, caution should be used when using the comparable sales method for establishing fair-market value for evidentiary purposes in litigation because proper documentation of legal sales of fossils may be difficult to find. In that case, the cost approach, i.e., using replacement costs of similar specimens available on the open market or current appraisals of museum property may be another alternative.

Highest and best use of the subject property is an important concept in the final opinion of value, especially in the appraisal of real property. The value added to the surface estate of *in situ* paleontological resources must be considered where there is known potential for the occurrence of paleontological resources. If a known fossil occurrence is proven to be an isolated occurrence, it may be easily excavated and recovered, and the opinion of value may exclude any potential for additional occurrences. In the context of personal property, highest and best use may be equated to the choice of the appropriate market, such as museum property, research, or educational use.

For a credible appraisal of real and personal property, the most current version of the "Uniform Standards of Professional Appraisal Practice" must be followed. An assessment of value in lieu of an appraisal may be adequate for internal agency actions; but to be acceptable in litigation, an opinion of value by a professional appraiser may be necessary. Table 1 summarizes the basic reporting requirements for an appraisal of personal property under Standard 8 for personal property of the "Uniform Standards of Professional Appraisal Practice." The reporting requirements for an appraisal of real property under USPAP Standard 2 are similar.

ASSESSMENT OF VALUE

Assessment of paleontological resources involves the assessment of natural resource value which is a very intangible and subjective concept. For paleontological resources, natural resource values can be categorized into personal property values and real property values. In the first category, paleontological resources may be assessed for scientific or museum property values. In the second, paleontological resources may be assessed for stewardship value and resource potential.

Scientific value, or significance, is a subjective concept that for a paleontological resource would include its contribution and importance to the history of life on Earth, i.e., specimen-based significance; or its value as a type specimen or stratigraphic indicator, i.e., context-based significance. Under the Archaeological Resources Protection Act of 1969, a fossil specimen associated with cultural resources may have both scientific and heritage values. As of this writing, scientific significance of paleontological resources is a very much debated issue. Table 2 is an example of the USDA Forest Service's effort to address the criteria for determining scientific significance of fossil resources for management purposes on National Forest System lands. In determining potential museum value of a fossil specimen, the degree of preservation of the specimen, its quality and completeness, and unique characteristics are all important. In addition, the amount of preparation and its exhibit potential are also important in assessing its museum value. Some costs typically associated with museum property are the costs of acquisition, replacement, preparation, curation, and exhibition.

Stewardship value is an important concept in the assessment of *in situ* paleontological resources. First, the land's heritage asset value, i.e., its scientific, research, and educational values, must be recognized. Second, the cost of administration and management of these stewardship lands must be considered. Resource potential may be assessed by the probability or likelihood of a geologic formation to be favorable for the occurrence and preservation of paleontological resources. Table 3 shows the USDA Forest Service's recommended classification of geological units based on the relative probability of finding paleontological resources that are of resource management concern. It is used as a planning tool for land-use planning and assessment of resource potential. The monetary value

TABLE 1. Summary of the requirements for an appraisal of personal property.

- USPAP Standard 8: Personal Property Appraisal, Reporting
- . Each appraisal report, oral or written, must clearly and accurately describe the appraisal so that it is not misleading; must contain enough information so that the users of the report understand it; and clearly and accurately disclose all assumptions, including any that are extraordinary, hypothetical or limiting.
 - . Each written appraisal must be prepared using one of the following three options, and state clearly which option is being used: Self-contained Appraisal Report, Summary Appraisal Report, or Restricted Use Appraisal Report. The self-contained appraisal report must contain:
 - . The identity of the client and any intended users.
 - . The intended use of the appraisal.
 - . A description of the property to be appraised.
 - . Any property interest to be appraised.
 - . A statement of the type and definition of value.
 - . The effective date of the appraisal and the date of the report.
 - . A description of the scope of work used to develop the appraisal.
 - . A clear statement of all extraordinary assumptions and hypothetical conditions, and any affect on the results of value.
 - . A description of the information analyzed, the appraisal procedure followed, and the reasoning that supports the analyses, opinions, and conclusions.
 - . Where appropriate, a statement of the use of the subject property at the date of valuation, as well as the use of the property reflected in the appraisal. When reporting an opinion of market value, describe the support and rationale for the appraiser's opinion of the highest and best use of the property.
 - . A statement and explanation of any permitted departures and the reasons for excluding any of the usual approaches of valuation.
 - . Include a signed certification.
 - . Each written appraisal must contain a signed certification with certain qualifying assertions.
 - . Each oral appraisal report must at minimum address substantive matters as set forth under a Summary Appraisal Report.

of the resource can usually be inferred from actual expenditures to administer and manage the lands with its resource. But, it can also be estimated by quantifying what has been called, "stakeholder values," i.e., the hypothetical cost of the willingness of any stakeholder to pay for the resource's protection, preservation for future generations, or acquisition of lands for maximum protection.

The Federal Accounting and Standards Advisory Board (FASAB) has recognized stewardship resources, i.e., heritage assets and stewardship lands, as accountable federal property for which federal agencies are responsible to report on annually. Stewardship resources are usually coincident with the mission of the federal agency and associated with a resource protection mandate. As such, stewardship lands containing heritage assets have no revenue-generating value or potential as would timber or oil and gas resources. FASAB's Statement of Federal Financial Accounting Standards (SFFAS) 29, July 2005, establishes the standards for the classification of heritage assets and stewardship lands, and how to report them. As defined by SFFAS 29, paleontologic resources can be considered federal heritage assets for their natural significance, educational importance, and value as museum property. Also under SFFAS 29, those lands containing *in situ* paleontological resources can be classified as stewardship lands. What is of interest in this discussion of federal accounting standards is the recognition of heritage assets that are unique for their natural significance and educational importance, the need for the federal government to be accountable for those assets, and the expectation for management and protection of these assets in perpetuity.

TABLE 2. USDA Forest Service Scientific Significance Criteria for Fossil Resources.

Specimen-based criteria:	Context-based criteria:
1. Represents an unknown or undescribed/unnamed taxon of invertebrate, plant or vertebrate.	1. Is associated in a relevant way with other evidence of scientific interest, providing taphonomic, ecologic, environmental, behavioral, cultural or evolutionary information.
2. Represents a rare taxon, or rare morphological/ anatomical element or feature of invertebrate, plant or vertebrate. The “rareness” criterion comprises either absolute rareness in the fossil record, or relative or contextual rareness as described below.	2. Is evidence that extends and/or constrains the stratigraphic, chronologic and/ or geographic range of a taxon or functional paraphyletic group.
3. Represents a vertebrate taxon.	
4. Exhibits an exceptional type and/or quality of preservation.	
5. Exhibits remarkable or anomalous morphological/anatomical character(s) or taphonomic alteration.	
6. Represents “soft tissue” preservation or presence of invertebrate, plant or vertebrate.	
7. Exhibits cultural affiliation, e.g., alteration or use by ancient man.	

TABLE 3. USDA Forest Service Fossil Yield Potential Classification.

- Class 1. Igneous and metamorphic geologic units (excluding volcanic ash) that are not likely to contain identifiable fossil remains.
- Class 2. Sedimentary geologic units which are not likely to contain vertebrate fossils or scientifically significant non-vertebrate (invertebrate and plant) fossils.
- Class 3. Fossiliferous geologic units whose fossil content varies in significance, abundance, and predictable occurrence. Sedimentary units or volcanic ash with unknown fossil potential are included in this class.
- Class 4. Class 4 geologic units are Class 5 units (see below) that have lowered risks of human-caused adverse impacts, resource conflicts, or natural degradation. May also include units with isolated fossil occurrences that can be mitigated by recovery.
- Class 5. Fossiliferous geologic units that regularly and predictably yield vertebrate fossils or scientifically significant non-vertebrate fossils, and that are at risk of natural degradation, resource conflicts, and/or human-caused adverse impacts.

Note: The classification is assigned by a qualified professional to geologic units based on information gathered from a literature search, geologic maps, and field verification.

Appraisal of Museum Property

Once a fossil specimen has been removed from the ground, i.e., it is no longer an *in situ* paleontological resource, and usually becomes a

part of a university or museum collection or exhibit. As museum property, certain standards for the curation of fossil specimens and their valuation are applied in accordance with a museum’s collection management plan and requirements under museum accreditation standards. Generally, appraisals of museum property are required when a specimen or collection is loaned, transferred or exchanged, or otherwise deaccessioned, or when valuing a donation for tax purposes. In some instances, museum property may be classified as controlled property of high value and would require an appraisal for insurance purposes. A current appraisal will provide the best opinion of market value in case of theft. In his 2000 paper in “Cultural Resources Management,” Dan Chure revealed the insidious theft of vertebrate fossils from museum collections as the result of increasing fossil trafficking and their value.

Resource Damage Assessments

Resource damage assessments are not opinions or assessments of value. However, in the management and protection of paleontological resources, the resource damage assessment is an important tool for assigning cost, and hence a type of “value,” for the damage, vandalism, loss, and destruction of natural resources. These costs typically include the costs of restoration, repair, or replacement of the resource and its immediate environs; the loss of scientific value or loss of use of the resource; the cost of response for professionals and law enforcement; cost of preparation, excavation, and conservation; cost of monitoring; cost of litigation, cost of an appraisal or assessment, and cost of report preparation. Associated costs considered in the damage assessment would take into account direct and indirect costs such as labor, equipment and supplies, travel, and overhead. Table 4 contains a list of some common direct and indirect costs, and costs associated with the assessment of resource damage.

TABLE 4. Business and associated costs.

Business costs
Direct costs:
Labor, including fringe benefits
Travel
Equipment
Materials and supplies
Support: computer software, telephone
Regulatory costs – fees and related costs
Indirect costs:
Overhead – rent, utilities, technical support, manager oversight, etc.
Costs associated with damage –
in addition to business costs
Cost of response – by professional and law enforcement, etc.
Cost of inventory
Cost of salvage, including excavation, preparation, transportation, conservation, storage
Cost of restoration, including stabilization, reseeding, protective barriers, etc.
Cost of repair or replacement
Cost of loss, either scientific value or use
Cost of report preparation
Cost of monitoring
Cost of litigation
Cost of appraisal

SUMMARY AND CONCLUSION

Value is the worth or desirability of the subject property. An appraisal is a professional opinion of fair-market value of the subject property in space and time. An assessment is the process of placing an estimate of value on the subject property usually for management purposes. Costs are the time, money and resources expended to manage the subject property, and can be equated to value where that value is intangible. For paleontological resources, there are no questions about the scientific, research, and educational values of these resources. Many times resource specialists are called upon to put a monetary value to a fossil specimen that is stolen, or a stewardship land value, i.e., a natural resource value, that may be vandalized or exchanged. Some of the most

irreparable crimes committed on federal lands are the vandalism and theft of paleontological, archaeological, and cultural resources. Yet, they are the hardest crimes to prosecute and get a conviction. Establishing formal guidelines for the appraisal and assessment of paleontological resources especially for litigation is sorely needed in the paleontology community. This is paper is an attempt to open a dialogue for more discussion on how to quantify the value of federal paleontological resources so that land managers can better aid in their management and protection.

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LEGISLATIVE AND REGULATORY HISTORY OF PALEONTOLOGICAL RESOURCES

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Abstract—Since the early 20th Century there have been many legislative and regulatory attempts by the federal government to protect paleontological resources within federal lands, particularly lands containing vertebrate fossils. The effort for a more consistent resource management policy for paleontological resources began in 1906 with the passage of the Antiquities Act and the designation in 1915 of Dinosaur National Monument by President Woodrow Wilson. A new legislative attempt to protect paleontological resources began in the 107th Congress after the publication of the Secretary of the Interior’s report to Congress on the status of paleontological resources management on federal lands. In order to understand the need for protection of paleontological resources on federal lands, a chronology of federal legislative and regulatory actions regarding paleontological resources since the passage of the 1906 Antiquities Act was developed by the author.

INTRODUCTION

In the Fiscal Year (FY) 1999, the Interior Appropriations Subcommittee requested that the Department of the Interior (DOI), the U.S. Department of Agriculture (USDA) Forest Service (FS) and the Smithsonian Institution prepare a report on fossil resource management on public lands. The request was to focus on (1) the need for a unified federal policy for the collection, storage and preservation of fossils; (2) the need for standards that would maximize the availability of fossils for scientific study; and (3) to evaluate the effectiveness of current methods for storing and preserving fossils collected from public lands. The report was published in May 2000 and was well received by Congress and the public (DOI, 2000). As a result of this report, in October 2001 (107th Congress), Representative McGovern of Massachusetts introduced H.R. 2974, the House version of the Paleontological Resources Preservation Act; in July 2002, Senator Akaka of Hawaii introduced S. 2727, the Senate version. The proposed legislation encompassed the following seven principles as detailed in the DOI report:

1. Fossils on federal land are a part of America’s heritage.
2. Most vertebrate fossils are rare.
3. Some invertebrate and plant fossils are rare.
4. Penalties for fossil theft should be strengthened.
5. Effective stewardship requires accurate information.
6. Federal fossil collections should be preserved and available for research and public education.
7. Federal fossil management should emphasize opportunities for public involvement.

In February 2005, the bill was reintroduced in the 109th Congress for the third time. In an attempt to understand the need for legislative and administrative protection for paleontological resources, extensive legal research was conducted by the author with a focus on the regulatory attempts by the Bureau of Land Management (BLM) and USDA Forest Service (FS). That research is summarized in Table 1 which is a chronology of the federal legislative and regulatory history of paleontological resources since the passage of the 1906 Antiquities Act.

TABLE 1. Chronology of legislative and regulatory history of paleontological resources.

YEAR	AGENCY	LEGISLATIVE OR REGULATORY MILESTONE	EXPLANATION	OUTCOME
1906	59 th Congress	Preservation of American Antiquities, P.L. 59-209	Protection of antiquities on federal lands. Prohibition against appropriating, excavating, injuring or destroying any historic or prehistoric ruin or monument, or any object of antiquity. Used by the President for the designation of national monuments.	Uniform regulations under the Antiquities Act at 43 CFR 3; see below. 1979 USDA regulations at 7 CFR 3100; see below. Dept of Army (DOA) policy - Uniform code at 16 USC 431-433 also protects paleontological paleontological resources.
1915	GLO/ DOI,	44 LD 325 (1915), Earl Douglass President Woodrow Wilson	In 1909, Earl Douglass, paleontologist with the Carnegie Museum, discovered dinosaur bones on federal lands which later became Dinosaur National Monument. In 1913, in order to protect his find from homesteaders, Douglass tried to file a placer mining claim with the General Land Office (GLO) on the 80 acres of land containing the bones. The GLO cancelled his mineral entry and he	Decision: Fossil remains of dinosaurs and other prehistoric animals are not minerals; and lands containing fossils are not subject to mineral entry. After the Douglass case was decided, President Woodrow Wilson designated this area in Utah as Dinosaur National Monument. In 1938, the monu-

YEAR	AGENCY	LEGISLATIVE OR REGULATORY MILESTONE	EXPLANATION	OUTCOME
			appealed to the DOI.	ment was enlarged to 209,000 acres in both Utah and Colorado.
1954	USDA, DOI, DOA	Final Rule – 43 CFR 3, Preservation of American Antiquities: Uniform Regulations	Addresses antiquities permits and process, including reports and inspections and curation. Prohibition authority for anyone appropriating, excavating, injuring or destroying any historic or prehistoric ruin or monument or any object of antiquity.	Regulations in effect in 2006. Amended to address curation of federally owned archaeological collections. Final Rule, 36 CFR 79, 1990; see below.
1962	87 th Congress	H.R. 10540, P.L. 87-713, Act of September 28, 1962	Congress declared petrified wood (a fossil) to be a “mineral material” under the Mineral Materials Act of 1947 and authorized removal of limited quantities without charge.	Contract and free-use regulations for petrified wood; see next.
1963, 1964	BLM	Proposed Rule – 1963, 43 CFR 259, Free-use of Petrified Wood Final Rule – 1964, 43 CFR 3612 Amended – 1983, 43 CFR 3622	Regulations provided for free use of petrified wood without a permit by amateurs and scientists. Under the proposed rule, 10 pounds per year was the limit for removal by amateurs. Under the final rule, the limit was increased to 250 pounds per year.	Amounts to be removed by amateurs amended in 1983 to 25 pounds per day plus one piece, not to exceed 250 pounds per year (43 CFR 3622).
1974	9 th Circuit Court	U.S. v. Diaz, 499 F 2d. 113	The court declared that “objects of antiquity” was unconstitutionally vague because of lack of a definition.	DOI attempted to define “objects of antiquity” in 1978, see next. USDA and DOA have never addressed the issue.
1978	HCRS (DOI)	Proposed Rule – Heritage Conservation and Recreation Service (HCRS) DOI	Proposed rule to address <i>U.S. v Diaz</i> , 499 F. 2d 113 (9 th Circuit, 1974) regarding unconstitutionality of “objects of antiquity.” Proposed definition of “objects of antiquity” under the 1906 Antiquities Act; included vertebrate paleontological resources.	Never published as final rule. A footnote contained DOI current policy regarding protection of vertebrate paleontological resources.
1979	Office of Environmental Quality (USDA)	Final Rule – 7 CFR 3100, Enhancement, Protection and Management of the Cultural Environment	7 CFR 3100.41(a). The Antiquities Act of 1906 provides for the protection of historic or prehistoric remains or any object of antiquity on Federal lands; includes paleontological resources. Proposed rule did not contain this provision for paleontological resources.	Regulations in effect in 2006.
1979	96 th Congress	H.R. 1825, Rep. Udall (NM) P.L. 96-95 (16 U.S.C. 470aa), Archaeolog-	Protection of paleontological resources when found in context with cultural	Uniform rulemaking process began in 1980. Finalized in 1984; see

YEAR	AGENCY	LEGISLATIVE OR REGULATORY MILESTONE	EXPLANATION	OUTCOME
		ical Resources Protection Act	resources.	below.
1980	BLM	Notice of Proposed Rulemaking – Regulatory Agenda, 43 CFR 7631	Public notice of BLM’s intent to publish rules on management of paleontological resources. The rule would provide the procedure for the management of paleontological specimens located on public lands.	Proposed rules published August 17, 1982 as 43 CFR 3630, Geologic and Hobby Mineral Materials – Collecting. Withdrawn in 1993.
1981	BLM	Notice of Proposed Rulemaking – Regulatory Agenda, 43 CFR 8360	Public notice of BLM’s intent to publish rules on recreation management and operations.	Finalized in 1983; see below.
1981	FS	Final Rule – 36 CFR 261.9 (g) and (h), Prohibitions for paleontological resources	The following is prohibited: Digging in, excavating, disturbing, injuring, destroying, or in any way damaging, and removing any paleontological ... resource.” Paleontological resources were not addressed in the proposed rule.	Amended in 1986; see below.
1982	BLM	Proposed Rule – 43 CFR 3620, 3630, 8360, August 17, 1982 Proposed Rule – 43 CFR 8360, December 23, 1982	On geologic and hobby mineral materials, including fossils. Recreation Management; Prohibited Acts and Penalties.	August 17 th proposed rule placed on hold during the NAS study on Paleontological Collecting. Withdrawn in 1993. Final Rule, 1983; see next.
1983	BLM	Final Rule – 43 CFR 8360	Provided for collecting of reasonable amounts of common invertebrate fossils for noncommercial purposes.	Regulations in effect 2006.
1983	98 th Congress	S. 1569, S. Pressler (SD) Bill, Paleontological Resources Conservation Act	Unified federal policy for vertebrate fossils collection and established different permit requirements for scientific, commercial and amateur collectors. Allowed for commercial collection of fossils.	Never passed.
1984	DOI	Secretarial Order 3104, Sept. 28, 1984	Delegated Secretarial authority to issue permits under ARPA and the Antiquities Act from the National Park Service to the other DOI land management agencies; included permits to collect paleontological resources.	205 Dept Man (DM) 3, 3.1, Release no. 2615 dated 1-7-1985.
1984	NAS	National Academy of Sciences (NAS) study on paleontological resources on federal lands	Purpose: to develop a general statement on the appropriate role of government in the regulation of collecting fossils. Final report included findings and recommendations for	Final report published in 1987. Recommendation # 5 would allow commercial collection of fossils from public lands under permit.

YEAR	AGENCY	LEGISLATIVE OR REGULATORY MILESTONE	EXPLANATION	OUTCOME
			fossil collecting from private, state and federal lands.	
1984	DOI, USDA, TVA and DOD	Final Rule – 43 CFR 7, 36 CFR 296, 18 CFR 1312, 32 CFR 229, Protection of Archaeological Resources: Uniform Regulations	Uniform regulations under the 1979 Archaeological Resources Protection Act (ARPA). Paleontological resources in association with cultural resources are protected.	Regulations in effect in 2006.
1985 to 1987	98 th and 99 th Congress – Interior Appropriation Bills	Congressional Hold – P.L. 98-88, P.L. 99-190; P.L. 99-591	FY 1985 to FY 1987 – Congressional hold by Sen. Pressler - Prohibition on promulgating BLM regulations involving paleontological research until NAS report completed.	Negotiated rulemaking initiated as a result of the NAS study.
1986	FS	Interim Rule, 36 CFR 261.9, Prohibitions for paleontological resources	Revised the 1981 regulation to reflect NAS study, including permitting for vertebrate fossils and commercial collection of fossils.	Regulations in effect in 2006.
1988	100 th Congress	H.R. 1975, Rep. Boucher (VA), P.L. 100-691 (16 U.S.C. 4301), Federal Cave Resources Protection Act	Protection of paleontological resources associated with cave resources on federal lands.	FS Rulemaking – See next. BLM Proposed Rule 1992.
1989	FS	Notice of Proposed Rulemaking, 36 CFR 290, Cave Management	Notice for public comment purposes on Cave Management regulations.	Proposed Rule published 1991. Final Rule, 1994.
1989	BLM	Notice of negotiated rulemaking for paleontological resources management, 43 CFR 8270, as a result of the NAS report on “Paleontological Collecting.”	Under federal negotiated rulemaking procedures, a group was convened that included amateurs, scientists and commercial collectors to discuss regulations for collecting fossils for scientific purposes; federal fossils in non-federal repositories; and commercial collection of fossils from public lands.	Two meetings were held and proposed rules were drafted including commercial collection. BLM Director, Cy Jamison (George H.W. Bush Administration), did not support the proposed rules, so they were never published.
1989	FS	Notice of delay of final rule, 36 CFR 261.9, Prohibitions for paleontological resources	Action on final rule is delayed to receive and consider NAS report on Paleontological Collecting.	A final rule never published and was withdrawn in 1991. Interim Rule in full force and effect.
1990	DOI	Final Rule, 36 CFR 79, Curation of Federally-Owned and Administered Archaeological Collections	Amended by ARPA to address curation of federally owned and administered archaeological collections.	Regulations in effect in 2006.
1992	102 nd Congress	S. 3109, S. Baucus (MT) Bill, Vertebrate Paleontological Resources Protection Act	Permit system for vertebrate fossil collection by scientists and amateurs. No commercial collection of fossils authorized.	Never passed.

YEAR	AGENCY	LEGISLATIVE OR REGULATORY MILESTONE	EXPLANATION	OUTCOME
1992	DOI	Proposed Rule, 43 CFR 37, Cave Management	Separate regulations for DOI because of different Law Enforcement authorities on NFS lands.	Final rule 1993. Regulations in effect in 2006.
1993	BLM	Notice of withdrawal of 43 CFR 8270 in Regulatory Agenda	Notice stated they were withdrawn with no further action at this time.	Proposed rules were in conflict with Senate legislation, S. 3109.
1994	FS	Final Rule, 36 CFR 290, Cave Management	Protection of paleontological and other resources associated with cave resources on federal lands.	Regulations in effect in 2006.
1994	FS	Proposed Rule, 36 CFR 261 and 262 (all)	Proposed language combined the paleontological and archeological paragraphs and removed reference to commercial activities.	Notice in the April 2000 Regulatory Agenda that because of the "high level of interest and comment" on Part 261, that revisions to Part 261 would proceed separately.
1996	BLM	Notice of Proposed rulemaking, 43 CFR 6600, Paleontological Resources, in Regulatory Agenda.	Notice stated BLM rules were being revised as part of "Reinventing Government" initiative in the Clinton Administration. BLM rules from 43 CFR 3622 and 8365 regarding paleontological resources management were to be consolidated and rewritten in plain English.	Proposed rules were never published. Johnson bill was introduced in 1996 in the Senate. The action to consolidate was withdrawn in 2001.
1996	104 th Congress	H.R. 2943, S. Johnson (SD) Bill, Fossil Preservation Act	Provided for reconnaissance fossil collecting of all fossils by amateur, commercial and scientific fossil collectors without a permit. Provided for quarrying permits for commercial collection of fossils that generated fees and royalties to the federal government.	Never passed.
1998	BLM	BLM Manual 8270 and Handbook H-8270-1, Paleontological Resources Management	BLM policy and procedures for Paleontological Resources Management on public lands.	Policy in effect in 2006.
1998	CRS	Report to Congress, "Fossils on Federal Lands: Current Federal Laws and Regulations"	Congressional Research Service (CRS) reports are generated by requests from members of Congress or their staff.	In 1999, the Senate requested a report from the federal land management agencies, the Smithsonian and the USGS assessing the status of federal fossils.
2000	DOI agencies, FS, SI	Final Secretarial Report to Congress on Fossil Resource Management on Federal and Indian Lands	S. Rept. 105-227 request on behalf of Senators Johnson and Daschel (SD) added to Committee report on Interior Appropriations (FY 1999) for these	Recommended seven principles for further action by Congress and the agencies regarding paleontological resources management. The

YEAR	AGENCY	LEGISLATIVE OR REGULATORY MILESTONE	EXPLANATION	OUTCOME
			agencies to assess paleontological resources management on federal lands with the goal of working towards a uniform policy on federal lands administered by NPS, BLM, FS, BIA, FWS and the Tribes.	report is the basis for subsequent legislation introduced in Congress the 107 th Congress.
2001	107 th Congress	H.R. 2974, Rep. McGovern (MA) Bill, S. 2727, S. Akaka (HI) Bill, Paleontological Resources Preservation Act	Comprehensive and uniform authority for the management of paleontological resources on federal lands managed by DOI and FS. Contained strong civil and criminal penalties for fossil theft; clear authority for amateur collecting of invertebrate and plant fossils without a permit; clear authority for permits for collecting of vertebrate fossils. Does not provide for commercial collection.	Never passed. Reintroduced in the 108 th Congress.
2002	FS	Notice of proposed rulemaking, 36 CFR 251.50 and CFR 261.9 (j), Special Uses and General Prohibitions for Paleontological Resources, Regulatory Agenda	Proposal for technical changes to the special use and prohibited acts regulations for paleontological resources. Would have changed the definition of "paleontological resources" similar to 36 CFR 292.21, and required a special use permit for vertebrate paleontological collecting.	Proposed rules never published and withdrawn in 2004.
2003	108 th Congress	H.R. 2416, Rep. McGovern (MA) Bill, S. 546, S. Akaka (HI) Bill, Paleontological Resources Preservation Act	Comprehensive and uniform authority for the management of paleontological resources on federal lands managed by DOI and FS. Contained strong civil and criminal penalties for fossil theft; clear authority for amateur collecting of invertebrate and plant fossils; clear authority for permits for collecting of vertebrate fossils. Does not provide for commercial collection. H.R. 2416 contained language for authority to collect rocks and minerals on NFS lands. S. 546 passed the Senate in June 2003; this is the first time a fossil bill passed in a house of Congress.	S. 546 passed in the Senate with amendments and sent to the House of Representatives where it died in Committee. Reintroduced in the 109 th Congress.
2004	FS	Notice of withdrawal of proposed rulemaking, 36 CFR 251.50 and CFR 261.9 (j), Special Uses and General Prohibitions for Paleontological Resources, Regulatory Agenda	Proposed rules were withdrawn.	Continue to manage paleontological resources under the Organic Act of 1897.
2004	CRS	Two Reports for Congress were requested	"Paleontological Resources Preservation Act: Proposal for the	Requested by Sen. Akaka at the end of the 108 th Congress in

YEAR	AGENCY	LEGISLATIVE OR REGULATORY MILESTONE	EXPLANATION	OUTCOME
			Management and Protection of Fossil Resources Located on Federal Lands,” (Sept. 2004) and “Federal Management and Protection of Paleontological (Fossil) Resources Located on Federal Lands: Current Status and Legal Issues,” (Nov. 2004).	support of the introduction of the PRPA in the 109 th Congress. Placed on the Senate Calendar as No. 50. Awaiting further action. No House companion bill has been
2005	109 th Congress	S. 263, S. Akaka (HI) Bill, Paleontological Resources Preservation Act	Virtually the same language as S. 546 as passed in the Senate in the 108 th Congress which reduced the level of penalties from S. 2727 with technical amendments on procedure.	introduced to date.

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FOSSIL TRACKS AT THE RAYMOND ALF MUSEUM OF PALEONTOLOGY AND MANAGEMENT OF TRACKS ON PUBLIC LANDS

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Abstract—The Raymond M. Alf Museum of Paleontology houses one of the greatest fossil footprint collections in the world. This collection is a testament to the work of Raymond Alf, whose interest in trace fossils translated into a decades-long search for tracks throughout the western United States. The Alf Museum track collection consists of about 800 specimens from the Coconino, Moenkopi, Moenave, Wasatch, Barstow, Avawatz, Tecopa and Muddy Creek formations including 22 holotype, syntype or paratype specimens representing 14 ichnotaxa. The stratigraphic utility of the collection is limited by the lack of precise locality data for many specimens. However, excellent photographs of Alf's collecting sites in the museum archives have been used in many cases to relocate sites, work that needs to be extended to all Alf Museum track sites. Many important fossil track-trackway sites are located on public lands. Float tracks should be collected. Exposed *in situ* trackways should be excavated if they cannot be protected from erosion and theft or vandalism. Protection of sites is critical as the paleontological information each site yields is usually unique. Removal of trackways should be done with care as each site poses particular challenges because of variation in track preservation, rock type, geographic setting and other factors. Trackways from the Barstow and Coconino formations housed at the Alf Museum demonstrate that an excellent way to preserve trackways is to collect and reassemble them for exhibit so they are accessible to the public and the scientific community.

INTRODUCTION

The Raymond M. Alf Museum of Paleontology (RAM) is the only large museum in the world devoted solely to paleontology located on a secondary school campus (The Webb Schools). The museum is named for its creator, Raymond Alf, a teacher who eventually became intensely devoted to the study of paleontology. After establishing himself as a college track star, Alf served as first alternate on the 1928 U.S. Olympic Track Team. In 1929, Alf moved west to run for the Los Angeles Athletic Club and later that year joined the faculty at Webb School of California, a private high school on the outskirts of Los Angeles. In 1935, inspired by seeing a fossil horse jaw from the Barstow Formation on display in a local store, Alf took Webb students to the Mojave Desert in search of fossils. In 1936, Alf and student Bill Webb found a skull and jaw fragments of a Miocene peccary in the Barstow Formation. They took the specimens to Chester Stock at the California Institute of Technology who named a new genus and species, *Dyseohyus fricki* (Stock, 1937), based on the material. Inspired by their Barstow success, Alf and students went to South Dakota in the summer of 1937 and met John Clark, a paleontologist from the University of Colorado who was studying the Chadron Formation (Clark, 1937). The discovery of *Dyseohyus fricki* combined with meeting Clark inspired Alf to pursue a career in paleontology. Alf took a sabbatical from Webb and studied geology and paleontology under Clark's tutelage at the University of Colorado. He then returned to Webb and launched the Peccary Society, an innovative melding of paleontology into secondary school education where Webb students were active participants in all aspects of paleontological collecting and research. Alf inspired some Webb students to pursue paleontology careers (such as Dwight Taylor, Malcolm McKenna, David Webb, Daniel Fisher and the late Donald Kron).

From the late 1930s through the early 1970s Alf took students on collecting trips, called peccary trips, traveling to sites in California, Utah, Wyoming, South Dakota, Nebraska and Arizona. Alf concentrated on recovery of fossil vertebrates and by the 1960s had amassed a large regional collection (45,000 specimens). Alf was especially interested in collecting tracks and trackways and obtained 800 specimens from the Avawatz, Barstow, Coconino, Moenkopi, Moenave, Muddy Creek,

Tecopa and Wasatch formations (Fig.1); the largest collection in the western United States. By the 1960s the incredible amount of material Alf and his students had collected overwhelmed the small museum that Alf had established in the basement of a library on the Webb campus. By 1967 a new facility was built and it was dedicated to Alf in 1968.

The new museum included two exhibit halls: 1) the Hall of Life, where specimens were ordered by geologic time showing the history of life; and 2) the Hall of Footprints, which displayed an overview of Alf's extensive track collection including very large slabs with multiple tracks. The Hall of Footprints, renovated in 2002, is the largest, most diverse collection of fossils tracks and trackways on display in North America.

The fossil track and trackway collection at RAM contains many type specimens and other specimens of significant scientific importance,



FIGURE 1. Map of the southwest United States showing location of Alf Museum fossil footprint collecting areas: (1) Barstow Formation; (2) Avawatz Formation; (3) Tecopa Formation; (4) Muddy Creek Formation; (5) Coconino Formation; (6) Moenkopi Formation; (7) Moenave Formation; (8) Wasatch Formation.

but the entire collection has never been discussed as a unit. Here we review the museum's extensive track collection, organized by formation and presented in ascending geologic age. Each formation section includes an overview of field activities and general locality information and a brief discussion of the collection, including types and other significant specimens. We also offer suggestions on how to effectively manage the large number of fossil track sites located on public lands using examples from the RAM collections.

COCONINO FORMATION (EARLY PERMIAN)

RAM Locality

All specimens were collected from RAM locality V94004, north of Seligman, Arizona.

Discussion

The Coconino Formation is comprised primarily of cliff-forming, cross-stratified sandstone exposed over a wide area of northern Arizona. In the Grand Canyon, the Coconino Formation is about 107 m (350 feet) thick, but it can be up to 275 m (900 feet) thick elsewhere (Middleton et al., 1990). In the late 1930s Alf went to the Grand Canyon at least twice with Webb students to hike the Kaibab and Bright Angel trails and got his first glimpse of the Coconino Formation. On one of these trips he met Edwin McKee, who was in the beginning stages of his decades-long study of the geology of Grand Canyon National Park. McKee was investigating the canyon's Paleozoic formations (McKee, 1937, 1939) and was developing a particular interest in the numerous trackways of vertebrates and invertebrates found in the Coconino Formation (McKee, 1933, 1944, 1947). McKee told Alf about a site near Seligman, Arizona, where he could collect specimens of Coconino tracks. Shortly thereafter, Alf began to lead trips to Seligman on an annual basis until the early 1970s. Alf and students collected in a canyon a few kilometers north of Seligman (Fig. 2); the precise site has not been relocated but easily could be using the many photos of the site housed in the museum's archives.



FIGURE 2. Ray Alf (kneeling on left) and students collecting the huge slab (RAM 244) now on display in the museum's foyer from the Coconino Formation.

Alf and Webb students collected 142 track specimens that include ichnogenera *Laoporus* (over 120 specimens), *Agostopus* (RAM 128), *Octopodichnus* (RAM 139) and *Paleohelcura* (RAM 142). Over 90% of Coconino specimens exhibit one or multiple trackways of the vertebrate represented by *Laoporus*. Many large slabs have unidentified and poorly preserved invertebrate tracks on them in addition to *Laoporus*. Specimens range in size from 10 cm square, up to the massive slab (RAM 244) displayed in the museum's foyer (Fig. 3), which is about 5 m in length, 1.3 m in width, and 20 cm thick. The only Alf Museum Coconino holotype is RAM 139 (Fig. 4) representing *Octopodichnus raymondi* (Sadler,

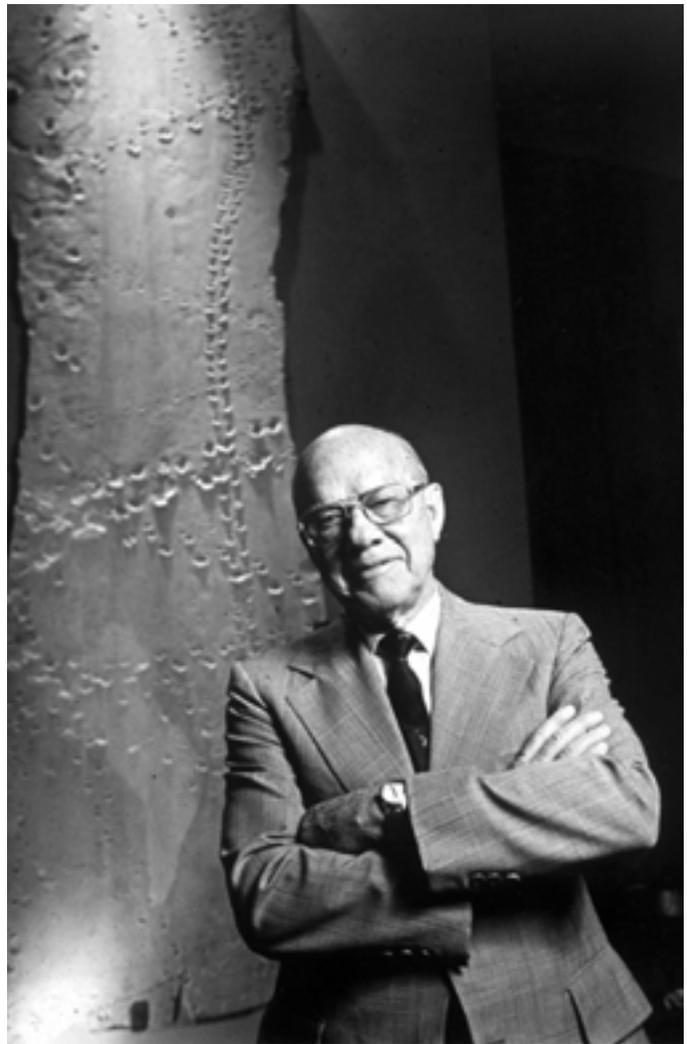


FIGURE 3. Ray Alf standing beside RAM 244 in the museum's foyer.

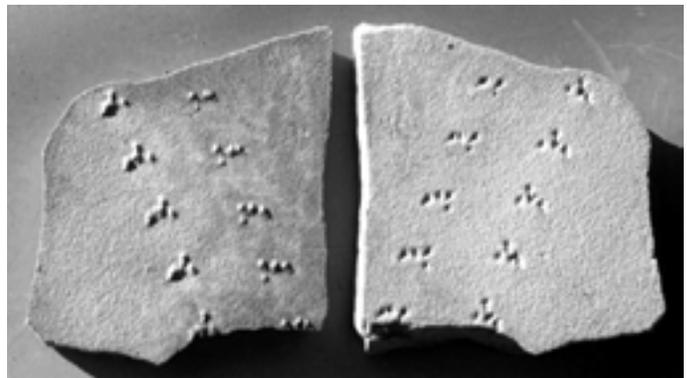


FIGURE 4. Holotype of *Octopodichnus raymondi* (RAM 139) from the Coconino Formation.

1993; original specimen number JF 5905 was recatalogued as RAM 139). Alf compared modern spider tracks with RAM 139 and concluded the tracks preserved on RAM 139 represented a spider, but did not name it (Alf, 1968). Sadler's (1993) more extensive study supported Alf's original hypothesis and the species *O. raymondi* was named in his honor.

For many years it was generally accepted that the large scale and abundant cross stratified sandstones of the Coconino Formation that often preserve vertebrate and invertebrate tracks represented eolian de-

posits. However, a relatively recent challenge was presented by Brand and Tang (1991), who argued for a subaqueous origin of the tracks. Using slabs on display at the Alf Museum (RAM 244 is figs. 2a and 2f, RAM 235 is figs. 2g and RAM 132 is fig. 2e in Brand and Tang, 1991) and other specimens, Brand and Tang (1991) noted that many *Laoporus* trackways displayed odd characteristics, such as abrupt starts and ends of track sets on undisturbed bedding planes and that individual tracks are often oriented perpendicular to the trend of the trackway. Tests performed with modern newts in shallow flowing water created tracks similar to those made in the Coconino Formation and formed the basis of the underwater hypothesis (Brand and Tang, 1991). However, the geology of the Coconino Formation supports an eolian hypothesis because the large scale bedforms, low angled cross stratification, abundance of well sorted quartz sandstone and the absence of ripple marks all indicate the probability of eolian deposition (for further discussion of this controversy see Brand, 1992; Lockley, 1992; Loope, 1992; Lockley and Hunt, 1995).

MOENKOPI FORMATION (EARLY-MIDDLE TRIASSIC)

RAM Locality

All specimens were collected from RAM V94005, a few miles southwest of Cameron, Arizona.

Discussion

The Moenkopi Formation is composed of sandstones, siltstones and mudstones of fluvial origin (McKee, 1954). As Alf became more interested in collecting fossil tracks, he developed an annual Webb spring break trip that was organized into a general Arizona-Utah-Nevada loop route with stops at Seligman, Grand Canyon National Park, Cameron Junction (where he encountered the Moenkopi Formation), Kanab and Zion National Park. On these trips Alf and students collected track specimens at Seligman (Coconino Formation) and Kanab (Moenave Formation) in addition to those from the Moenkopi near Cameron Junction. Alf's spring break trips ran for nearly 35 years and collections were made in the Moenkopi from around 1950 to 1970. As with many Alf Museum track localities, V94005 has not yet been precisely relocated. There are only a few photos in the museum's archives showing collecting activities in the Moenkopi Formation, but they probably would provide adequate information for site relocation.

The Alf Museum collection from the Moenkopi consists of 25 specimens, each in red siltstones with one or two tracks (usually one), which vary from moderately distinct to very faint. Ten specimens are referred to *Chirotherium* in the Alf Museum catalog, with the remaining 15 unidentified. However, all tracks are of similar size and shape and thus appear to represent a single ichnotaxon. *Chirotherium* has distinctive five digit impressions that superficially resemble human handprints, with the fifth digit on the pes remarkably similar to a thumb imprint (Lockley and Hunt, 1995). *Chirotherium* tracks from the Moenkopi Formation show a wide variety of sizes and probably represent various types of quadrupedal archosaurs (Lockley and Hunt, 1995).

MOENAVE FORMATION (EARLY JURASSIC)

RAM Locality

All specimens were collected from RAM V94277, in a canyon north of Kanab, Utah.

Discussion

The Moenave Formation, confined mainly to northern Arizona and southern Utah, is composed of the Dinosaur Canyon Member, the Whitmore Point Member and the Springdale Sandstone Member (Harshbarger et al., 1957; Miller et al., 1989). On Webb spring break trips, Alf and students would often collect north of Kanab in the Dinosaur Canyon Member (V94277 was relocated in 2000). These trips

yielded 69 specimens of small to large three toed tracks attributed to bipedal dinosaurs (Fig. 5). The Alf Museum catalog lists 22 specimens of *Eubrontes*, 15 of *Grallator* and 13 of *Anchisauripus*. These identifications, made by Webb students, are based on size and may not be entirely accurate, as according to Lockley and Hunt (1995), *Anchisauripus* has not been identified in the western United States. The Alf Museum has 19 other specimens identified only as dinosaur tracks. Of the 69 Moenave specimens, only one (RAM 176) has more than two tracks. RAM 176, catalogued as *Grallator*, has 11 full or partial tracks oriented in various directions (Fig. 6), which indicates they may represent more than one individual.



FIGURE 5. Webb students with *Eubrontes* track (RAM 239) from the Moenave Formation.

WASATCH FORMATION (EARLY EOCENE; WASATCHIAN NALMA)

RAM Locality

All specimens were collected from RAM V94207, located in Carbon County, Wyoming.

Discussion

The exact location of V94207 is uncertain. However, excellent photos of the site are present in the museum archives and presumably the site could be relocated without great difficulty. What is known is that the site occurs north of Baggs in outcrops adjacent to Muddy Creek, which parallels State Highway 789 in south central Wyoming. Based on this general location, the site is probably within the main body of the Wasatch Formation, which would indicate that the Early Eocene-Wasatchian age determination is probably correct.

In 1969 and/or 1970, Raymond Alf and crew collected 24 specimens, seven of which represent birds of very small size that remain undescribed. The other 17 appear to represent tracks of a single mammalian taxon (some slabs with mammal tracks have small and faint bird tracks on them as well). Based on these 17 specimens, Sarjeant et al. (2002) described and named the ichnogenus and species *Quiritipes impendens*. The type is RAM 154, a set of tracks reconstructed from nine individual slabs arranged in their presumably original position and then set in cement. The paratype is RAM 267, a left pes. Sarjeant et al. (2002) thought the tracks of *Quiritipes impendens* belonged to a carnivore and noted the lack of claw impressions, which could indicate they represented a feloid. But their overall morphology was unlike any known feloid (Sarjeant et al., 2002) and the Early Eocene age of the site virtually precluded any alliance with the much younger feloid clade. Based on

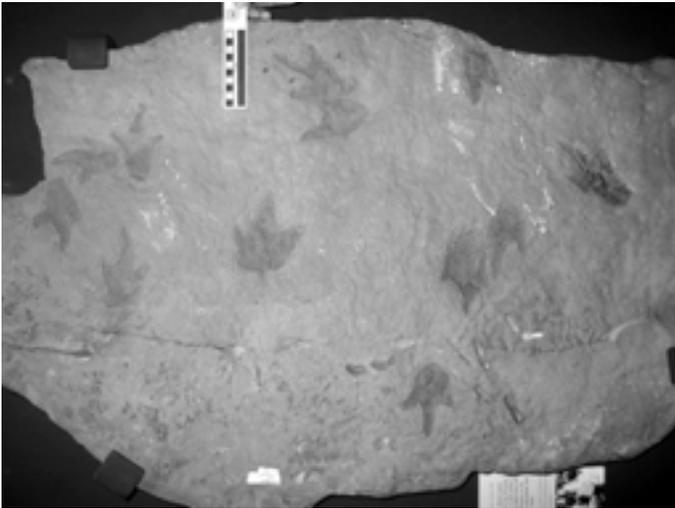


FIGURE 6. *Grallator* imprints (RAM 176), common tracks from the Moenave Formation.

their age and morphology, Sarjeant et al. (2002) surmised that the tracks were probably made by a creodont. In any case, the tracks of *Quiritipes impendens* housed at the Alf Museum represent a taxon not found in any other museum collection.

BARSTOW FORMATION (MIDDLE MIOCENE, BARSTOVIAN NALMA)

RAM Localities

Specimens were collected from RAM sites V94064, V94065, V94176, V94272, V94281, V94283, V94284 and V94293, in the Mud Hills, northwest of Barstow, California.

Discussion

The Barstow Formation is about 1,000 m thick and is composed of a sequence of fluvial and lacustrine sediments and air-fall tuffs (Woodburne et al., 1990). The formation is subdivided into the Owl Conglomerate, Middle and Upper members (Woodburne et al., 1990). All the Barstow Formation tracks at the Alf Museum were collected in the Middle and Upper members. Alf first prospected for fossils in the Barstow Formation in 1935. After the discovery and publication of the new genus and species of peccary, *Dyseoehyus fricki* by Stock (1937), Alf realized Barstow's great potential as a paleontological resource and the Barstow Formation became his main collecting area for the next 40 years. Exactly when Alf collected his first track from the Barstow Formation is unknown. But it could not have been before 1959 as in that year he described mammal tracks from the Avawatz Formation and claimed they were the first ever reported from the Mojave Desert (Alf, 1959). It is reasonable to assume that the success of finding tracks in the Avawatz Formation inspired Alf to expand his search to the Barstow Formation. Unfortunately, locality data for nearly the entire Alf Museum track collection from the Barstow Formation is very poor and stratigraphically unreliable. The only exceptions are the amphicyonid (RAM 100, V94272, Fig. 7) and proboscidean (RAM 187, V94176, Fig. 8) trackways which were relocated in 1994 using photos in the museum's archives.

The Barstow Formation has yielded more track specimens, about 322, than any other formation from which Alf and Webb students collected. The majority of these specimens were collected in the 1960s and early 1970s and include 295 tracks/trackways of camels, 22 of felids, one set of canid prints (RAM 183) and the amphicyonid (RAM 100) and proboscidean (RAM 187) trackways. There are seven holotype, syntype or paratype specimens from the Barstow Formation in the Alf Museum



FIGURE 7. Ray Alf (bottom) and Richard Tedford (top) measure the amphicyonid trackway (RAM 100, holotype of *Hirpexipes alfi*) prior to its excavation from the Barstow Formation.



FIGURE 8. Webb students pose with the partially excavated proboscidean trackway (RAM 187) from the Barstow Formation.

collection.

One of the most important Barstow specimens is the amphicyonid trackway (RAM 100, Fig. 7), which Alf (1966) briefly described and identified as representing an amphicyonid. The trackway was collected in 1964 and reassembled for exhibit in the Hall of Footprints in the late 1960s. RAM 100 is the holotype of *Hirpexipes alfi* (Sarjeant et al., 2002). The large size, five digits and rake-like claw marks of *H. alfi* strongly support the interpretation that the tracks represent an amphicyonid (Alf, 1966; Sarjeant et al., 2002). Their very large size and stratigraphic position in the Middle Member of the Barstow Formation suggest they were made by *Amphicyon ingens* (Sarjeant et al., 2002). Based on RAM 100, *A. ingens* had a stride of 245 cm and a pace of 120 cm (Sarjeant et al., 2002).

The Alf Museum collection includes two other reconstructed trackways from the Barstow Formation, both of which are on display in the Hall of Footprints. One is a set of four proboscidean tracks (RAM 187, Fig. 8) from the Upper Member that were removed in large slabs (around 1969) and reconstructed at the museum. The other is a large slab (RAM 166, Fig. 9) containing two sets of camel prints that were broken into blocks (date unknown) and later reassembled at the museum. These camel prints (RAM 166) were designated as a syntype of *Lamaichnum alfi* by Sarjeant and Reynolds (1999). The other syntypes were RAM 159 (a right pes) and RAM 182 (a right manus). RAM 166 is particularly important because it clearly shows the gaits of at least two camels. The majority of Barstow camel prints in the Alf Museum collection are



FIGURE 9. Multiple camel trackways (RAM 166, syntype of *Lamaichnum alfi*) from the Barstow Formation on display with a camel skeleton mounted above.

similar in morphology to *L. alfi* (Sarjeant and Reynolds, 1999).

Other types in the Alf Museum collection from the Barstow Formation include the felids *Felipeda bottjeri* and *Felipeda scriverni*

described by Sarjeant et al. (2002). The holotype of *F. bottjeri* is RAM 103 (right pes?) and the paratype is RAM 104 (right manus?); figured specimens of *F. bottjeri* also include RAM 181 and RAM 275 (Sarjeant et al., 2002). The holotype of *F. scriverni* is RAM 242 (now part of the collections at Death Valley National Park) and the paratype is RAM 105 (left manus?). *Felipeda bottjeri* differs from *F. scriverni* in its more elongate shape and lesser digital span (Sarjeant et al., 2002). Specimens of *F. bottjeri* are more numerous in the Alf Museum collection than *F. scriverni*. *Felipeda* tracks may represent those of *Pseudaelurus* (Alf, 1966; Sarjeant and et al., 2002).

Other specimens of particular interest include RAM 183, a small canid print referred to *Canipeda* species "A" that may represent the track of *Tomarctus* (Sarjeant et al., 2002) and a bird print on the amphicyonid trackway slab (RAM 100) that was used to emend the diagnosis of *Gruipeda becassi* Panin and Avram (1962) (Sarjeant and Reynolds, 2001).

AVAWATZ FORMATION (LATE MIOCENE, CLARENDONIAN NALMA)

RAM Localities

Specimens were collected from RAM sites V94021, V94134, V94135 and V94136, in the southern part of the Avawatz Mountains,



FIGURE 10. Ray Alf on ladder collecting trackway slabs (RAM 215 and 216) from the Avawatz Formation.

north of Baker, California.

Discussion

The upper part of the Avawatz Formation yields vertebrate fossils and is composed of coarse to fine grained tuffaceous sedimentary rocks interbedded with distinct white to buff colored volcanic ashes that can be over a meter thick (Henshaw, 1939; Alf, 1959). While on a trip with Alf in February of 1957, student Robert Baum discovered mammal footprints on steeply dipping bedding planes, high on the side of a steep canyon in the Avawatz Formation. Two more trips were made soon thereafter to remove the tracks, which had to be excavated while standing on a ladder (Fig. 10). These were the first mammal tracks described from the Mojave Desert (Alf, 1959). The Avawatz Formation proved to be an untapped treasure trove of tracks as nearly 140 specimens were collected by Alf and Webb students following Baum's original discovery. These Avawatz specimens include 81 bird, 49 camel, 4 felid and 7 unidentified vertebrate tracks. All of these specimens were assigned to the general Avawatz locality V94021 because the locations of the three main Avawatz collecting sites (V94134, V94135 and V94136) were unknown. In 1994, Robert Baum led an Alf Museum crew back to the Avawatz Formation and precisely relocated two (V94134 and V94135) of the original collecting sites. Reassignment of specimens from V94021 to V94134 and V94135 was completed in 2005.

Eight holotype, syntype or paratype specimens from the Avawatz Formation are housed at the Alf Museum. The birds, all described by Sarjeant and Reynolds (2001), include: RAM 110, the holotype of *Avipeda gryponyx*, a series of seven prints with partial impressions of others that probably represent a small wading bird (Sarjeant and Reynolds, 2001); the holotype (RAM 115, left pes) and paratype (RAM 269, right pes) of *Anatipeda californica*, webbed footprints of small to moderate size with three digits directed forward and a fourth backwards; the holotype (RAM 111, right and left pedes) of *Anatipeda alfi*, a web-footed species named in honor of Raymond Alf (specimens figured by Sarjeant and Reynolds (2001), also include RAM 113, Fig. 11, a left pes and RAM 112, left and right pedes) and ?*Anatipeda* sp. based on RAM 274, a left pes, which is like others of the genus but is larger in size. Footprints

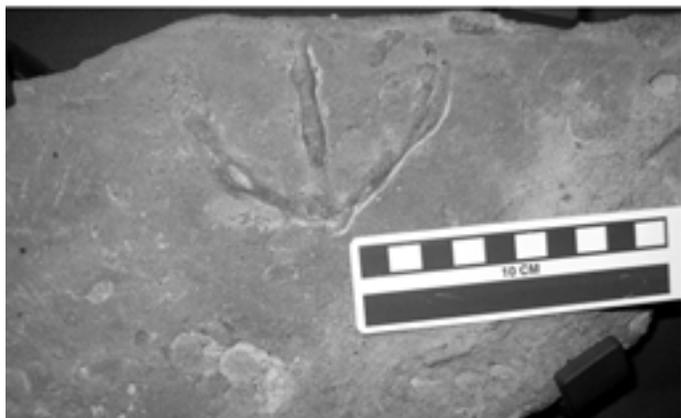


FIGURE 11. Left pes of *Anatipeda alfi* (RAM 113) from the Avawatz Formation.

of *Anatipeda* were probably made by pelicans, flamingos, ducks, geese, swan or other similar birds (Sarjeant and Reynolds, 2001). Also, Sarjeant and Reynolds (2001) used RAM 272 and 278 to emend the diagnosis of *Aviadactyla vialovi* Kordos and Prakfali, 1990, and RAM 270 to emend the diagnosis of *Charadriipeda recurvirostrioidea* Panin and Avram (1962).

Other important specimens include: RAM 205, a small slab with two cat prints (right manus and left pes?) that was described as the holotype of a new genus and species, *Pycnodactylopus achras*, by Sarjeant et al. (2002); RAM 197 (manus) and RAM 209 (left pes), syntypes of

Dizygopodium dorydium, a camel of moderate size (Sarjeant and Reynolds, 1999) and RAM 216 (slab with left manus and right pes), the syntype of *Dizygopodium quadracordatum*, another camel of moderate size (Sarjeant and Reynolds, 1999).

TECOPA FORMATION OR "CHINA WASH BEDS" (LATE MIOCENE, CLARENDONIAN NALMA)

RAM Locality

All specimens were collected from RAM V94215, a few miles south of Tecopa, California.

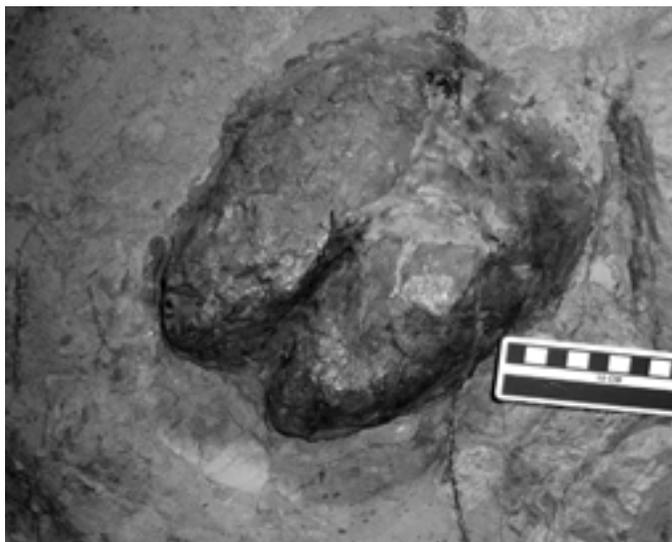


FIGURE 12. Print of *Lamaichnum macropodum* (RAM 165, syntype) from the Tecopa Formation made by a very large camel.

Discussion

The Tecopa Formation is comprised of a series of tuffaceous sedimentary rocks that outcrop south of Tecopa in the Sperry Hills; these same rocks are informally referred to as the "China Wash Beds" by Sarjeant and Reynolds (1999). This collecting area was only visited by Alf and Webb students a few times in the late 1960s. Photos of locality V94215 are housed in the museum's archives and were used to relocate the site in March 2006.

Thirteen specimens were recovered from locality V94215, all of which represent camels. Most slabs preserve the tracks of a very large camel. Sarjeant and Reynolds (1999) assigned these specimens to *Lamaichnum macropodum* and designated RAM 146 (manus) and RAM 165 (pes, Fig. 12) as syntypes. These tracks measure about 20 cm in length and width and probably were made by either *Aepyamelus* or *Megatylopus* (Sarjeant and Reynolds, 1999), the largest known camels of the late Miocene.

MUDDY CREEK FORMATION (LATE MIOCENE, HEMPHILLIAN NALMA)

RAM Localities

Specimens were collected from RAM sites V94163, V94164, and V94286, a few miles north of Glendale, Nevada.

Discussion

The Muddy Creek Formation is comprised of a thick series of sandstone, siltstone and mudstone with lesser amounts of conglomerate and tuff (Stock, 1921) that was deposited in a series of small basins in southern Nevada that coalesced into a single large basin (Reynolds and

Lindsay, 1999). Photos in the museum's archives of the Alf Museum track sites from the Muddy Creek Formation are not labeled as to which site number they represent. Thus, it is doubtful that even if the Muddy Creek Formation sites could be relocated, specific specimens could be assigned to specific localities.

In the late 1960s Alf and Webb students collected about 53 track specimens and one large trackway slab from the Muddy Creek Formation. They represent camels and 2 types of carnivores, an ursid and a canid. This ursid formed the basis of the new genus and species, *Platykopus ilycalculator*, which was described by Sarjeant et al. (2002). RAM 277 (manus) was designated as the holotype and RAM 232 (pes) the paratype. Because of its large size and the presence of five digits, *P. ilycalculator* was interpreted to represent a large bear (Sarjeant et al., 2002). There are other specimens of this large ursid in the Alf Museum collection including a large trackway (RAM 218) comprised of multiple slabs preserving 10 tracks which were numbered in the field and then reconstructed for display at the museum (RAM 218 was removed from exhibit in 2002). Another example of this large ursid is RAM 327, which has two tracks.

RESOURCE MANAGEMENT

Fossils are present on public lands in the western United States, sometimes in vast numbers. Effective management of paleontological resources can pose special challenges, especially tracks and trackways. For instance, to collect vertebrate fossils from public lands a permit is required because vertebrate fossils are considered rare and worthy of special protection. A permit is not required to collect invertebrate fossils on public lands unless they occur in a specially protected area (such as a national park or monument). However, invertebrate tracks and trackways are usually much rarer than those of vertebrates in rock units where fossil tracks are present. Managers of paleontological resources on public lands where trackways occur should take this into consideration when drafting plans for managing the resource. Unlike other public land management agencies, the National Park Service (NPS) requires research permits for collection of any material, including all fossil specimens, in an NPS unit.

"Float" Tracks and Trackways

Tracks and trackways occur in two types of settings based on how they have been exposed by erosion. The first is float, a term that describes fossils that are lying loose on the ground. In the case of tracks,



FIGURE 13. Ray Alf (standing far right) and students with trackway slabs from the Coconino Formation.

specimens are chunks of rock with tracks (Fig. 13) or multiple tracks (Fig. 5) that usually lie adjacent to the outcrop from which they eroded. Tracks found as float are usually preserved in well-indurated rock, oth-

erwise they would have been destroyed as they eroded. A preserved track can be the imprint the animal made (mold), the cast of the imprint (sediment that later filled the imprint) or the undertrack of the imprint (impression preserved below original bedding plane of imprint). Unless extremely large, these float tracks can be simply picked up, given a field number and then transported to a suitable repository. Float tracks can often be traced to a specific layer in the outcrop from which they eroded and more tracks may be exposed on the same bedding plane. Other times the original bedding plane of the track float may have been completely removed by erosion. In either case, track float should always be collected as erosion will eventually destroy even the most indurated rock.

In situ Tracks and Trackways

In situ tracks and trackways on public lands are another matter as a decision must be made on whether to remove them, leave them *in situ* or perhaps do a combination of the two. Tracks exposed *in situ* are preserved on bedding planes that often contain both the molds (tracks themselves) and the casts (infilling of tracks) of one or multiple individuals. Thus, the tracks are still in their original position in relation to the sediments in which they were imprinted. The decision to be made is it in the best interest of the resource to collect the tracks or leave them in place? The main factor to consider in this regard is whether the trackway can be protected from erosion and theft or vandalism.

In situ trackways are exposed to the elements and even if treated with hardening agents will eventually be destroyed. If it is important that the trackway be left *in situ* or that the tracks can't be collected due to size, geographic setting or another factor, casts of representative tracks should be made and placed in a suitable repository so a permanent record of the trackway is preserved. Then a method must be employed to preserve the *in situ* trackway for as long as possible. In most cases, the trackway can be covered with loose sediment to slow the rate of erosion of the bedding plane preserving the tracks. Thus, the site is both protected from erosion and very difficult to find. Covering the site is important, even in remote areas on public lands, to minimize potential for theft or vandalism. Even if visitors are aware that collecting is illegal without a permit, it only takes one irresponsible person to try and excavate part or all of the trackway. The resource is then damaged in the unsuccessful process of removal and/or is excavated and lost (usually never recovered). Even in a specially protected area like a national park where sites are patrolled, the resource is still in danger from theft or vandalism. A protective covering of plastic or some other material would be desirable, but that could be counterproductive as it draws attention to the site. If feasible, important trackway sites should be covered by a permanent structure that can be secured and monitored. Examples of this would be Dinosaur National Monument (Utah) and Ichthyosaur State Park (Nevada) for vertebrate fossils and the new St. George Dinosaur Discovery Site at Johnson Farm (Utah) where trackways will be preserved *in situ*, housed within a large building. Although this option is extremely expensive, it does provide an exceptional setting for the public to view a unique resource.

Collecting Tracks and Trackways

If a trackway is to be collected then different approaches can be employed, based on the condition of the tracks and the lithology and degree of induration of the sedimentary rock in which the tracks are preserved. Slabs of thick indurated rock containing trackways can be collected in one piece if a natural break in the bedding plane can be located. A good example of this is the Coconino Formation, which is notable for its many bedding planes that contain well-preserved vertebrate and invertebrate trackways (Lockley and Hunt, 1995; and references therein). Once a productive interval of the formation is located, a slab can usually be separated from outcrop along natural breaks in the rock and then loaded for transport. Slabs can range from 10 cm square to over 5 m in length. Large specimens, like the latter, can weigh over two

tons. Unless machinery is employed, it takes a large crew to move large slabs into a vehicle for transport. Ray Alf was able to collect many large track-bearing slabs of the Coconino Formation, which are now housed at the Alf Museum, with the help of Webb students. Every spring Alf would lead a trip to RAM locality V94004 near Seligman, Arizona, where a large trackway-bearing slab would be located and readied for removal. A few weeks later, in early June, Alf would return with the entire Webb senior class (about 40 students) who were on their way to Grand Canyon National Park to hike the canyon before graduation. Using pry bars, Alf and students would manually elevate a large slab so that rollers could be placed beneath. The slab was then slowly moved downslope (Fig. 2) to a large flatbed truck. Because of Alf's interest in Coconino tracks and the availability of large numbers of Webb students, the Alf Museum now has a large and unique collection from the formation. Specimens such as RAM 244 (Fig. 2) are extremely large and difficult to store or exhibit. Alf placed RAM 244 on exhibit by mounting it on a reinforced wooden platform, lowering it by crane, and placing it in the foyer of the Alf Museum (Fig. 3) while the building was still under construction. This unique exhibit provides a breathtaking experience for the public as the resource is displayed in an unusual and dramatic fashion.

However, most trackways are not preserved in well indurated rock that often naturally breaks into large and thick slabs like the Coconino Formation. If the decision is to preserve a trackway by collecting it, then different approaches can be employed depending on the geographic setting of the site, hardness of the rock and other factors. For example, Ray Alf used a 20 ft ladder to collect the first mammal tracks from the Avawatz Formation in 1957 because the tracks were situated high on the side of a canyon (Fig. 10). Before removal is attempted, casts should always be made while the tracks are still *in situ*. This insures that the morphology of the tracks will be preserved even if the collecting process causes damage. Also, having casts will guide repair of a damaged track and aid in the process of reassembling the trackway at a later date. Although opinions vary on the issue, we recommend that if a trackway has significant scientific value and cannot be protected *in situ*, then all exposed tracks should be removed. Examples of partially exposed trackways from the Barstow Formation that were collected and are now housed at the Alf Museum are an amphicyonid trackway (*Hirpexipes alfi*; RAM 100; Fig. 7), a proboscidean trackway (RAM 187; Fig. 8) and a multiple camel trackway (*Lamaichnum alfi*; RAM 166; Fig. 9).

The amphicyonid trackway was discovered in 1960 when a manus-pes track set was found exposed on a moderately dipping bedding plane. Excavation of the rock overlying this bedding plane revealed 4 additional manus-pes sets (Fig. 9). In 1964, the trackway bedding plane was carefully cut into square sections using a power rock saw with the sections aligned so that each manus-pes set was intact. Each section was numbered in the field and then transported to the Webb campus and stored in a shed. In the late 1960s the entire bedding plane was reassembled for exhibit in the Hall of Footprints.

The proboscidean trackway was a different situation as four large round tracks were exposed on a single bedding plane that was dipping at about 30 degrees and the tracks were already showing signs of damage from erosion. The tracks needed quick removal and Alf and students collected the tracks in 1969 by cutting the rock into sections (Fig. 8). The sections were reassembled a few weeks later and displayed in the Hall of Footprints.

The multiple camel trackway preserves two sets of tracks of mid-sized camels, which are now displayed on a large reconstructed bedding plane in the Hall of Footprints (Fig. 9). Details of where the trackways were collected and when this was done are obscure. However, in contrast to the amphicyonid and proboscidean trackways, the bedding plane preserving the camel trackways is a highly indurated limey mudstone. This unit was not cut, but was broken into sections and then reassembled for exhibit. Breaking the bedding plane into sections is a simple removal process compared to cutting the rock, but it should be employed rarely

and only with great caution.

The amphicyonid, proboscidean and camel trackways from the Barstow Formation housed at the Alf Museum are unique and scientifically important specimens. The amphicyonid trackway is the only known example from North America, the proboscidean trackway is an early record of the migration of these animals from Asia into North America in the mid-Miocene and the camel trackways preserve evidence of two individuals walking in the same direction, perhaps side by side. By collecting and exhibiting these trackways, the Alf Museum has provided a valuable service to both the public and scientific community as the trackways are easily accessible.

For both the amphicyonid and proboscidean trackway sites, more tracks probably could be collected. Each trackway is situated in rock whose maximum bedding plane dip is oriented parallel to the direction of movement of the individual who left the tracks. Thus, it appears that both trackways extend underground and that if a major excavation was initiated it would likely result in recovery of more tracks. But before further excavation is attempted, it must be for good reason. If no additional information of scientific value will be gained or if more tracks are not needed for exhibit or other purposes, the unexposed portion of the trackway should remain undisturbed. All excavated, *in situ*, and float track sites should be mapped, photographed and inventoried so the sites can be revisited if required.

Limiting Site Information Access

Finally, to protect the proboscidean and amphicyonid trackway sites, or any track site, it is important to both severely limit access to site information and ensure that the site looks undisturbed. Site location information should only be available to researchers or resource management staff as wide distribution of site information could lead to harmful resource impacts including theft or vandalism (in this paper, we selected close-up photos of sites so the sites can't be relocated using the photos). The NPS, for example, has a Freedom of Information Act (FOIA) exemption for specific site, or locality, information (1998 NPS Omnibus Management Act, Section 207). This provision authorizes the NPS to withhold information from the public in response to a FOIA request concerning the nature and specific location of "mineral or paleontological objects" within units of the National Park System. Also, the area where the tracks were collected must be groomed so even though more tracks are not exposed, the site looks natural and does not attract inadvertent attention. In the Barstow Formation in the 1960s, there were many track sites that were exposed and not collected by legitimate entities. By the 1990s, theft or vandalism had destroyed virtually all of these sites.

SUMMARY

The fossil footprint collection at the Raymond M. Alf Museum of Paleontology consists of approximately 800 specimens and is one of the best in the world. These tracks and trackways were recovered from eight formations, with those from the Barstow (322 specimens), Coconino (142 specimens) and Avawatz (141 specimens) formations comprising the largest holdings. The collection includes 22 holotype, syntype or paratype specimens representing 14 ichnotaxa (Sadler, 1993; Sarjeant and Reynolds, 1999, 2001; Sarjeant et al., 2002). The Alf Museum once housed seven specimens from Tertiary rocks in Death Valley National Park, some of which represent the holotypes or syntypes of 4 ichnotaxa: *Hippipeda gyripeza* (equid, holotype RAM 204); *Lamaichnum etoromorphum* (camel, syntypes RAM 203 and RAM 200) (Sarjeant and Reynolds, 1999); *Alaripeda lofgreni* (bird, holotype RAM 201) (Sarjeant and Reynolds, 2001); and *Felipeda scrivneri* (felid, holotype RAM 242) (Sarjeant et al., 2002). These specimens were returned to the National Park Service in the late 1990s and presumably have been recatalogued.

The track collection at the Alf Museum is a testament to the life's work of museum founder Raymond Alf whose early interest in trace

fossils translated into a career-long search for fossil footprints throughout the western United States. Students and faculty at The Webb Schools assisted Alf in this endeavor that spanned nearly four decades (late 1930s to early 1970s). The stratigraphic utility of parts of the collection is limited by the lack of precise locality data for many specimens. However, there are many excellent photographs of Alf's collecting sites housed in the museum archives. These photos have been used to relocate specific sites in the Barstow, Avawatz, Moenave and Tecopa formations. This work needs to be expanded to all museum track sites.

Management of fossil tracks-trackways on public lands is a challenge as protection of sites from erosion and vandals is paramount as the paleontological information each site yields is usually unique. Float track should always be collected. Exposed *in situ* trackways are at risk and should be excavated if they can't be protected. Because each site is different in terms of the quality of track preservation, type of rock, geographic setting and other factors, removal of trackways can be easy to difficult depending on the site. Examples from the Alf Museum show that collecting trackways and reassembling them for exhibit makes the resource readily accessible to both the public and the scientific community.

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THE APPLICATION OF PHOTOGRAMMETRY, REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO FOSSIL RESOURCE MANAGEMENT

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Abstract—Change is one of the many challenges facing fossil resource managers today. This concept is not restricted to physical alterations affecting the resource such as erosion, visitation, vandalism or even preservation. Changes in the views of the public, policies of an administration and in the field of geospatial technology are also greatly affecting how a particular resource program or significant locality is managed. Geospatial technologies are changing and evolving at an incredible rate, resulting in not only an increase in capability, but also of complexity and expectations for the resulting product. Today, it is not uncommon to integrate a number of geospatial tools, some of which require a sophisticated knowledge of computer systems, data requirements and techniques. This is not necessarily a negative, as it sets the foundational need for partnerships with other resource specialists, academic researchers and the public across disciplines, across administrative boundaries and across agencies. Within the cadre of geospatial technologies, there are a number of tools that can greatly streamline and support land management decisions and the implementation of these decisions. These tools include utilizing imagery data sets through photogrammetry (the art and science of making measurements from photographs) and analyzing remotely sensed data. Data sets may be collected through active sensors, such as RADAR or LIDAR, or passive sensors, which collect multi- or hyper- spectral imagery. The processing of these data sets can result in detailed data files representing the terrain or geological and soil maps, to name only a few. Data sets can be combined with both coordinate and attribute data collected in the field and processed geospatially using Geographic Information Systems, a combination of computer hardware, software and data that allows information to be organized around a specific location. At paleontological localities such as the Red Gulch Dinosaur Tracksite, Twentymile Wash Dinosaur Tracksite and Picketwire Canyonlands Dinosaur Tracksite innovative geospatial technologies were tested, refined and integrated. This integrated approach not only resulted in documentation of the paleontological resource, but also supplied products used in site development, resource protection and interpretation.

INTRODUCTION

The challenges facing land managers today can be immense. Of these challenges, perhaps one of the most significant is the effects of change. Not only can a particular fossil resource be changed through time by erosion, visitation, vandalism or even preservation, but the changing views of the public and policies of an administration can drastically affect how a particular program or locality is managed. In addition, the tools used to manage fossil resources, in particular geospatial technologies, are changing and evolving at an incredible rate, which is both a blessing and a curse. Changes that have taken place over the past two years have given us the capability to quickly take a series of photographs and effectively transform them into a detailed terrain surface. The resulting surface and draped image can be posted on the World Wide Web so that the world can visit a site virtually or conduct virtual research on a specimen. Unfortunately, the incredible power available in this technological advancement comes with a price. Twenty, or even ten years ago, a “generalist” could dabble in the world of geospatial technology and be fairly confident that they had a good handle on the capabilities of a system. A project could be taken to successful conclusion using one or two techniques or software packages. As the tools have increased in capability and complexity our expectations of the resulting product have also increased. Today it is not uncommon to use a number of geospatial tools to get from point A to point B, making it more difficult for any one individual to know everything there is to know, or possibly even to complete a project to their full expectations unassisted. This is not necessarily a negative, as it sets the foundational need for teamwork and partnerships not only among spatial analysts, but with other resource specialists, academic researchers and the public across disciplines, across administrative boundaries, and across agencies.

In 1998, at the Fifth Federal Conference on Fossil Resources, presentations encouraged paleontologists and resource managers to dig in and learn everything there was to know about Geographic Information Systems (GIS). Today with the increase in technology and complexity, we recommend looking, listening, learning and reaching out to those who have geospatial expertise. Become familiar with the vast possibilities that are available in the geospatial toolbox and capitalize on them. A geospatial specialist should be included at the inception of a project, not at the end when all the data has been collected and the need for GIS analysis has arisen. These days, a cadre of highly skilled spatial analysts exists throughout our agencies although they may not exist within every office. If a geospatial specialist or team of spatial analysts are not readily accessible, request such support from management, to elevate the importance of geospatial expertise.

Past papers have provided detailed discussions of technologies that included specifics such as what type of camera to use, which software and what button to push. With the incredible rushing forward of technology, these papers, some only a few years old, are now out dated. Instead of falling into that trap for yet another paper, the following discussion will describe the available technology, what tools have worked in the past, how they can be applied to the present, thus making planning for future projects more successful.

BACKGROUND

As stewards of our natural world, we realize that all fossils are important as a natural resource for the information they provide to interpret our geologic past. As stewards of public lands, we are mandated to regulate the collection, preservation and curation of vertebrate and other fossils deemed significant. Thus, the focus of this document will be

on the management of vertebrate and other significant fossil resources. Fossil resource management, in a broad sense, can be grouped into phases: resource identification, resource location and documentation and resource interpretation and management. Each of these phases of fossil resource management can benefit from the capabilities found within the geospatial toolbox. Before we discuss examples of management applications, let's fling open the lid of the geospatial toolbox and see what's inside.

World Wide Web

One of our most powerful tools, although not strictly geospatial, is information, and one of the best free sources of information is the World Wide Web. The ability to search the Web and connect to information brings the technical world to our fingertips. By simply typing a word or phrase into one of the many search engines, one can go from an overview down to very detailed information on a subject. Fast-streaming raster technology allows us to move from a digital view of our backyard to a location around the world in seconds. The descriptions of geospatial technologies that follow are intentionally brief and selective, focusing primarily on techniques that are tried and true or exhibit great potential for fossil resource management. The reader is encouraged to utilize the Web to find out more information on methods and technologies of interest. Unlike this document, the information found through the Web will continue to change and evolve over time, helping us keep current with a changing world.

Photogrammetry and Remote Sensing

Photogrammetry can be defined as the art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and other remotely sensed data (Alspaugh, 2004). Although, by definition remote sensing is a subset of photogrammetry popular use has put it into a category of its own. For many people remote sensing has become synonymous with satellite imagery imposing an unfortunate limitation on the term. Remote sensing is the act of remotely collecting data about a subject. Often this data is the signature or spectra of electromagnetic (EM) radiant energy (Lillesand, 1987). Two of the most powerful remote sensing tools have been with humankind since its inception, the human eye and brain. The eye is an extremely powerful sensing device that sends data to the brain to be processed and interpreted. Current sensor technology extends our natural capability for perceiving the visible range of the EM spectrum into very short waves, such as gamma rays and to very long waves, such as radio waves. Other phenomena, such as gravity or magnetic fields, can also be recorded. In general there are two types of sensors, active and passive, used to collect remote sensing data (Alspaugh, 2004).

Active or Detecting and Ranging Sensors

Active sensors transmit EM energy and record the reflected signals in the form of waves or data points; they include Radio Detection And Ranging (RADAR), Synthetic Aperture Radar (SAR), Interferometric Synthetic Aperture Radar (IfSAR), Light Detection And Ranging (LIDAR) and Sound Navigation And Ranging (SONAR) (Wang and Dahman, 2002). These sensors measure the length of time signals take to strike an object and be reflected back. By knowing the location of the sensor, which is provided by yet another technology, distances are transformed into elevations. The result is a digital file containing an array of points that define the surface struck by the signals (Crane et al., 2004). These files containing horizontal and vertical coordinate values are commonly referred to as digital terrain models (DTM). When evaluating the resulting DTM, two components must be considered: the spacing and the precision at which the data points are collected. To a large extent, both of these components are governed by the capabilities of the sensor; however, the object to sensor distance is also a factor (Wang and Dahman,

2002). Active sensors can be placed on a variety of platforms including satellites, airplanes, unmanned airborne vehicles and surveying tripods.

Synthetic Aperture Radar (SAR) and IfSAR, often satellite-based systems, are not limited by light conditions, thus data collection can occur at any time of day or night. The wide wavelengths of SAR and IfSAR can penetrate haze, clouds, water, snow and even sand. The DTMs resulting from these systems make a good supplement to imagery obtained by photogrammetry and are suitable for orthorectifying medium- and high-resolution satellite images (Wang and Dahman, 2002). A variety of data layers can be overlain, combined and analyzed in the GIS environment, thus new information can be generated. In addition, overlapping SAR images can be viewed in stereo and used to construct three-dimensional models (Wang and Dahman, 2002). SAR, IfSAR, and Side-Looking Airborne Radar (SLAR) have been successfully used to analyze and monitor geologically active areas such as eolian dune fields, volcanic terrain and tectonically active areas (Ford et al., 1998).

Light Detection and Ranging (LIDAR) systems emit and receive pulses from an optically-safe laser; the return provides horizontal and vertical coordinates and intensity values. The intensity values correspond to the reflectance of the material returning the signal and can greatly assist with post processing of the data. There are both aerial- and ground-based LIDAR systems. Aerial LIDAR data is often used in conjunction with aerial photography to produce digital orthophotographs (Wang and Dahman, 2002) and can be used in the production of high-resolution topography (contour intervals of one meter or greater). Ground-based LIDAR (gbLIDAR) systems, also known as laser scanning (Louden, 2003) are high-speed, high-accuracy three-dimensional data collectors with the capability to capture hundreds of points per second. Currently, these data points have a positional accuracy of +/- 6 mm (or better) when scanning at distances of less than 50 m (Matthews et al., 2001a). Ground-based laser systems are transportable, robust, field units that provide near real-time access to the data. An advantage of these systems is that measurements can be made directly from the raw three-dimensional digitized or point cloud data while in the field. This data can be utilized in a variety of software packages for the production of three-dimensional surfaces, contours and site visualization (Matthews et al., 2001a).

There are other detecting and ranging sensors that emit and receive other portions of the electromagnetic spectra, as well as other types of wave phenomenon. Several such systems use sound and include SONAR and ultra sonic guidance systems. SONAR and some specialized LIDAR systems make it possible to collect elevation beneath the surface of the water providing bathymetric data along coastlines or in shallow fluvial systems (Crane et al., 2004).

In addition to sensors that penetrate the air and water, our geospatial toolbox also contains sensors with the capability of detecting features in the ground beneath our feet. For exploration geophysics, the three main types of sensors are magnetic, gravitational and seismological. As with the active sensors discussed above, the platform can vary from satellite- to ground-based (Short, 2006). Data collected from these sensors has given us an incredible wealth of information that has increased our understanding of geological processes on a global scale. However, it is the ground-based use of these techniques that prove most directly beneficial to fossil resource management. As with the active remote sensing technologies described above, there are a wide variety of techniques and sensors that record and measure different types of information. Although there are most certainly many sensors that could prove useful for fossil resource management, the discussion below will feature three techniques with proven results and future possibilities.

Ground-penetrating radar (GPR) is a geophysical method that involves the transmission of high frequency radar pulses from a surface antenna into the ground. The elapsed time that it takes for the energy transmission to be reflected back to the surface is measured (Conyers, 2004). The near-surface features that reflect the signal can include buried materials such as fossil specimens or changes in sediments and soils. When antennas are moved along grided transects, many thousands of

radar reflections are measured and recorded, thereby producing a three-dimensional picture of subsurface soil, sediment and material changes (Conyers, 2004). The power of this technology is the detection of change below the surface; unfortunately, there are several factors that can adversely affect this capability. These factors include the presence of significant amounts of clay minerals, high moisture content and materials of similar reflectance (Gillette, 1994; Conyers, 2004).

Geophysical diffraction tomography (GDT) utilizes acoustic energy to create a seismic profile. Data is collected from a string of hydrophones (water-coupled microphones) in a water-filled borehole; a seismic gun is moved along a sequence of lines radiating out from each borehole. The acoustic waves are recorded and after processing a sequence of vertical seismic profiles result (Witten et al., 1992). The velocities at which the acoustic waves pass through the ground are affected by the composition of the rock layers. Thus, variations in rock density, moisture, fault lines and other variables can affect acoustic wave transmission through the subsurface (Witten et al., 1992; Gillette, 1994).

Radiological survey instruments (RSI) detect ionizing radiation, i.e., gamma radiation, emitted by elements such as uranium and vanadium (Jones et al., 1998). When materials containing these elements are present in the subsurface they are often detectable at the surface. The RSI collects these ions and sends them to an instrument that measures the ions. Once measured, a response is generated and recorded. By utilizing a predetermined grid system a survey can be conducted and a spatial representation of the radiation is produced. For this technique to be effective it is necessary to have materials with levels of radiation higher than their surroundings (Gillette, 1994; Jones et al., 1998).

Passive or Raster Sensors

Passive sensors record reflected or emitted EM energy. These sensors rely on the external illumination from a light source (such as the sun). Some passive sensors can pick up thermal emissions, thus are most effectively used during times of low sun illumination such as sunset or at night (Alspaugh, 2004; Short, 2006). There is a large cadre of passive sensors; most detect the EM energy that falls within the visible part of the spectrum. However, there are a growing number of sensors that operate in the upper end of the visible and well into the thermal wavelengths. The resulting image data commonly falls within the categories of panchromatic, multispectral, hyperspectral and ultraspectral (Alspaugh, 2004; Short, 2006).

Panchromatic images are collected by single-band sensors that capture wavelengths in the visible or near infrared (IR) part of the EM spectrum (Lillesand, 1987). An excellent archival resource, especially for foreign countries, is imagery taken from the declassified CORONA satellite missions (Alspaugh, 2004). The resolution of these black and white images varies, but is often around 5 m. This data can be useful in parts of the world where aerial photography or even maps of adequate scale are not available.

Multispectral sensors commonly collect from four to eight EM bands at intervals through the visible and near IR part of the spectra (Short, 2006). Currently, there are 30 optical civil land-imaging satellites and four privately funded systems in orbits that cover the United States (Stoney, 2006). When evaluating imagery data for its utility, a very important consideration is the resolution or ground sample distance (GSD). The current orbiting sensors can be divided into two major resolution groups: high-resolution systems (0.5-1.8 m) and mid-resolution systems (2.0-39 m). The area an image can cover is called the swath width; high-resolution swaths are in the 8 to 28 km range and mid-resolution swaths are generally between 70 and 185 km (Stoney, 2006). Due to the large variety of image collection capability represented by these systems, it is very difficult to discuss them individually. An excellent resource for information on these satellite sensor systems is available on the Web and is provided by the American Society for Photogrammetry and Remote Sensing (Stoney, 2006). Commercial satellite imagery

can be very current, very expensive and often comes with licensing restrictions that controls who the imagery can be shared with. However, much of the commercial imagery is also available archivally making it a more affordable data source. Of worthy mention is imagery from Landsat 7. This imagery has proven to be an excellent tool for mapping geology and vegetation. The U.S. Geological Survey (USGS), Earth Resources Observation Systems (EROS) data center, provides an archive and source for obtaining current and older Landsat data, as well as other types of imagery (Stoney, 2006).

Hyperspectral sensors collect EM radiation centered over the visible, extending into the thermal and infrared, and can record this spectrum in over 200 bands. As with other passive sensors, the GSD is related to the height of the platform on which the sensor is housed. Satellite-based hyperspectral sensors produce resolutions from 15 to 90 m (Short, 2006), while much higher resolutions can be obtained when sensors are housed on airplanes. Hyperspectral imagery can offer a much greater spectral resolution resulting in an almost continuous spectral signature. As with multispectral imagery, the analysis' power comes with the ability to combine various bands and classify the results. However, with hyperspectral imagery, there are a much greater number of possible band combinations many of which are extremely sensitive to geological features (Short, 2006). To help interpret these data there are spectral libraries that link reflectance and wavelength to the materials that produce them. Also, as with multispectral sensors, it is important to incorporate ground truthing into the data collection and analysis process. Portable ground based spectrometers can be taken into the field and used concurrently with aerial data acquisition. When the spectra of features are collected on the ground, a supervised classification of the imagery can occur providing a higher probability of success (Short, 2006).

Although currently in the developmental stage, there is an emerging group of sensors referred to as Ultraspectral. These sensors are being developed by the military to target very narrow bands of the EM spectra, particularly radioactive wavelengths (Jasani, 1997). Although developed to detect signals emitted from weaponry and other nuclear sources, in the future there could be potential applications to geology and paleontology.

Photogrammetry

As with the term remote sensing, popular use has synonymized photogrammetry with the measurement or processing of aerial photography. Photogrammetry has traditionally utilized commercially acquired, large-format aerial photography. The photogrammetric processing of aerial photography has generated extremely valuable products such as topographic maps, digital orthophoto maps and digital elevation models series produced by the USGS. But with new advances in technology there is more to photogrammetry than the predominant 1:24,000 scale products.

Photogrammetry can be used to measure, document or monitor almost anything that is visible within a photograph and can be divided into categories based on the distance of the camera from the subject. Aerial photogrammetry typically refers to oblique or vertical images acquired from distances that are greater than 300 m (Breithaupt, et al., 2004b). The distance of the camera from the subject in commercial aerial photography is a limitation imposed by the Federal Aviation Administration. When aerial photography is flown at a height of 305 m (1000 ft) above mean terrain with a 153 mm focal length lens, the result is photography at 1:2000 scale. The smallest object that can be detected is 5 cm. Most large format aerial photography is acquired through commercial contractors and is available in hard copy or digital formats. Generally, aerial acquisition is designed and planned according to the specifications needed to generate a particular product over a specified area (Breithaupt et al., 2004b). Larger area acquisitions (whole counties or states) are conducted by federal and local governments. Many land management agencies, including the Bureau of Land Management (BLM), maintain

aerial archives that contain historical aerial photography over the lands they manage. Information on these archives is available through agency websites. The National Agriculture Imagery Program (NAIP) is managed by the U.S. Department of Agriculture Farm Services Agency (FSA) and covers agricultural lands in the United States. Other governmental agencies are partnering with FSA to produce statewide coverage of current orthorectified natural-color, one, two and ten meter imagery.

Close-range (also referred to as terrestrial or ground-based) photogrammetry (CRP) has an object-to-camera distance of less than 300 m. A variety of cameras and platforms may be used to obtain the photographic images to be used in CRP processing, including cameras housed in unmanned airborne vehicles, suspended below helium-filled blimps and mounted on tripods (Breithaupt et al., 2004b). It is proposed that the definition of close-range be restricted to between 50 and 300 m, and that object-to-camera distances of less than 50 m be referred to as extreme close-range photogrammetry. Theoretically there is no limit to the resolution that can be achieved from CRP images.

The same requirements that exist for a successful aerial photogrammetric project—camera calibration, control coordinates for camera orientation and stereo-photo pairs—are also required by CRP (Matthews and Breithaupt, 2001; Breithaupt et al., 2004b). Conventional survey techniques, such as Global Positioning Systems (GPS), may be adequate for close-range projects where the ground sample distance (GSD) is larger than the accuracies achievable by GPS methods. In extreme CPR, the GSD is often very small (less than one millimeter) requiring a ground control survey method of similar accuracy. So far, survey instruments that can achieve that level of precision are not economical for use in a field setting, thereby requiring a more affordable hybrid method to be developed (Matthews et al., 2004a,b).

Three-dimensional measuring and modeling software (3DMM) is a hybrid process that can be integrated into the traditional photogrammetric process that meets the requirement for high-level accuracy in a nontraditional way. Sophisticated camera calibration is the key to the 3DMM software that can be performed on any camera that can be set to a repeatable focal length (for example, at infinity). The software can use many photographs taken from many different perspectives in addition to stereo pairs of photographs. The 3DMM software has the ability to mark circular objects at the subpixel level greatly improving project accuracy. In addition to simple circles, the software supports coded targets to aid in the task of identifying the same point on multiple photographs (Matthews et al., 2004a,b). Coded targets are essentially circular bar codes with a center circle and arcs of varying lengths surrounding it.

The tools required for field collection of photogrammetric data using the hybrid method are a digital camera and fairly inexpensive software. This process is very robust and can be applied to a large variety of resource issues and used by persons with a wide range of technical expertise. Once photographs have been acquired and oriented with 3DMM software, the resulting camera orientations can be imported directly into a softcopy photogrammetric workstation because the cumbersome processes of control point collection and aerotriangulation have been circumvented. Although traditional photogrammetric control is not required to orient the stereo photographs, it can be utilized to tie the microtopographic data into a real-world coordinate system (Matthews et al., in press). Microtopographic data is generated in the photogrammetric workstation through a process known as automated digital terrain extraction, commonly referred to as autocorrelation or digital image matching. It is a process in which sophisticated software matches pixels (picture elements) with unique spectral and geospatial values within one digital image to similarly valued pixels in the adjacent image of the stereo pair.

The result of the data generated using extreme CPR and softcopy photogrammetric analysis yields a dense grid of x, y and z coordinate points that can be accurate to ± 0.5 mm depending on project scale. Photographs taken from high resolution consumer digital cameras (six

megapixels or greater) utilizing the hybrid method can easily produce digital three-dimensional surfaces and detailed microtopographic contour maps for areas as large as 5 m². Larger areas can also benefit from this type of documentation; however, camera platforms other than handheld or tripod may be required to achieve the required photo orientations. Depending on size of the area and height above the subject positional accuracies may be reduced.

Both the traditional aerial and hybrid photogrammetric processes enables the interpretation of imagery and the collection of data necessary to produce reliable maps that give land managers confidence that their decisions are defensible. The data for the photogrammetric process customarily take the form of topography (terrain or land surface) or planimetry (such as streams, transportation routes, vegetation and cultural information). However, all raw photographs have inherent distortions predominantly from effects of camera tilt and relief displacement whereby features at higher elevations are displaced away from the center of the photo (Alspaugh, 2004). To eliminate these distortions, the ground geometry is re-created as it would appear from directly above each point in the photo. This is accomplished by applying a process called differential rectification to each pixel in the image. However, an orthophoto is a photograph that has already been corrected to eliminate distortions and can be utilized as a map. Orthophotos, as discussed previously, can be produced from many types of raster data, from 30 m satellite imagery to one-millimeter extreme close-range photographs (Breithaupt et al., 2004b). The geospatially corrected imagery products are an integral component in the next tool we will take from our geospatial toolbox, Geographic Information Systems, or GIS.

Geographic Information Systems

The concept of using two-dimensional lines and symbols to convey information about our three-dimensional world dates back to the time when man first started to communicate. Presenting information about our natural world has always been an important part of our existence—from etching hunting locations or techniques on a rock wall or preserving building stone locations scribed on papyrus. As the tools used to locate ourselves on the earth have become more sophisticated, our maps have become more accurate, easier to produce, and easier to update. Tools such as GIS not only allow us to make better maps faster, but provide us with real-time access to data. The most significant part of GIS is the analysis, specifically, the ability to generate new information by manipulating preexisting data. Powerful expert systems allow multiple data sets to be modeled and integrated proving very useful in resource management problem solving. This capability changes our concept of geospatial data, how it is viewed, processed, analyzed and utilized.

A GIS is a combination of computer hardware, software and data that allows information to be organized around a specific location. This technology integrates database functions and statistical analysis with map-like visualization and geographic analysis allowing for the integration, visualization, management, analysis, interpretation and presentation of a variety of geological and paleontological data in ways never before possible. All types of data collected about a specimen, a locality, a rock unit, a state or any other type of geographic container can be integrated using GIS. Complex relationships can now be documented and evaluated in ways that could not be done previously using any other type of analysis, thereby increasing the value of that data. Data that is brought into the GIS can be acquired through a wide variety of methods, including orthoimagery, field collection and geospatial data via the World Wide Web.

Geospatial Clearing Houses

Geospatial clearing houses provide a digital portal to free or low cost geospatial data. These data gateways provide digital versions of USGS 7.5 minute quadrangle maps, digital orthophoto quads, vector

files (depicting such features as transportation, vegetation and hydrography), digital terrain models (DTM) and even geological and soils maps. Understanding the parameters and quality of data is fundamental to reliable analysis. Consideration must be given to manipulating data of varied quality or resolutions. The Federal Geographic Data Committee (FGDC) is an interagency committee that promotes the development, use, sharing and dissemination of geospatial data and imagery. To this end the FGDC has developed a standard for metadata. A metadata file contains data about the geospatial data including coordinate system information, how the geospatial data was captured and produced and attributes of the data file they accompany.

Coordinate Collection

The acquisition of field data has been incredibly streamlined by the use of GPS. GPS technology has changed rapidly over the past few years thereby making accurate receivers very affordable. In addition, innovations such as the data logger and personal digital assistant (PDA) allow tabular data and images to be linked to GPS points. These data can be brought directly into the GIS. Currently, many consumer-grade receivers are accurate to five meters, although a number of factors can affect accuracy for better or worse. A GPS unit receives signals from satellites. When signals are available from four or more satellites, a position can be determined mathematically. The accuracy depends upon the geometry of the tracked satellites, how strong the signals are and how long the unit can communicate with the satellites. The result is a position that can be captured and then transformed into a variety of coordinate systems such as geographic (Latitude and Longitude) or projected (Universal Transverse Mercator (UTM) or State Plane) coordinate systems (Chapman et al., 2002).

Differential GPS (DGPS) can achieve accuracies that are good to the centimeter level. To achieve this level of accuracy at least two GPS receivers are needed; one remains stationary (the radio base station) while other units rove collecting position measurements for unknown points. The stationary receiver is set up on a survey point of known accuracy, such as a benchmark and uses the known position to calculate the timing to the satellite (Matthews et al., in press). The travel time of the GPS signal is compared with that collected from the rover unit, a correction factor is computed and later processing applies this correction factor to the rover position measurements resulting highly accurate geographic coordinate locations. The National Aeronautics and Space Administration, U.S. Coast Guard and other entities maintain highly accurate reference networks, such as High Accuracy Reference Network (HARN) that have reference points throughout the world. These reference points can be used with DGPS and when using a single receiver. Computer software takes the input from the GPS receiver and, when on a computer linked to the Web, goes out to specific sites and downloads very up-to-date information about these reference points. The corrections from these points are then incorporated in the post processing. Positional accuracies using a single GPS receiver and post processing using the reference networks can be good to 0.5-1 m depending on the type of GPS unit used (Chapman et al., 2002; Matthews et al., in press). High positional accuracies can also be achieved by subscribing to broadcast services such as ProXRS, (OmniStar). These services mimic the radio base station component of DGPS.

It is important to keep in mind that there is more to a particular GPS collector than positional accuracy. User interface and the ability to store and handle attributes along with the location can vary. Both the collection of field data and the carrying of attribute data into the field are desirable for scientific work. As with GPS, data collected from more traditional survey equipment such as electronic distance meters (EDM), total stations and similar systems can be imported into a GIS (Breithaupt et al., 2004b). Robotic total stations and computerized EDMs record coordinate and attribute data much the same way as the data loggers and PDAs. Conversion software is available that supports the processing

and import of these systems into a GIS format. The resulting accuracy can rival DGPS; however, these survey devices provide location data in a user-defined coordinate system. In order to tie data to a real world system, known benchmarks or locations documented through the use of GPS must be used. In addition, basic string-line grid systems can be accurately and efficiently converted into a digital system when care is taken in the accuracy of their construction and supporting measurements made on elevation and orientation of elements.

Imagery Analysis

In some cases, valuable field data can be collected without even leaving the office. The source of these data comes from the interpretation of imagery. As discussed previously, a wealth of geological, paleontological and resource management information can be collected from a variety of imagery types. By inspecting and interpreting imagery, time spent conducting field prospecting can be greatly streamlined. Aerial imagery can be used to focus on particular areas that meet the necessary criterion and avoiding those that do not. Thus, the same amount of time may be spent in the field, but that time is maximized. Ground-truthing is still necessary when it comes to finding fossil resources.

Data Synthesis

Once the field data has been collected, the process of combining the various components—airial and close-range photography, survey and GPS coordinates, field observations and measurements and information taken from other maps or DTMs—begins. Images can be registered to the coordinate data, three-dimensional data sets can be processed and evaluated and tabular (or spreadsheet) data can all be integrated into the GIS environment. The ability to link tabular data to graphic displays makes GIS a very powerful tool. Vector (point, line and polygon) data all have associated tables (Breithaupt et al., 2004b; Matthews et al., in press). These tables or databases can contain an abundance of information, such as year collected, species, bone orientation or length of track (Chapman et al., 2002). Unique identifying fields (e.g. specimen number) can link several tables, which can all be queried as one, allowing different categories of data about the same subject to be kept in discrete databases. With a common identifying field, databases, regardless of origin, may be “attached” and combined for analysis. This can be helpful when databases (perhaps housed in universities) can be separated from precise location information and used for statistical analysis. An exciting component of GIS is the ability to link the database to graphic locations and symbolizing these locations based on different attributes found in the database. Thus, relationships between paleontological elements become more obvious and perhaps, things that appeared to be related in the field may actually be random or random observations may fall into a pattern (Chapman et al., 2002; Breithaupt et al., 2004b).

Not only can a GIS aid in analysis through the use of a number of tools, but the advanced graphical capabilities support virtual three-dimensional reconstruction of a resource. One such application could be the construction of a virtual quarry map, representing fossils and other elements found within a site. The virtual map could be used not only as a primary research tool but, for interpretive and educational applications as well; individuals could take virtual tours and select individual components, bringing up more detailed data including high resolution images and three-dimensional models. These views can be digitally rotated and analyzed at an infinite number of angles to help piece together the prehistory of the site (Chapman et al., 2002; Breithaupt et al., 2004b).

EXAMPLES

As with technology, fossil resource management is very complex, often changing and always demanding. Within this paleontology, great potential for conflicts exist and often many options must be explored in order to reach an acceptable outcome. A few selected projects have been chosen for illustration of where some of the tools in the geospatial toolbox

have been applied to fossil management issues. In looking at past projects, it is helpful to keep in mind the goals of fossil resource management. Generally stated, these goals are to identify areas where fossil resources exist, support scientific study through documentation, preserve the resource through collection and curation and keep the resource safe when it is *in situ*.

The following projects were chosen for illustration because of space limitations or because they represent first hand experience of the author. They are by no means the only ones that have utilized geospatial technology and there are most certainly other projects that are excellent illustrations of how best to use GIS, photogrammetry or remote sensing. Remember, these projects they are already dated because the technology has evolved, been refined and can be applied more economically and more quickly. But, for these very reasons they deserve consideration for future projects.

Finding the Resource

Geographic Information Systems (GIS) can be an incredible tool for reconnaissance-level resource management. Several different digital data layers such as geology, vegetation, soil type, topography and ownership can all be viewed and analyzed as described above. This type of analysis allows examination of such questions as, "Where can I find exposures of the Morrison Formation with sparse vegetation, on BLM land?" Utilizing digital geologic maps and other supporting digital data, geologic formations and their geospatial expressions can be grouped or classified according to the likelihood that they would contain vertebrate fossils. The level of management awareness or sensitivity with which a formation should be regarded can then be attributed within the GIS (Bryant and Matthews, 1998; DeBlieux et al., 2003; Kirkland et al., 2006).

A limitation to this type of analysis is, unfortunately, data that is incomplete or too generalized. Often geological maps of the appropriate scale are not available, or when available, do not completely cover the area of interest. However, metadata can be of great assistance in determining when and how data can be used in a particular project. Fortunately, imagery analysis using natural color aerial photography and multispectral and hyperspectral sensors can provide refined geologic and lithologic information. An example of this is lithofacies mapping of the exposed Jurassic section in the Bighorn Basin of north-central Wyoming. This mapping was conducted using remote sensing data, specifically Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data sets (Strasen, 2004). Principal component analysis, band ratios, minimum noise fraction and spectral sharpening techniques were performed on the visible and near infrared (VNIR) and shortwave infrared (SWIR). Data calibration was accomplished by acquiring field spectral readings of a wide variety of lithofacies at known locations with a portable spectroradiometer. Results of the analyses exhibit subtle and dramatic spectral variations that correlate to known lithologic changes in the field. These changes were not evident from simply analyzing high-resolution digital air photos. By extrapolating ASTER data from known lithofacies to areas with no field data, promising outcrops were identified. UTM coordinates were extracted from the ASTER data and located in the field using GPS for navigation. One of the benefits of this analysis was the location of an oolitic limestone facies in the field not detected by other remote sensing methods. These promising results demonstrate the utility of combining and analyzing imagery data sets as an important tool in geologic mapping (Strasen, 2004).

By combining GIS analysis with imagery classification processing and aerial photograph interpretation, on the ground paleontological surveys can be greatly streamlined and focused. By adding GPS and data loggers, positional and attribute data about resources can be entered in the field. The navigational, or waypoint, capability of most GPS units can also provide great assistance in locating the resource for further investigations. Digital data on fossil locations can be more easily inte-

grated into State databases. A Statewide, comprehensive digital database for the State of Utah is being developed through a cooperative project between the BLM and the Utah Geological Survey. This database is being inputted into a spreadsheet format and includes data on locality, geology and repository (DeBlieux et al., 2003; Kirkland et al., 2006). This data can also be utilized in developing and refining paleontological sensitivity maps (Bryant and Matthews, 1998; DeBlieux et al., 2003; Kirkland et al., 2006). By utilizing the capabilities of relational databases, information about exact fossil locations can be kept separate from pertinent paleontological information. This allows for proprietary information to remain secure while information important to researchers or the general public can be made available in a more generalized format.

Resource Documentation and Interpretation

Once the existence of a fossil resource is established, decisions on how best to approach documenting and preserving that resource must be made. In the case of skeletal remains, will fossils be extracted or as with a tracksite, will the resource be open and interpreted for public benefit? In either case, documentation is essential to the scientific understanding and future management of the resource.

Determining the extent of a proposed quarry or amount of overburden to be removed before the resource is exposed can significantly influence how an excavation proceeds. Tools such as geophysical diffraction tomography (Witten et al., 1992; Gillette, 1994) and radiological survey instruments (Gillette, 1994; Jones et al., 1998) can be effective for planning where to dig. These systems can provide the information on the sub-surface position of material and other features. Geophysical diffraction tomography (GDT) can create a probable three-dimensional sub-surface map showing extent, thus providing information about the volume of sediment to be removed.

Once skeletal materials are exposed, current technology can be an enormous help in mapping the fossils and recording important contextual data. A great deal of information is available from the context of the fossils within the sediments, including distribution of other flora and faunal elements and changes in lithology that may be present. These data can indicate the environment that produced the outcrop and even significant bits about the biology of the dinosaurs found there. Electronic Distance Measurement devices (EDMs) and other advanced surveying equipment can help document the spatial location of fossils within a quarry with sub-centimeter accuracy. For elongate fossils, the position of each end is recorded to provide orientation data (Chapman et al., 2002). In addition, close-range photogrammetry of a quarry site taken from the surface or through the use of a blimp or other unmanned airborne vehicles can not only provide detailed measurements and coordinate data, but a visual record of materials surrounding the bones (Breithaupt et al., 2004b).

Ground-based LIDAR (gbLIDAR) has been widely utilized to document historic structures and archeological sites (Louden, 2003), but its use in the documentation of paleontological resources is somewhat limited (Breithaupt et al., 2004b; Matthews et al., 2004a,b). gbLIDAR is an excellent means to capture a wealth of three-dimensional data on a subject in a very short time, but there is a high expense associated with this technology. However, considering the product, it may prove to be an affordable means of data collection. Photo-realistic virtual outcrops have been created by combining gbLIDAR with digital imagery to document geological features. These spatially and geometrically precise models of real-world surface exposures are being utilized to visualize, analyze and interpret geologic features such as bedding planes, faults and three-dimensional fracture networks and other sedimentary structures (McCaffrey et al., 2005; Clegg et al., 2005). A feature of LIDAR that could prove very beneficial to skeletal documentation is the intensity value that is returned along with the coordinate value. By utilizing this information, variations in surface textures between bone and matrix may be detected. Not only can a virtual outcrop be produced, but also virtual

reconstruction of quarry sites and skeletons, thus allowing the subject to be viewed from a variety of perspectives. Three-dimensional laser imaging technology shows great promise for the documentation, study, interpretation and archiving of paleontological resource data (Breithaupt et al., 2004a; Matthews et al., 2004a,b).

Tracking Dinosaurs

The evidence of the interaction of a prehistoric animal with its environment is preserved in the fossil footprint record. Detailed aerial and close-range photogrammetry along with digital spatial data utilized in GIS, provide excellent tools for documenting tracksites. Paleontological sites on public land in Colorado, Wyoming, and Utah have been extensively documented using a synthesis of close-range photogrammetry and established ichnological field methods resulting in a very precise approach for the measuring, recording and evaluating of fossil tracks (Breithaupt and Matthews, 2001; Breithaupt et al., 2001; Breithaupt et al., 2004b).

The Red Gulch Dinosaur Tracksite (RGDT) lies on the eastern flank of northern Wyoming's Bighorn Basin and is located approximately 22 km southwest of Shell, Wyoming. The initial discovery of tracks at the RGDT in 1997 was in a "dry wash" exposed along the Red Gulch/Alkali National Backcountry Byway. The floor of the dry wash is composed of an oolitic limestone member of the Middle Jurassic Sundance Formation (Breithaupt and Matthews, 2001; Breithaupt et al., 2001; Breithaupt et al., 2004a,b). Established ichnological field methods were utilized to locate and document the very subtle tracks on the limestone surface. GPS data collecting, precision surveying and photogrammetry were utilized to produce a geospatial framework. A comprehensive database of information was constructed from the field documentation and the geospatial framework.

Extensive photographic documentation of the tracksite included 30 m resolution satellite imagery, standard format aerial photography, 35 mm photos taken from tripod heights of 2-10 m, a remote-controlled airplane, an Ultralight aircraft, a blimp and close-range photogrammetric images (0.3 mm resolution) of a single track (Figs. 1-3). As a result of this combined approach to documentation over 1,000 dinosaur tracks were identified, described, geospatially located and photographed at the RGDT (Fig. 4)(Breithaupt and Matthews, 2001; Breithaupt et al., 2001; Breithaupt et al., 2004a,b). Based on the analysis of this synthesized data, interpretations about the animals that were present in northern Wyoming during the Middle Jurassic may be made.

The limestone surface at the RGDT contains tridactyl pes impressions of small- to medium-sized carnivorous dinosaurs estimated to weigh between 10 and 230 kg. Statistical analysis of individual track measurements indicated that only one taxa of dinosaur was present at RGDT (Sizemore, 2000; Breithaupt et al., 2001; Breithaupt et al., 2004a). These tracks are arranged into at least 125 discrete trackways (ranging from 2 to 45 steps). Based on a statistical analysis of the trackways, pace angulations (ranging from 158 to 180 degrees) represented those typical theropod dinosaurs (Wright and Breithaupt, 2002). Calculated trackway speeds ranged from 3.6 km/h (2.2 mph) to 10.8 km/h (6.5 mph), indicating that the majority of dinosaurs were walking (Breithaupt et al., 2001, 2004a, in press). Further spatial analysis revealed that trackway arrangements are present. One such arrangement consists of straight, nearly parallel groups of trackways with very similar orientation. Within these groupings, consistent distances were maintained between trackways and no evidence of overprinting of one track on top of another was observed. Another arrangement consisted of individual trackways exhibiting a more sinuous, intertwining path, which overprints other tracks, representing separate intervals of track generation (Breithaupt et al., 2004a, in press).

Through the study of the RGDT exciting interpretations on the behavioral complexities of a Middle Jurassic theropod community can be made. Evidence of adjacent trackways groups with no overprinting



FIGURE 1. Extensive photographic documentation of the Red Gulch Dinosaur Tracksite utilized a variety of camera platforms included tripod heights of 2-10 m, a remote-controlled airplane, an Ultralight aircraft and a blimp.

suggests gregarious behavior in this community. Data for the Red Gulch Dinosaur Track Site supports the interpretation of small, mixed-age packs of theropod dinosaurs (ranging from yearling to adult) traveling together, possibly as a family group (Breithaupt et al., 2004a, in press). The presence of an oolitic limestone indicates a peritidal zone, rich with diverse marine biota. It is possible that the dinosaurs that left their footprints may have been journeying to a food source or foraging as they traversed the ancient tidal flat (Breithaupt et al., 2004a, in press).

The Twentymile Wash Dinosaur Tracksite (TWDT) is located approximately 25 km southeast of the town of Escalante, Utah in BLM's Grand Staircase-Escalante National Monument. The site was discovered in 1998 (Foster et al., 2000; Hamblin and Foster, 2000) during a paleontological survey. Exposed along the top of a bench of Middle Jurassic Entrada Sandstone is a five-meter thick, track-bearing horizon. Within this horizon, tracks and trackways are exposed at multiple levels representing numerous episodes of track formation and preservation. Tridactyl tracks (ranging in length from 15 to 45 cm) of theropod dinosaurs and unique sauropod tracks and traces were noted (Foster et al., 2000; Hamblin and Foster, 2000).

Based on experiences gained from the documentation of the RGDT, project planning began with an archival search. Raster data found in the search included USGS digital raster graphic and orthophoto quadrangle maps. Natural color aerial photography taken in 1995 at a 1:24,000 scale was obtained from the BLM Aerial Photography Archive housed at the National Science and Technology Center in Denver, Colorado. Based on this imagery, it was decided to obtain three additional scales of photography—commercial aerial photography at a scale of 1:3000, close-range aerial blimp photography at a scale of 1:70 and extreme close-range photographs at a scale of 1:30.

High-accuracy DGPS ground control coordinates, collected in conjunction with the blimp photography, were utilized to georectify the digital versions of the 1:3000 scale and blimp photography (Breithaupt

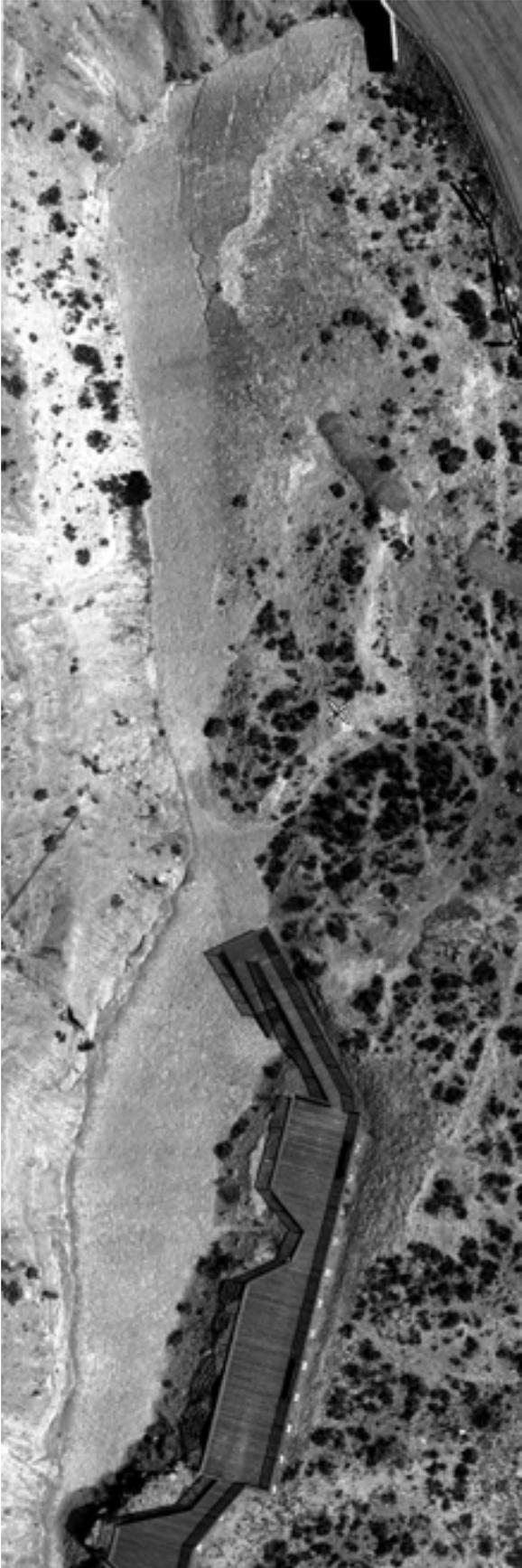


FIGURE 2. Low-level aerial image of the Red Gulch Dinosaur Tracksite taken from the blimp.

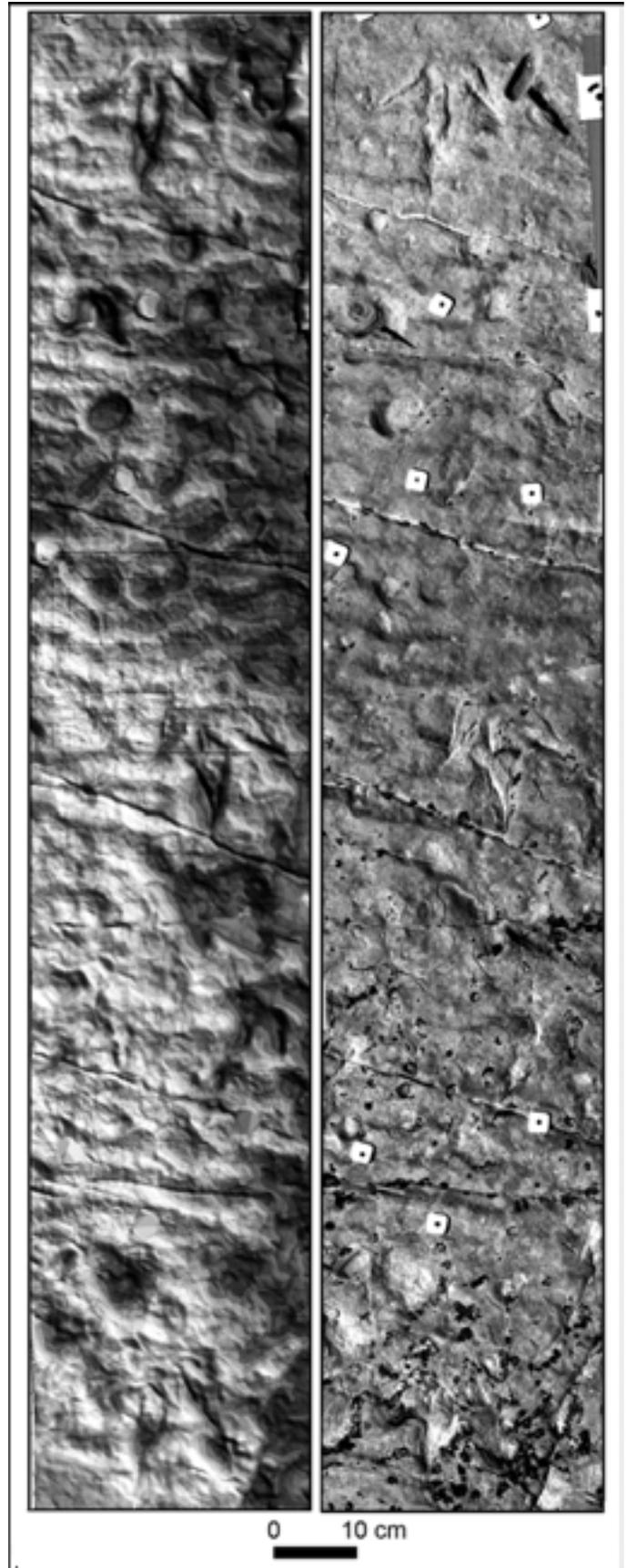


FIGURE 3. Digital terrain model (on left) with 2 mm post point spacing, color banding represents changes in elevation. Digital orthophotograph (on right) of three steps in a dinosaur trackway at the RGDT.

et al., 2004b; Matthews et al., 2005a,b, in press). As with RGDT project, automated terrain extraction from the commercial aerial photography was conducted in the softcopy photogrammetric workstation, resulting in a digital terrain model. The softcopy photogrammetry system in turn utilized the DTM to remove distortions in the imagery caused by changes in terrain. The result is digital orthophotographs for both scales of photography producing an integrated data set of imagery allowing a user to zoom from an overall perspective of the site to a photograph of an individual track (Matthews et al., in press).

Complete stereoscopic coverage of the main track-bearing layer was obtained using the blimp. These photographs were viewed in the softcopy photogrammetric workstation. The stereo models were inspected and a polygon outline was digitized around each track. A field inspection of the digital track database was conducted and on the ground measurements were made of selected tracks and trackways. GIS analysis of the database supports sequentially numbering of individual tracks and the grouping of tracks into trackways. Statistical analysis of trackway geometry (including foot length and width ratios, pace angulations, stride lengths and straddle widths) was conducted in the GIS environment (Breithaupt et al., 2004b; Matthews et al., 2005a,b, in press).

When initially reported in 2000, the number of tracks recorded at the TWDT was around 300 (Foster et al., 2000; Hamblin and Foster, 2000). As a result of the in-depth geospatial documentation of the site 964 dinosaur tracks and associated traces have been identified and documented in three-dimensional space (Fig. 5). The great majority of the tracks at TWDT exhibit significant morphologic variation. Within a single trackway, morphology can vary in as few as three steps from distinct tridactyl footprints (with evidence of digital pads and claw impressions) to oval concentric (or ovoid) rings representing deep underprints. Variations in pace angulations, ranging from 135 degrees to 170 degrees or higher, are also exhibited.

The horizontally-bedded sandstone units of the “upper sandy member” of the Middle Jurassic Entrada Sandstone can be informally grouped into stratigraphic horizons. Within these horizons there is evidence of changes in track to trackway ratios, track way orientation and pace angulation. Also present are horizons of multi-directional trample



FIGURE 4. A map, produced from surveyed point locations, of tracks in the “Ballroom” at the Red Gulch Dinosaur Tracksite (RGDT). Track icons are scaled to relative sizes based on measurements made during documentation and input into the GIS database. Overall view of the main track bearing area at RGDT (upper left inset). Illustration of a “typical” RGDT dinosaur track (lower left inset).

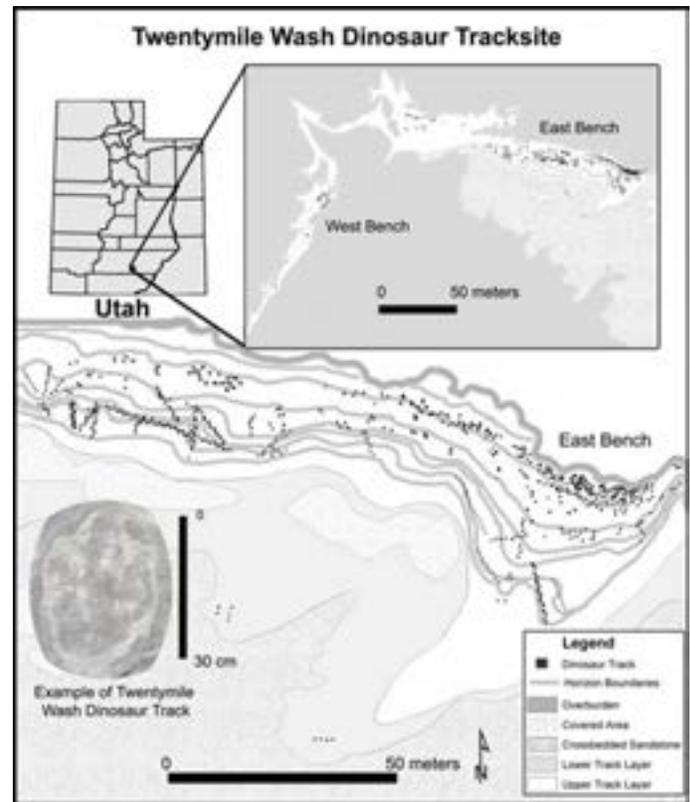


FIGURE 5. Map of the main track-bearing layer at the Twentymile Wash Dinosaur Tracksite (TWDT). Track locations were compiled photogrammetrically from low-level aerial images taken from the blimp. Gray lines represent boundaries between stratigraphic horizons. Representative TWDT footprint (lower left inset). Overall view of the TWDT (upper right inset).

zones (with as many as 90 randomly placed tracks in an 80 m² area) (Matthews et al., 2005a,b, in press). The Entrada Sandstone of southern Utah was deposited in eolian dune fields on the margins of a large intracontinental seaway that stretched from Idaho and Wyoming into southern Utah. Coastal fluctuations occurred as tidal flats, lacustrine and fluvial systems influenced the area (Foster et al., 2000). Stratigraphic horizons at TWDT appear to contain variations in trackway orientation, current direction and possibly faunal assemblage. Interpretations based on the analysis of the geospatial database support paleobehavioral responses, exhibited by populations of theropod dinosaurs, to fluctuating environments. These responses can be traced over time through the stratigraphic horizons and may possibly represent seasonal migrations, feeding or faunal variations through time. These types of changes can reflect ecosystem changes occurring on a broader scale in the terrestrial systems of the Middle Jurassic (Matthews et al., 2005a,b, in press).

Resource Management

The process of fossil resources management is an iterative one that relies on a number of factors. One fundamental factor is obtaining the information necessary to formulate options and develop management strategies. Optimally, these management strategies would be based on complete scientific evaluation and documentation of a resource. As mentioned previously, in many cases complete data may not exist or may be too costly to obtain. In addition, the pressures of multiple-use and desired future condition may be in conflict resulting in a streamlined decision-making process.

For such cases, GIS may be of great assistance, especially in areas of high paleontological significance. By defining the paleontological sen-

sitivity of geological formations, significant areas can be distinguished. Sensitivity levels are based on the type and distribution of fossils. Examples of sensitivity categories include areas where fossils are absent, rare or present. In addition, areas with significant, very sensitive and extremely sensitive (such as world famous localities) can be delineated (Fig. 6) (DeBlieux et al., 2003; Kirkland et al., 2006). This can be valuable to land managers because it provides assistance in decisions to open or restrict areas from surface disturbing or other potentially destructive activities. Once delineated, certain activities may be precluded in or redirected to particular areas or restricted to specific areas in order to protect the resource and support multi-use. One facet of fossil resource management that most likely will not change is the potential impact of public opinion and the importance of including the public in the management process.

In February of 1999, the Wyoming BLM opened a 30-day com-

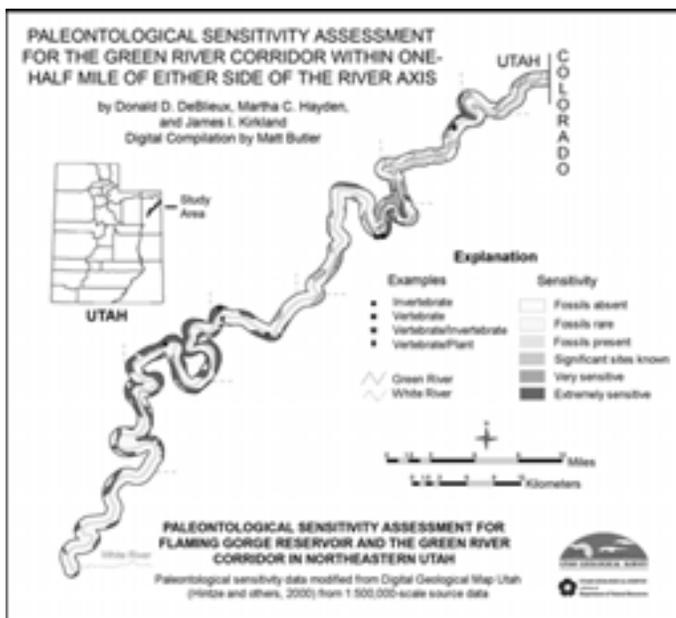


FIGURE 6. Paleontological sensitivity assessment map for the Green River corridor within one half mile on either side of the river (DeBlieux et al., unpubl. report for U.S. Bureau of Reclamation, 2002).

ment period for review of the environmental assessment and proposal to designate the Red Gulch Dinosaur Tracksite as an Area of Critical Environmental Concern (ACEC). Based on the resulting public input, a Decision Record and Finding of No Significant Impact (FONSI) were approved in July of that year. A recreation plan was developed based on the FONSI. Both the FONSI and ACEC designation are available for download from the BLM Worland Office Web page. Among the goals of the plan were to provide a safe visit to the site, allow scientific study to continue, prevent damage to the tracks and implement signage explaining the significance of the site. Planned improvements to the site included the construction of trails, installation of facilities (including shelters, picnic tables and walkways), addition of signs and improvement of the roadway. The graphical products created during the documentation and research stage of the project were used extensively to implement the goals of the recreation plan. Road improvements and the location of facilities utilized the topographic and planimetric maps made of the area surrounding the dry wash. The ramp that provides foot and wheel chair access to the track surface in the dry wash was located and designed based on the track locations found by the researchers and digitally documented in the GIS. Informational signs installed along the trail leading from the parking lot to the track surface utilized imagery and maps to both orient and interpret the site to visitors. The amount of documentation of the dry wash allowed for a base line to be established of the

condition of the resource prior to development. Future studies at the site can be compared to the baseline in order to assess the impacts of visitation and other factors to the site.

In addition to the impacts of the human population on fossil resources, it is also necessary to keep these resources safe from such natural phenomena as erosion. An excellent example of fossil resource *in situ* preservation is an ongoing effort of the U.S. Department of Agriculture Forest Service. The Picketwire Canyonlands Dinosaur Tracksite is located along the Purgatoire River on the Comanche National Grassland in Las Animas County, Colorado. At this site a one-quarter mile limestone exposure of the Late Jurassic Morrison Formation contains over 1300 tracks. The site contains large sauropod tracks as well as a variety of sizes of theropod and ornithopod footprints (Lockley et al., 1999) arranged into approximately 100 different trackways. The tracksite is exposed today due to the erosive effects of the Purgatoire River; unfortunately, that same force is also eroding the soft shale that lies beneath the limestone layer that forms the tracksite. When the river erodes this shale, the resulting undercutting of the tracklayer occurs causing it to fall into the river. Photography at a variety of scales (1:3000, 1:600 and close-range) was used to document the site. Black and white, 1:1300 scale, aerial photography was taken in 1994. Ground control was established and a topographic map with a 0.25 m contour interval was compiled. Aerial photography was taken again in 1998 and the riverbank was remapped. In 2001, photography at a scale of 1:650 and 1:600 was obtained using a blimp (Fig. 7) (Matthews et al., 2001b; Wright and Breithaupt, 2002; Breithaupt et al., 2004b). This photography allows further monitoring of the effects of erosion on the site and is being used to compile a very detailed track map. The Forest Service has taken steps to protect the tracksite and ensure its long-term preservation by installing erosion control structures. These structures are constructed from eroded blocks of limestone and help deflect the river's current energy away from the tracksite. In addition, these structures cause sediment build up against the tracksite further protecting it (B.A. Schumacher, personal commun., 2006) (Fig. 8).

Herein lays one of the conundrums of fossil resource management. On one hand, sedimentation is deliberately encouraged to cover and protect the resource; while on the other hand, studies continue to quantify its subsurface extent. This situation underscores the need to have the best data in order to make the soundest decisions. One such tool that can be used to help define the subsurface extent of the resource is Ground Penetrating RADAR (GPR). In the summer of 2000 and 2001, GPR was tested at the Picketwire Canyonlands Dinosaur Tracksite with



FIGURE 7. Oblique aerial view of the Picketwire Canyonlands Dinosaur Tracksite (PCDT) taken from the blimp.

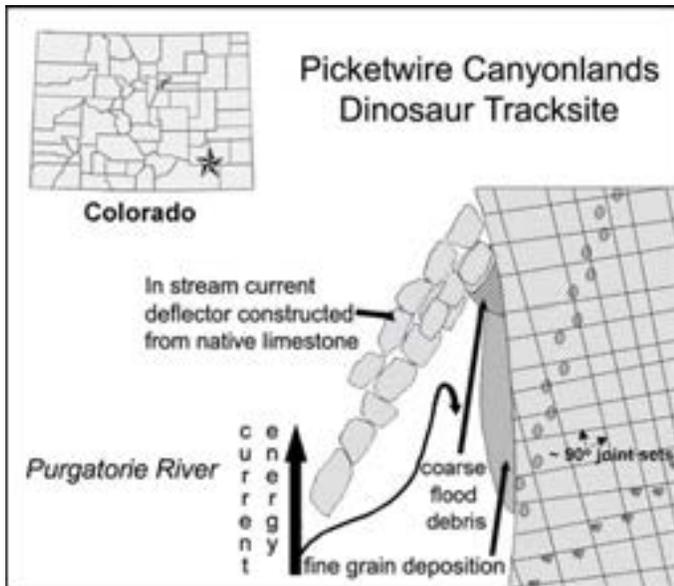


FIGURE 8. Design plan for erosion control structures to protect the PCDT limestone layer (Image courtesy USDA, Forest Service).

very promising results (L.B. Conyers, personal commun., 2006). Data profiles were collected through the overburden, showing very distinctly that tracks were present (Fig. 9A). Based on the post processing of the data, a spatial distribution of the detected depressions in the limestone layer was produced (Fig. 9B). The result is perplexing—while many of the features are undoubtedly tracks, other surface features were also detected. A variety of factors can adversely affect the return of the GPR signal, including clay and water content. This technology can be very beneficial in distinguishing between where tracks do and do not exist in the subsurface (L.B. Conyers, personal commun., 2006), thus making it a potentially valuable tool, especially at sites adjacent to planned construction.

CONCLUSION

Advances in technology are occurring at an astonishing rate providing resource managers with more efficient and cost effective methods for data collection and analysis. However, to more fully utilize developing geospatial capabilities, sophisticated users of these technologies may be needed, thus setting the foundation for teamwork and partnerships. These partnerships can be forged across disciplines, across agencies and may include resource managers and the public. By combining individuals with a variety of skills, experiences and knowledge, working toward a common goal, often more can be accomplished.

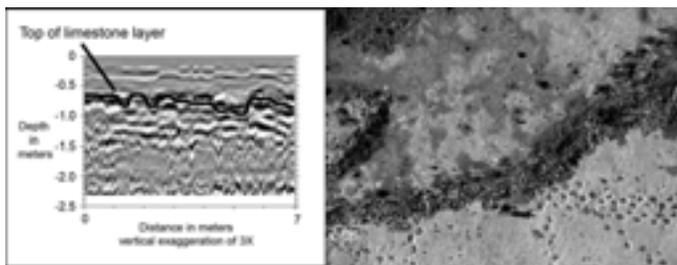


FIGURE 9. A, Ground Penetrating Radar (GPR) profile collected at the Picketwire Canyonlands Dinosaur Tracksite (PCDT). The GPR signal penetrated the overburden, showing distinct track impressions. B, Post processed GPR data depicting the spatial distribution of depressions in the limestone track layer PCDT. Back ground image was taken using the blimp (Images courtesy L.B. Conyers).

The same may be said for geospatial technologies. Techniques, such as photogrammetry, ground-based LIDAR and Ground Penetrating RADAR can be combined to produce a virtual three-dimensional recreation of a paleontological resource. These virtual resources can be utilized for research, to analyze the effects of certain management practices and for interpretation to the public. Acquiring and archiving quality digital data so that it is portable and accessible is a priority that must not be ignored.

Technologies that may have been dismissed in the past due to cost, or which were considered inaccessible due to the need for technical expertise, should be given new consideration. As a technology evolves it often becomes more transportable, cost effective and user-friendly. Even as existing technologies are being refined and applied, a whole new set of advancements are looming over the horizon for fossil resource management. These include the use of wireless data transfer, rapid prototyping, websites with fast data streaming capabilities and single-portable files that contain embedded layer and coordinate information (3-D.pdf), to mention only a few. Although incredibly exciting, these “new” technologies bring up questions of accessibility to data as well as security risks to the computer system that house them which must be assessed and addressed in an enlightened manner.

With the burgeoning of geospatial technology, the process of defining project goals, developing data standards, defining successful outcomes and developing an achievable implementation plan is vital. Just because a geospatial technology or dataset is available, inexpensive or looks impressive does not mean that it will always work for every application. It is important to do a thorough investigation of the technologies to ensure that the data being acquired supports the result to be achieved, the World Wide Web can play a principal part in this process. Caution should also be taken to budget sufficient resources, not only for data acquisition, but also to analyze, interpret and maintain geospatial data sets.

Among the challenges that face the fossil resource manager are not only the changes seen in the advancement of technology and in the policies that govern decisions, but also the sheer volume of fossil resources contained on public lands in the western United States. The number of scientifically significant fossil localities is too numerous to list or reference and new localities are being found on a regular basis. These sites are often on public lands managed by state or government agencies (e.g., Bureau of Land Management, Forest Service, Bureau of Reclamation and the National Park Service). Often these sites must be managed with the goal of multiple-use and desired future condition in mind. Tools contained in the geospatial toolbox can be of vital assistance to identify areas where fossil resources exist, support scientific study through documentation, preserve the resource through collection and curation and keep the resource safe when it remains *in situ*.

At localities such as Red Gulch Dinosaur Tracksite, Twentymile Wash Dinosaur Tracksite and Picketwire Canyonlands Dinosaur Tracksite, innovative geospatial technologies were tested, refined and integrated (Breithaupt et al., 2004b). Such integrated approaches not only resulted in documentation of the paleontological resource, but also supplied graphic products used in site development, resource protection and interpretation. The data collected at these sites established a baseline of digital data ensuring vital scientific information is largely preserved should these resources be damaged or lost as the result of illegal collection, vandalism, erosion or human interaction. Future generations could still have access to these resources through digital virtual reconstructions served over the Web or as solid models constructed with detailed terrain data. As our society changes and the demands of an ever-increasing population draw heavily from our public lands, it is important to remember that many of these same challenges faced the prehistoric populations of the western United States. The behavioral responses exhibited by extinct animals to global and regional changes in climate, disease, sea level, deforestation and resource depletion could give vital insight into the future history of our world and how the management decisions made

today will influence that future.

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THE DIVERSITY AND STRATIGRAPHIC DISTRIBUTION OF PRE-DINOSAURIAN COMMUNITIES FROM THE TRIASSIC MOENKOPI FORMATION

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Abstract—Recent discoveries of tetrapod tracks in the Moenkopi Formation (Early Triassic) of Capitol Reef National Park (CARE), and Glen Canyon National Recreation Area (GLCA), Utah have revealed important new terrestrial and subaqueous vertebrate track localities on multiple stratigraphic horizons. The San Rafael Swell area to the north has also yielded important footprint horizons. These well-preserved track horizons are the oldest and most laterally extensive track-bearing horizons documented in the Western U.S. Ichnogenera (*Chirotherium*), (*Rhynchosauroides*), and (*Rotodactylus*), are the dominant forms. Rare fish fin drag marks (*Undichna*) relate to fish skeletal remains identified in the Torrey Member of the Moenkopi Formation.

Tracks are preserved either as positive relief “casts” filling impressions in the underlying mudstones or on plane bed surfaces as negative relief “impressions”. Exposed traces occur on the undersides of resistant sandstone ledges where the mudstone has eroded away and in finer grained sediments such as mudstones and siltstones. The Torrey Member represents deposition on a broad, flat-lying coastal delta plain (Blakey, 1973 and 1977). Both nonmarine (fluvial) and marine (principally tidal) processes influenced deposition. Even-bedded mudstones, siltstones, claystones, and fine grained sandstones, containing abundant ripple marks and parallel laminations dominate lithologic types. Ichnites indicating swimming/floating behavior of quadruped tetrapods are associated with the walking trackways. The water depth was sufficiently shallow to permit the vertebrates to touch the substrate with both manus and pedes when moving through the water.

Vertebrate tracks form locally dense concentrations of toe scrape marks which sometimes occur with complete plantigrade manus and pes impressions. Well preserved, skin, claw, and pad, impressions are common. Rare, well developed, tail-drag marks frequently occur in certain trackway sequences. Fish fin drag marks and fish skeletal material are preserved with tetrapod swim tracks. Vertebrate ichnites occur with fossil invertebrate traces *Arenicolites*, *Paleophycus*, *Fuersichnus*, and *Kouphichnium* (horseshoe crabs). Traces of unique millipede body fossils, and complete 3-dimensional plant molds of *Equisetum* plants are present.

Lateral correlations of stratigraphic units with recognizable ichnites occur in the Moenkopi Formation throughout Utah’s national parks will aid interpretations of the paleoecology, and diversity of ichnofauna in the North American Western Interior during the Early Triassic known as “the dawn of the dinosaurs”.

INTRODUCTION

Important discoveries have been made during the course of GLCA history. The trackways in the Torrey Member of the Moenkopi Formation were first described in detail from this stratigraphic unit and suggest a great potential for finding other sites in this widely exposed unit in Capitol Reef, Glen Canyon National Recreation Area, and San Rafael Swell (Fig. 1). Extensive track bearing horizons in the Moenkopi provide correlation through the entire region.

Fossil footprints are a non-renewable resource on public land, and provide an opportunity for public education, scientific research, and an administrative opportunity and challenge for both scientists and land management authorities.

GEOLOGY

The Torrey Member of the Moenkopi Formation has been the subject of broad-based stratigraphic investigation for 50 years (McKee, 1954; Smith et. al., 1963; Blakey, 1973 and 1977; Stokes, 1980; Hintze, 1988; Morris et. al., 2000). Recently the Torrey Member has been studied in stratigraphic detail with emphasis on the extensive tetrapod track-bearing surfaces of pre-dinosaurian communities (Mickelson, et. al., 2000, 2001, and 2005; Mickelson, 2003) (Fig. 2). The Torrey Member vertebrate tracks are the oldest and most laterally extensive megatracksite

horizons yet recorded and are known to extend throughout Utah.

Following the deposition of the Sinbad Member in a clear shallow sea, a change in tectonic and/or climatic conditions caused the progradation of a major delta succession into Utah. This delta complex is preserved as the Torrey Member. A threefold lithofacies classification model produced by Smith (1987) was adapted to describe depositional environments of the Torrey Member delta-plain channels. Outcrop measured sections (a west to east trend) are similar to Smith’s (1987) lithofacies classification for meandering river estuarine systems (Fig. 3).

Basal deposits of the Torrey Member include interbedded siltstones, dolomites, and very fine-grained sandstones that were laid down in advance of the prograding delta. This sequence grades upwards into ledge-forming coarser grained sandstones and interbedded siltstones. The facies includes channel deposits of large-scale trough cross bedded fine to medium grained sandstone that was deposited within the fluvial-dominated reaches of the upperdelta-plain. Channel bodies dominated by ripple to large-scale trough cross bedded sandstones and interbedded mudstones are organized into inclined heterolithic packages (Fig. 2). Also present within these sandstone and mudstone-dominated channels are large-scale soft sediment deformational features and clay-draped ripple- and dune-scale bedforms. These inclined bar-forms are likely point-bar deposits that experienced tidal influence and may represent the more seaward lower delta-plain expression of the sandstone-domi-



FIGURE 1. Location map and stratigraphic nomenclature of multiple localities from the Early Triassic Moenkopi Formation southeastern and central Utah. The Moenkopi Formation is composed of the following members in ascending order, Black Dragon, Sinbad Limestone, Torrey and the Moody Canyon.

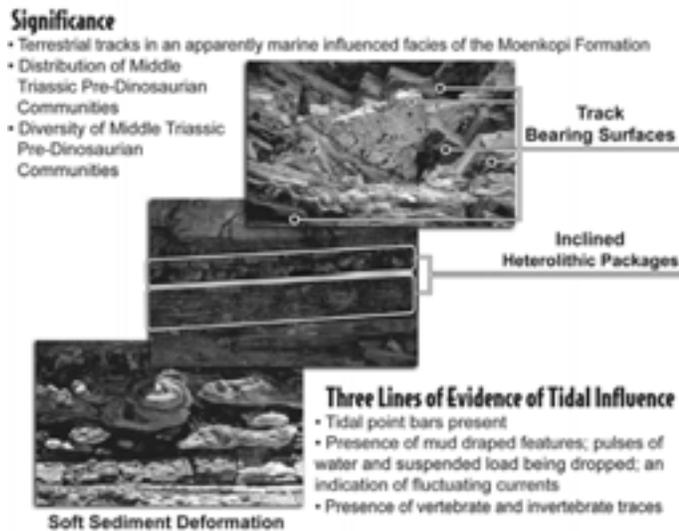


FIGURE 2. The significance of vertebrate footprints and evidence of environmental implications in the Torrey Member, Moenkopi Formation. nated fluvial channels.

Several track-bearing horizons are present within this delta-plain facies. Multiple tetrapod track horizons have been identified within the fluvial-dominated reaches of the upperdelta-plain. Tetrapod tracks and fish-fin drag marks are typically associated within the upper sandstone and mudstone-dominated channels.

VERTEBRATE ICNOLOGY

***Chirotherium* Tracks**

Chirotherium tracks have been previously described from continental North America, Europe and South America continents (Peabody, 1948; Leonardi, 1987; Tresise and Sargeant, 1997). The Moenkopi tracks are herein described as relatively narrow, quadrupedal trackways indicating the normal tetrapod walking gait. In the walking gait a small pentadactyl manus impression regularly occurs immediately in front of, but never overlapped by, a much larger, pentadactyl pes which generally resembles a reversed human hand. Manus and pes tends to be planti-

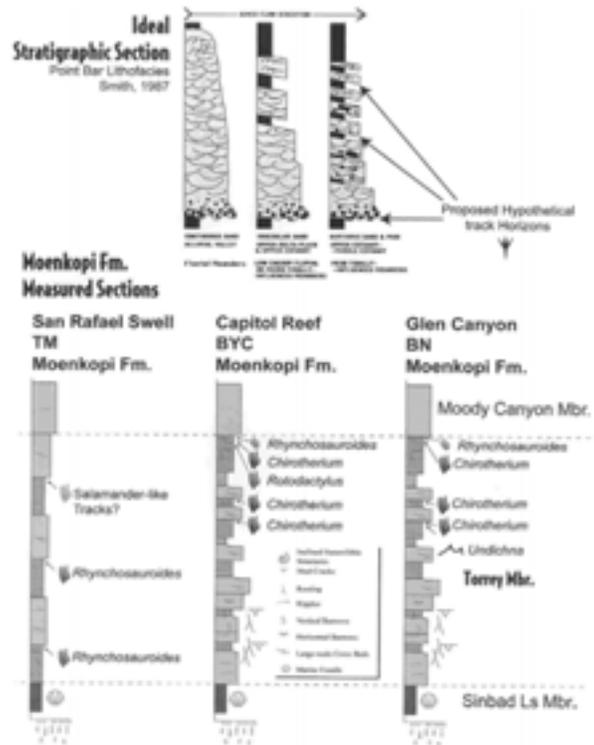


FIGURE 3. A comparison of Smith's 1987 ideal stratigraphic section of point bar lithofacies, to measured sections of the track-bearing units of the Moenkopi Formation.

grade; digits I-IV point more or less forward; manus digit IV is always shorter than III which is the largest; the footprints may or may not show specialized metatarsal pads. Clear impressions often show a granular or beaded skin surface (skin impressions). Associated swim tracks are common and often indicate current flow directions (Fig. 4) (Mickelson, et. al., 2000, 2001 and 2005; Mickelson, 2003)

***Rotodactylus* Tracks**

Long-striding, pentadactyl trackways of a medium-sized reptile are well preserved with rare skin and claw impressions. These tracks commonly occur with smaller *Rhynchosauroides* footprints. The manus is always closer to the midline than the pes, and in some cases overstepped even in the walking gait by the much larger pes in a moderately narrow trackway pattern; pace angulation (of the pes) is as high as 146 degrees in a running trackway and as low as 93 degrees in a walking trackway. The pes impression indicates a foot with an advanced digiti-

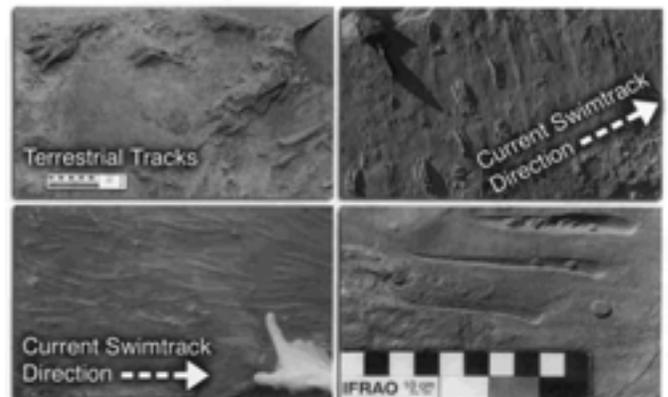


FIGURE 4. An example of terrestrial and swim tracks of *Chirotherium*.

grade posture (Peabody, 1948) and with a strongly developed but slender digit V rotated to the rear where it functioned as a prop. Manus digit V may or may not be rotated backward but it too had a propping function. Digit IV on both manus and pes is longer than III; digit I may fail to impress; claws are evident and distinct on digits I-IV. Well defined skin impressions, often preserved in exquisite detail, have a scaly plantar surface characterized by transversely elongate scales on the digit axis bordered by granular scales (Fig. 5).

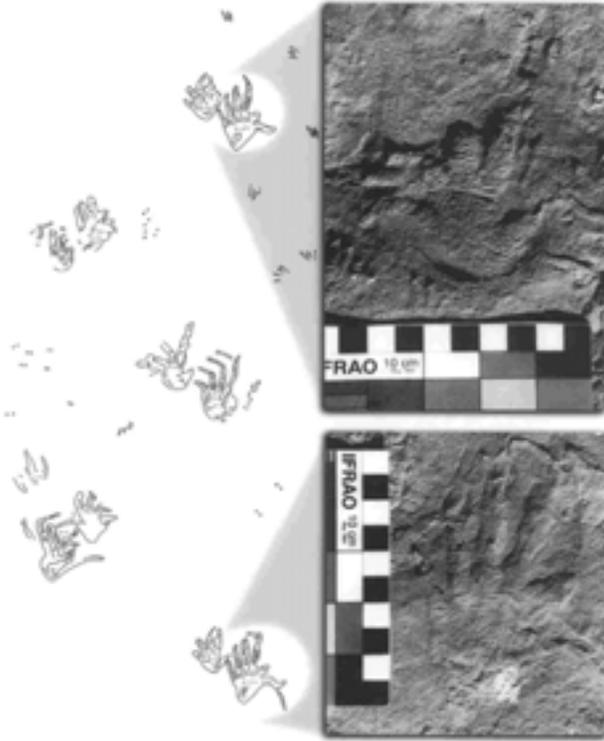


FIGURE 5. An example of *Rotodactylus* tracks preserved with rare skin impressions. Several consecutive manus and pes tracks are preserved in a trackway and illustrated by Susan J. Lutz.

***Rhynchosauroides* Tracks**

Dense concentrations of *Rhynchosauroides* tracks are commonly associated with the trackways of *Chirotherium* and *Rotodactylus*. These small lacertoid footprints are generally characterized by deeply impressed manus and a faintly impressed pes. Trackways exhibit a relatively wide pattern with pentadactyl footprint relatively distant from the midline. The pace angulation is low, below 90 degrees (100 to 120 degrees if figured from the manus pattern). Most often only 3 to 4 digits are preserved with occasional tail drag marks (Fig. 6). The digits are slender and relatively longer in the pes than in the manus and both sometimes exhibit distinct claw impressions. Swim tracks are common.

***Undichna* Fish Trails**

The Moenkopi Formation is known for its exceptional vertebrate fossil record. Fish are rare and have not been studied in detail, and fish trails (fish fin drag marks) have never been recorded in the Early Triassic (Mickelson, et. al., 2000, 2001, 2005; Mickelson, 2003). This study describes the first known occurrence of fish trails (fish fin drag marks), *Undichna* from the Early Triassic Torrey Member of the Moenkopi Formation (Fig. 7). This ichnogenus has been reported in abundance from the Late Paleozoic, Permian, Cretaceous, and more recently from the Eocene (Loewen, 1999). *Undichna* from the Torrey Member of the Moenkopi Formation represents the first and only known occurrence of fish trace fossils in the Triassic in the Western U.S.

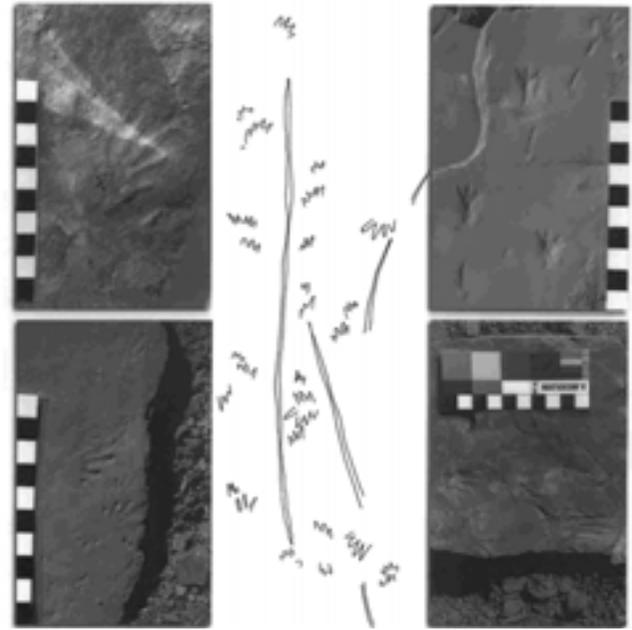


FIGURE 6. Dense concentrations of individual tracks and trackways of *Rhynchosauroides* are the dominant forms within the Moenkopi Formation. Illustrated trackway by Dan Channey and Susan J. Lutz.

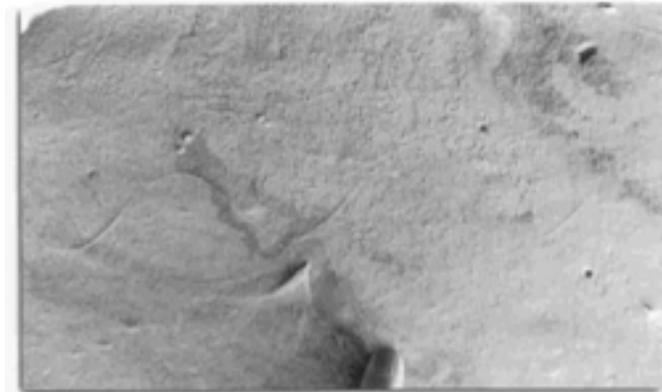


FIGURE 7. *Undichna* (fish fin drag marks).

The fish fin trace fossils are preserved as convex hyporelief sandstone casts filling imprints preserved in underlying mudstone. Exposed traces occur on the undersides of resistant sandstone ledges where the mudstone eroded away. *Undichna* commonly occur with locally dense concentrations of swim traces of *Chirotherium*. *Undichna* usually occur in clusters. One isolated fish fin trace consists of a single, slightly-asymmetrical, sinusoidal trail. The trace is 56 cm. long and includes 6.5 cycles with wavelengths varying from 9 to 10 cm and amplitudes of 3.5 to 4.5 cm. The trails were most likely produced by a fish with a large caudal or anal fin able to reach the sediment without any other fin doing so. The low wavelength to amplitude ratio is most consistent with a caudal fin. This occurrence of *Undichna* is similar to other previous descriptions made by (Loewen, 1999) and it supports that the preservation of these trails being favored in fine-grained sediments (Loewen, 1999).

Swim Tracks

Peabody (1948) first described swim tracks from the Moenkopi Formation from several locations in Arizona. Recently, (Pienkowski and Gierlinski, 1987, McAllister (1989), McAllister and Kirby (1998), Mickelson, et. al., 2000, 2001, 2005, Mickelson, 2003 and Kvale, et. al., 2001), criteria have been introduced for identifying and describing tetra-

pod swim traces that indicate trackmaker buoyancy. Swim traces in the Moenkopi Formation are characterized primarily by posterior overhangs and reflectures of the individual digit impression; and secondarily by striations and claw marks along digit impression length, and the often incomplete nature of the trails (Figs. 4 and 6). These swim tracks grade into subaqueous traces formed by more typical terrestrial propulsion and demonstrate less buoyancy as the water became more shallow, disappearing as the trackmaker becomes fully buoyant. When interpreting the environment of deposition, the sedimentary substrate should be consistent with the presence of the swim traces.

Bouyancy creates important differences between locomotion on land and in water. In a floating animal the digits can extend farther posteriorly in the propulsive phase without unbalancing (losing the necessary support to maintain posture) the organism. This allows the propulsive force to be on a more horizontal plane and produce a scrape mark instead of compressing downward into the sediment.

The Moenkopi tracks were originally impressed into a muddy matrix and later filled in with fine sand. The swim tracks are elongated, striated scratch marks (produced by scales and nails) preserved in the substrate. The propulsive phase leaves “kick-off scours” (Thulborn and Wade, 1989) which occur immediately posterior to the traces. The sandstone cast is unfilled, and the scour is seen as the irregular positive relief behind the digit scrapes. The scrapes represent the action of the water eddies created behind the digits as they pass close over the sediment at the end of the propulsive phase.

INVERTEBRATE AND PLANT ICHNOLOGY

Fuersichnus, *Palaeophycus*, and *Arenicolites*: The Torrey Member of the Moenkopi Formation assemblage studied is considered herein as an example of the *Glossifungites* ichnofacies and commonly contains vertebrate swim tracks. This ichnofacies is restricted to firm but unlithified nonmarine and marine surfaces. Tracks and traces in the *Glossifungites* ichnofacies are characterized by low diversity and high density assemblages which include *Fuersichnus*, *Palaeophycus*, *Arenicolites*, and *Skolithos*.

Fuersichnus

The ichnogenus *Fuersichnus* (Fig. 8) is a relatively rare trace fossil that has been documented from Triassic and Jurassic nonmarine deposits and only recently documented in marine deposits from the Upper Cretaceous (Buatois, 1995). The ichnogenus consists of horizontal to subhorizontal, isolated or loosely clustered, U-shaped, curved to banana-like burrows, characterized by distinctive striations parallel to the trace axis. It is interpreted as a dwelling structure probably produced by crustaceans or polychaetes (Hantzschel, 1975).

Palaeophycus

The ichnogenus *Palaeophycus* (Fig. 8) is a common trace fossil that has been documented from Precambrian to Holocene nonmarine and marine deposits (Pemberton and Frey, 1982). Galleries are branched, and irregularly winding, cylindrical or subcylindrical tubes, that sometimes cross-cut one another. Horizontal galleries most often have vertically striated lined burrows or rarely nearly smooth surface textures. *Palaeophycus* represents passive sedimentation within an open dwelling burrow constructed by a predaceous or suspension-feeding animal.

Arenicolites

The ichnogenus *Arenicolites* (Fig. 8) consists of simple U-tubes (paired tubes) without spereite, perpendicular to the bedding plane; usually varying in size, tube diameter, distance of limbs, and depth of burrows; limbs are rarely somewhat branched, some with funnel-shaped opening; walls are commonly smooth. This is a common trace fossil documented from Triassic to Cretaceous from marine and nonmarine deposits. The Torrey *Arenicolites* are very consistent in size, shape, and

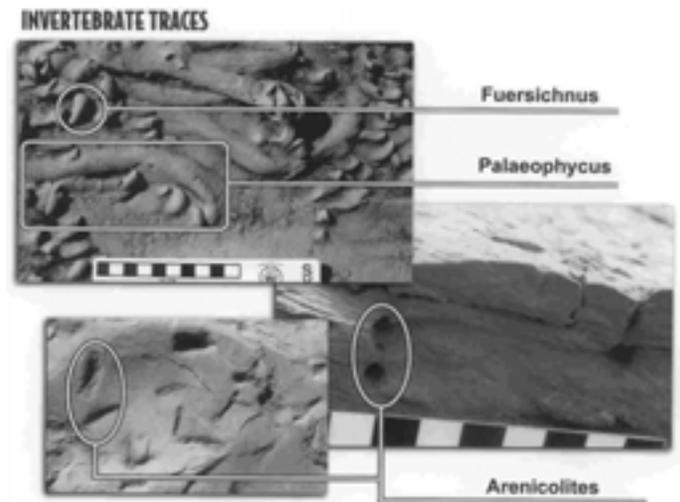


FIGURE 8. An example of invertebrate trace fossils found with associated vertebrate tracks.

distance apart from each other. *Arenicolites* are interpreted as being made by annelid worms (Hantzschel, 1975).

Kouphichnium

The ichnogenus *Kouphichnium* (Fig. 9) (horseshoe crab) tracks occur as several types of morphologies. Heteropodous tracks of great variety with either two chevron-like series of four oval or round holes or bifid v-shaped impressions or scratches that are forwardly directed. Imprints most often exhibit median drag-marks. These traces are found in both marine and terrestrial environments; horseshoe crabs have been extinct in terrestrial fresh water settings since the end of the Jurassic (Hantzschel, 1975). They are indicators of shallow, subaqueous to semi aquatic environments in firm substrates.

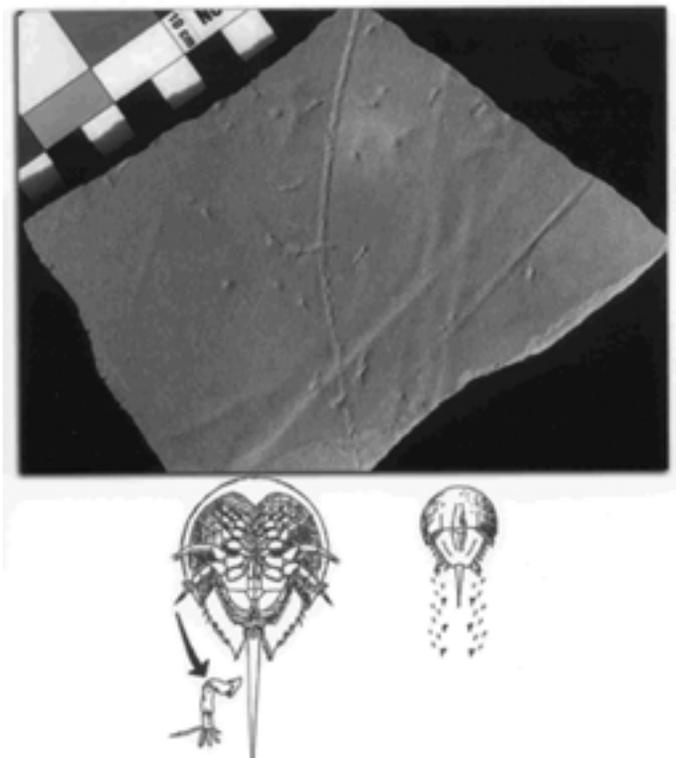


FIGURE 9. Horseshoe crab traces-*Kouphichnium*. These trails also occur as composite and over-lapping patterns associated with specific behaviors.

Millipede

A rare, well preserved body fossil trace portrays morphologies of a large millipede (arthropod) (Fig. 10). This diploplodid arthropod has a reconstructed length approaching 7cm, it is elongate, tapering front to back, with up to 53 body segments. Millipedes are generally rare in the fossil record due to their terrestrial habitats. This is the first occurrence of this type of arthropod from the Early Triassic in western North America.



FIGURE 10. A single millipede preserved with associated plant and terrestrial vertebrate footprints.

Equisetum

Sphenopsids (*Equisetum*) decreased in diversity and became increasingly restricted to herbaceous forms during the Triassic. Early Triassic *Equisetum* fossils in the Moenkopi are particularly rare, and are often preserved in situ and in 3-dimensional molds, probably because they tended to grow on freshly deposited substrates that are common in active depositional settings (Fig. 11).

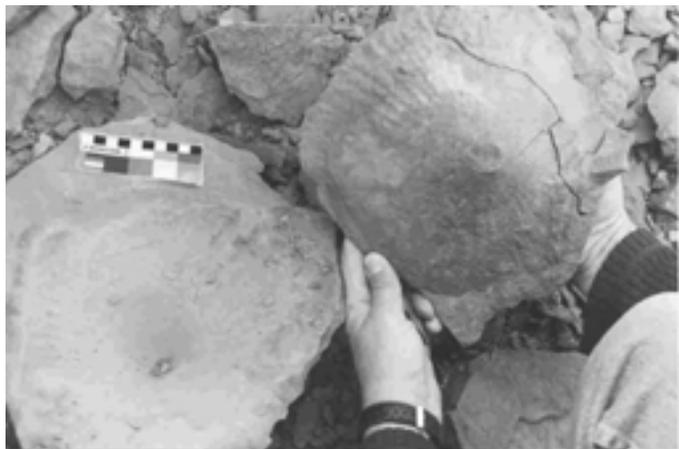


FIGURE 11. An example of a 3-dimensional mold of a fossilized horsetail plant (*Equisetum*).

All Mesozoic sphenopsids were based on the same basic body plan as the present-day *Equisetum*, having unbranched central axes bearing whorls of leaves. Large *Equisetum* (30 cm thick) may have attained heights of 10m. and grew along the banks of fluvial-tidal channels during

deposition of the Moenkopi Formation. During the early Mesozoic, the anatomy and distribution of Mesozoic sphenopsids is consistent with primary colonization of open or disturbed damp habitats where their rhizomatous growth and moderate size may have allowed them to form dense thickets.

SUMMARY

Significance

- Terrestrial tracks in an apparently marine influenced facies of the Moenkopi Formation
- Distribution of Middle Triassic Pre-Dinosaurian Communities
- Diversity of Middle Triassic Pre-Dinosaurian Communities

Evidence

- Tidal point bars present
- Presence of mud draped features; pulses of water and suspended load being dropped; an indication of fluctuating currents
- Presence of vertebrate and invertebrate traces

Conclusion

- Occurrence of terrestrial and sub-aqueous tracks in the Moenkopi Formation.
- Tracks occur in marine influenced environments.
- Implication is that these animals may have tolerated brackish water conditions.

DISCUSSION

Several important discoveries have been made during the course of GLCA and CARE history the last ten years. Trackways are first described in detail from the Torrey Member of the Moenkopi Formation. Their abundance suggests a great potential for finding other sites in this unit, which is widely exposed in Capitol Reef, Glen Canyon National Recreation Area, Zion, Canyonlands and Arches National Parks. Extensive track bearing horizons in the Moenkopi Formation provide a good basis for biostratigraphic correlation throughout the entire region.

Lateral correlations of the ichnostratigraphic units identified in the Moenkopi Formation throughout Utah's national parks will aid interpretations about the paleoecology, and ichnospecies diversity of the Western Interior during the Early Triassic—"The Dawn of the Dinosaurs".

As a non-renewable resource on public land, fossil footprints provide an opportunity for public education, scientific research, and an administrative opportunity and challenge for both scientists and land management authorities.

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JURASSIC DINOSAUR TRACKSITES FROM THE AMERICAN WEST

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Abstract—Middle Jurassic dinosaur megatracksites are rare in the Western Interior of the United States. This paper reports two previously unknown localities from the Bighorn Basin of northern Wyoming that constitutes the two most extensive Middle Jurassic tetrapod tracksites currently known in North America (Fig. 1). Track bearing horizons outcrop on Bureau of Land Management, National Park, and private lands throughout the basin. These trace fossils occur in carbonate units once thought to be totally marine in origin. The youngest (stratigraphically highest) of these occurs along a single horizon at or near the top of the “basal member” of the “lower” Sundance Formation (mid-Bathonian in age, ~167 ma) (Kvale, et al., 2001, Kvale, et al., 2001, Mickelson, et al., 2005). This discovery necessitates a major change in the paleogeographic reconstructions for Wyoming for this period. The older (stratigraphically lower) tracksites occur at multiple horizons within a 1 m interval (uppermost Bajocian in age, ~170 Ma) in the middle part of the Gypsum Spring Formation (Fig. 2) (Kvale, et al., 2001, Kvale, et al., 2001, Mickelson, et al., 2005).

Terrestrial tracks are tridactyl and attributed to small- to medium-size bipedal dinosaurs. At least some of these prints can be attributed to theropods. The Sundance tracks are represented primarily by digit impressions (Fig. 3), whereas both digit and heel impressions are preserved in some of the Gypsum Spring footprints (Fig. 4). Swim tracks of crocodile (Fig. 5) and possibly bipedal dinosaurs (Figs. 6A-B) are also present in the Gypsum Spring Formation.

Numerous similar trackways in the Sundance (Fig. 7) that trend in the same south-southwesterly direction may indicate gregarious animal behavior, the presence of a physically constrained path-way (e.g. along a tidal flat), subject to repetitive visitation by a small number of individuals. The northwest-southeast trending orientations of ripple crests on the Sundance surface in the Bighorn Basin trend have a slight asymmetry to the northeast. This indicates that open water conditions existed to the southwest. As such, the south-southwesterly trend of the majority of the trackways in the Bighorn Basin indicates that the animals were moving towards the local shoreline and not parallel to it. This implies that the pathways may not have been constrained physically. If the animals were moving towards the water this suggests, but certainly does not confirm, that these animals may have been swimmers or waders (Kvale, et al., 2001, Kvale, et al., 2001, Mickelson, et al., 2005). Moreover, one may infer that fish may have been a major food source for these opportunistic animals along the Sundance Sea shoreline (Kvale, et al., 2001, Kvale, et al., 2001, Kirkland, et al., 2005, Mickelson, et al., 2005).

Similarities between the two megatracksites include their formation and preservation in upper intertidal to supratidal sediments deposited under at least seasonally arid conditions. Microbial mat growth and salt crystals forming on the ancient tidal flats apparently initiated the preservation of these prints (Fig. 7). Penecontemporaneous microbial mats and the formation of salt crystals also prevented the initial reworking of the track-bearing surface by wind- or water driven currents (Kvale, et al., 2001).



FIGURE 1. Map of the northeastern part of the Bighorn Basin, northern Wyoming, showing the distribution of the Sundance and Gypsum Spring formations with exposed track surfaces.

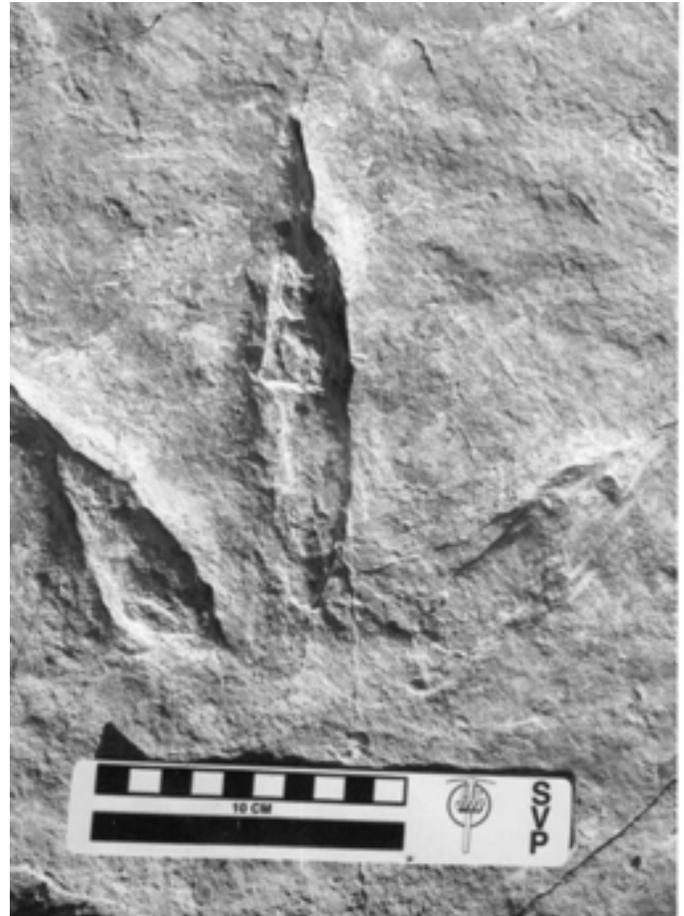


FIGURE 3. Sundance Formation tracks. Preserved as a concave epirelief impression, this track is one of several hundred. The majority of the Sundance tracks have no functional heel preserved.

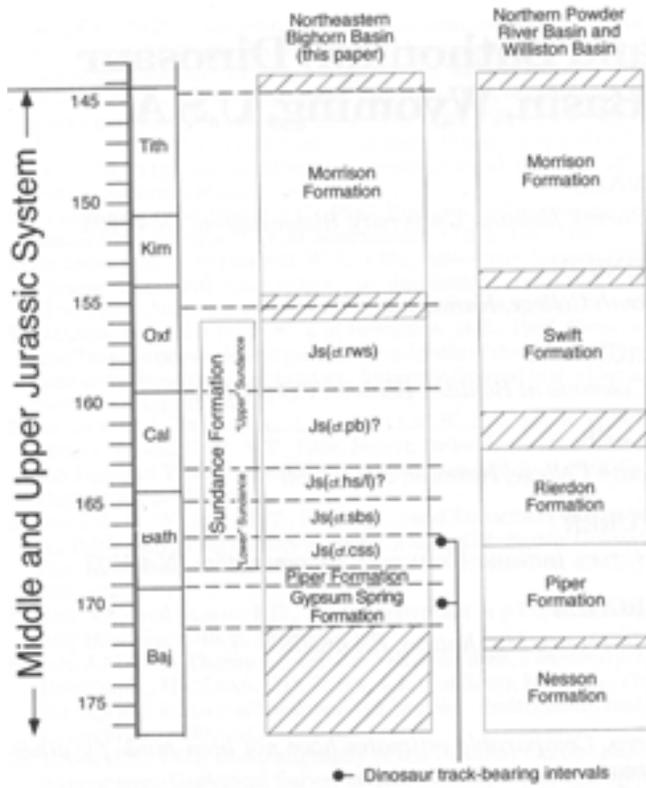


FIGURE 2. Generalized Jurassic stratigraphy of the northeastern Bighorn Basin and adjoining areas, Wyoming and Montana.

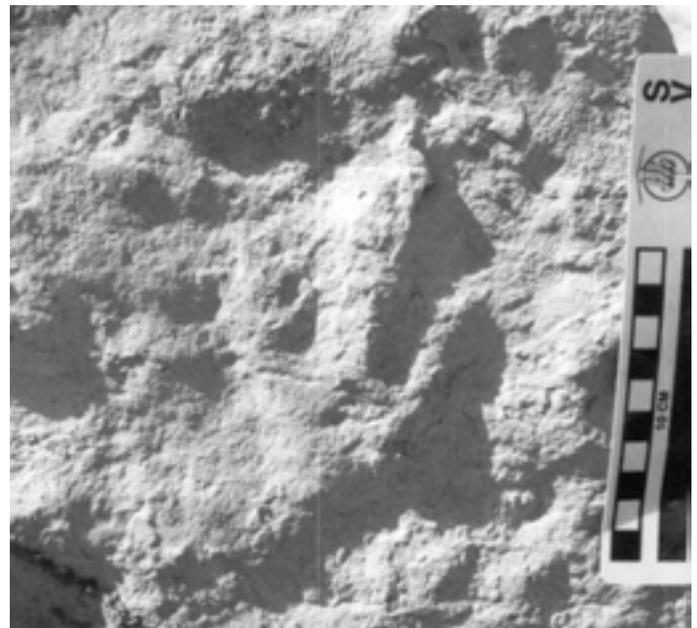


FIGURE 4. Gypsum Spring Formation tracks. The footprint, preserved as a cast from a single block of calcareous sandstone, is that of a small gracile-like dinosaur similar morphologically to *Grallator* tracks. This track differs from the vast majority of Sundance tracks in that it preserves a heel-like impression.

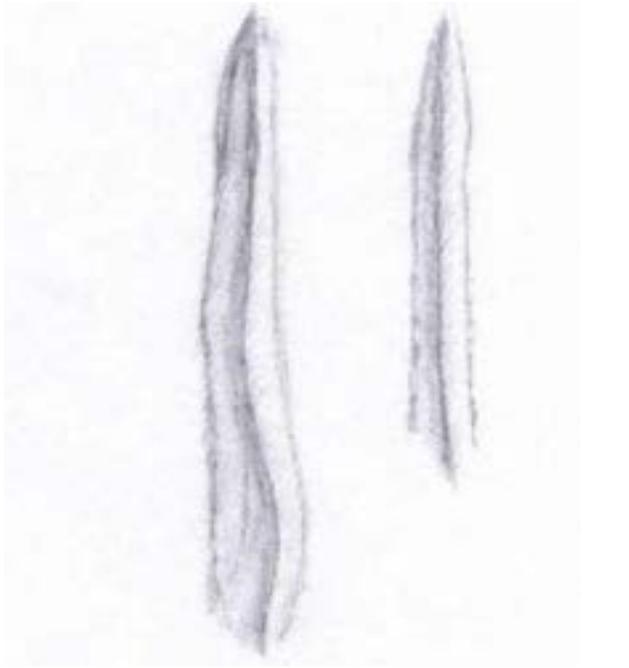


FIGURE 5. Illustration of a possible swim track of a bipedal dinosaur. The traces are mostly paired and sometimes single and rarely in threes, linear, grooves. The outer grooves are sub-equal in length, relative to the center groove when all three digits are preserved.

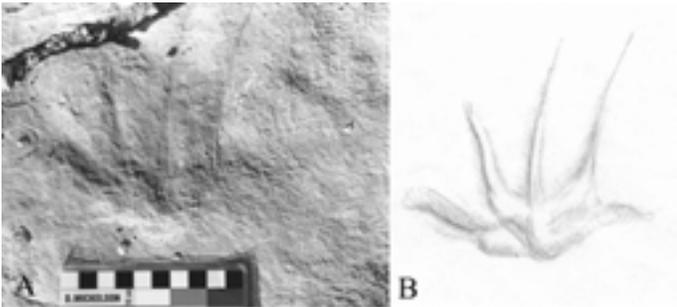


FIGURE 6. **A**, Photo and **B**, companion illustration of a crocodile pes track. Preserved are all 5 digits. Crocodiles have 4 digits on their manus and 5 digits on their pes.

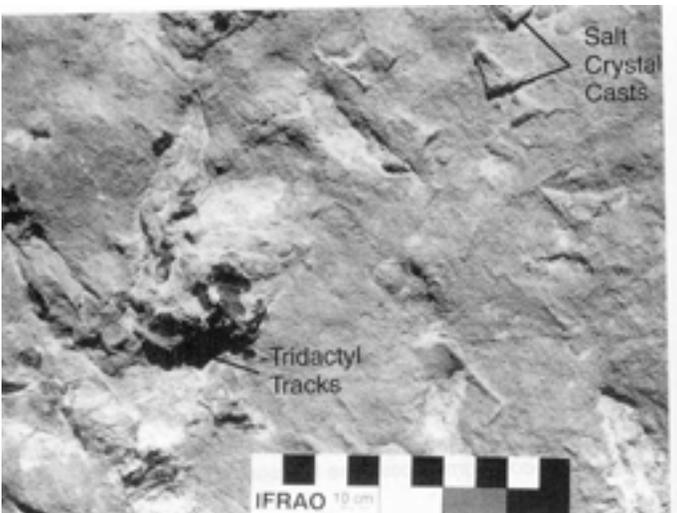


FIGURE 7. Salt crystal casts to the right of a tridactyl dinosaur footprint.

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THE OLDEST KNOWN EARLY TRIASSIC FOSSIL VERTEBRATE FOOTPRINTS IN NORTH AMERICA, FROM ZION NATIONAL PARK, UTAH

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Abstract—The spectacular rocks exposed in the Kolob Canyons District of Zion National Park in southwestern Utah include fossiliferous units of the Early Triassic Moenkopi Formation. The extensive exposures of this formation in the cliffs of the Kolob Canyons provide important information about the early Triassic and contain the earliest Mesozoic vertebrate footprint locality in North America. Regionally, Zion National Park lies at the western margin of the Colorado Plateau, near the transition zone between the Colorado Plateau and the Basin and Range physiographic provinces in the Western U.S. The Moenkopi Formation is Early Triassic in age (248 my-242 my) and is exposed in several areas of Zion National Park including the Kolob Canyons District, which lies in the northwest portion of the park. The Kolob Canyons lie 35 miles north of St. George, Utah and 150 miles south west of Capitol Reef National Park. The Moenkopi Formation is exposed in fault-bounded blocks along the Hurricane fault zone, and represents the Western margin of Pangea.

INTRODUCTION

In the summer of 2004 and spring of 2005 early Triassic footprints were discovered on fallen blocks in the Kolob Canyons District of Zion National Park. The blocks were traced back to the source bed, the track bearing host bed. Two of us (ARCM and JLM) discovered large, loose slabs with multiple tracks and tracks preserved *in situ* at the base of this stratigraphic unit while conducting fossil inventory assessments for the National Park Service.

Footprints are the only evidence of vertebrate animal life thus far from this time period in north, central and southern Utah. During this time when the environment was recovering from the biggest extinction in Earth's history the upper, lower red member seemingly was teaming with invertebrate and vertebrate life. There are two distinct ichnotaxa represented thus far at this Moenkopi locality. These animals portray a wide range of behavior characteristics. The rocks of Zion National Park provide a window to explore this dynamic ecosystem. The upper, lower red member, of the Moenkopi Formation is thought of as a regressive sequence environment and bears evidence of periods of sub aerial exposure. Multiple, staked, rhythmic beds, containing track horizons in vertical stratigraphic section, attest to fluctuating water levels. Periods of higher water levels are represented by ripple marks and swim tracks, while terrestrial walking tracks preserved with mudcracks attest to lower water levels.

PREVIOUS MOENKOPI FOSSIL REPORTS FROM ZION

Gregory and Williams (1947) reported bone fragments from the Moenkopi "red beds" in Zion National Park. Invertebrates, including the ammonite *Meekoceras*, asteroid starfish and the internal molds of mollusks are found in the Virgin Limestone in the Kolob Canyons region of Zion National Park (Santucci, 2000). While inspecting the collections housed at Zion we examined slabs of Virgin Limestone with trace fossils that appear to have been made by an arthropod and resting traces of the ichnogenus *Astrosoma* (brittle starfish) (DeBlieux and Kirkland, 2003).

GEOLOGY

The Moenkopi Formation of southwestern Utah, with its alternating reddish-brown, white and gray layers documents renewed sedimentation along the western margin of Pangea during the Early Triassic.

During the early-to- middle Spathian, a major transgression deposited deeper water carbonate facies on the shelf eastward and southward. The lower red member and Virgin Limestone Member of the Moenkopi Formation in southern Utah represent the southern extent of the early-to-middle Spathian marine regressive and transgressive sequence respectively (Blakey, 1973, 1977; Hintze, 1988; Dubiel, 1994; Marzolf, 1994; Paull and Paull, 1994; Schubert and Bottjer, 1995; Biek et al., 2000; Boyer et al., 2004).

The Early Triassic lower red member (early Spathian) and the Virgin Limestone Member of the Moenkopi Formation (middle Spathian) are interpreted to have been deposited in coastal and marine conditions. The Moenkopi Formation is bounded by the Tr-1 unconformity at its base and the Tr-3 unconformity at its top (Pirringos and O'Sullivan, 1978).

The marine to peritidal regressive sequence in the upper, lower red member tracksites reported herein occur in the top of the formation approximately 20 meters below a prominent bench of the Late Triassic Shinarump Conglomerate Member of the Chinle Formation. The track horizons are within a 3 m thick interval of gray shales and fine-grained sandstones. Above the track interval the Tr-3 unconformity of Pirringos and O'Sullivan, (1978), separates Early Triassic Moenkopi and Late Triassic Chinle rocks and marks a change from mostly shallow marine to continental sedimentation. The Moenkopi Formation at Zion is comprised of the following Members. In ascending order, the Rock Canyon Conglomerate Member, Timpoweap Member, lower red member, Virgin Limestone Member, middle red member, Shnabkaib Member and the upper red member (Table 1; Blakey, 1973 and 1977; Dubiel, 1994; Marzolf, 1994; Schubert and Bottjer, 1995; Biek et al., 2000; Boyer et al., 2004). These members record a complicated series of shallow-marine transgressions and regressions across a very gently sloping continental shelf. The Moenkopi Formation consists of three transgressive members, the (Timpoweap, Virgin Limestone and Shnabkaib Members), each of which is overlain by an informally named regressive red-bed member (the lower, middle and upper red members) (Blakey, 1973 and 1977; Hintze, 1988; Dubiel, 1994; Marzolf, 1994; Paull and Paull, 1994; Schubert and Bottjer, 1995; Biek et al., 2000; Boyer et al., 2004). A laterally extensive track-bearing unit lies within the upper most portion of the lower red member (Table 1, Fig. 1). Both terrestrial and subaqueous (swim) tracks of *Rhychosauroides* and terrestrial tracks of

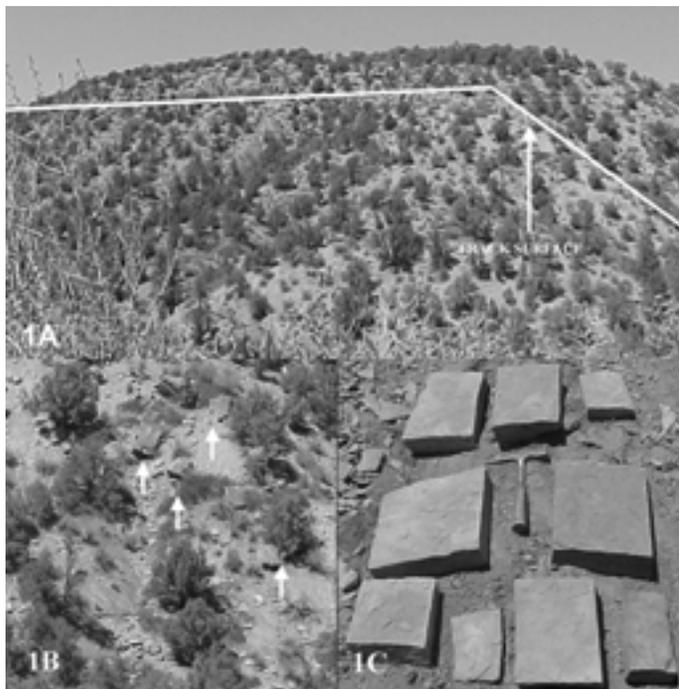


FIGURE 1. **A**, Outcrop of the lower red member of the Moenkopi Formation an extensive lateral track bearing surface denoted by a single horizontal line. The arrow denotes the location where *Rhychosauroides* and *Chirotherium* tracks were collected from. **B**, Arrows denote where *Rhychosauroides* and *Chirotherium* fallen track blocks were collected from in outcrop just below main track bearing horizon. **C**, Fallen track blocks.

TABLE 1. A comparison of stratigraphy of Zion National Park and Capitol Reef National Park vertebrate track localities. *** denotes stratigraphic units with preserved Moenkopi tracks. The upper, lower red member of the Moenkopi Formation at Zion N.P. are the oldest known occurrences of Early Triassic ichnogenera *Rhychosauroides* and *Chirotherium* (after Schubert and Bottjer, 1995; Boyer, et al., 2004; Biek, et al., 2000; Mickelson, et al., this volume).

SW Utah Zion N.P.	Central Utah Capitol Reef N.P.
Moenkopi Formation	
<u>upper red member</u>	
<u>Shnabkaib Member</u>	Moody Canyon Member
<u>middle red member</u>	
<u>Virgin Limestone Member</u>	Torrey Member ***
<u>lower red member ***</u>	
<u>Timpoweap Member</u>	<u>Sinbad Limestone Member</u>
	<u>Black Dragon Member</u>

Chirotherium exist with in these shales and sandstones. Several morphologic forms of tetrapod tracks and distinctly different “swim” tracks occur in mutually exclusive strata. Regional correlations of the Moenkopi (lower red member) stratigraphic and track bearing horizons at Zion indicate that they are similar to those of the Moenkopi Formation in central Utah. Capitol Reef Nation Park, Glen Canyon National Recreation Area and San Rafael Swell in central Utah, contain extensive track bearing horizons in the Torrey Member of the Moenkopi Formation (Table 1; Mickelson et al., this volume). Comparisons of the lower red member in Zion with the Torrey Member track horizons from central Utah show that each contain abundant, dense concentrations of

Rhychosauroides swim and terrestrial walking traces and walking traces of *Chirotherium*. The stratigraphically oldest known *Rhychosauroides* and *Chirotherium* track horizons known in North America occur in the upper beds of the lower red member at Zion (Table 1). Slightly younger track-bearing horizons at Capitol Reef, Glen Canyon and San Rafael Swell occur in the middle and upper most beds of the Torrey Member.

VERTEBRATE ICHNOLOGY

Described herein are a wide range of footprints from the upper, lower red member at Kolob Canyons. Swim tracks and terrestrial tracks of small quadrupedal reptiles are abundant. Preserved as positive relief “casts” and negative relief “impressions” are randomly oriented swim tracks and complete trackway sequences of walking animals. Tail drag marks and claw marks are very common. Swim tracks indicate that these animals were at least semi-aquatic. Invertebrate marine bivalves and trace fossils indicate that at least brackish water conditions existed.

Walking Tracks

Terrestrial trackways and isolated tracks of *Rhychosauroides* are the most abundant footprint type preserved in the park (site number 42Ws298t). Distinct, well-defined, manus and pes sets are well preserved in linear trackways (Fig. 2; Peabody, 1948; Leonardi, 1987; Tresise and Sarjeant, 1997). Medial tail drag marks, centered between foot falls within the trackway sequence and trackway widths, indicate that this small animal had a fairly wide gait proportional to body length and a body form built low to the ground (Fig. 3) (Mickelson et al., this volume).

Terrestrial tracks of *Chirotherium* are also preserved in the outcrop (Fig. 4). Although, these types of tracks are not very common at Zion they occur as isolated pes footprints.

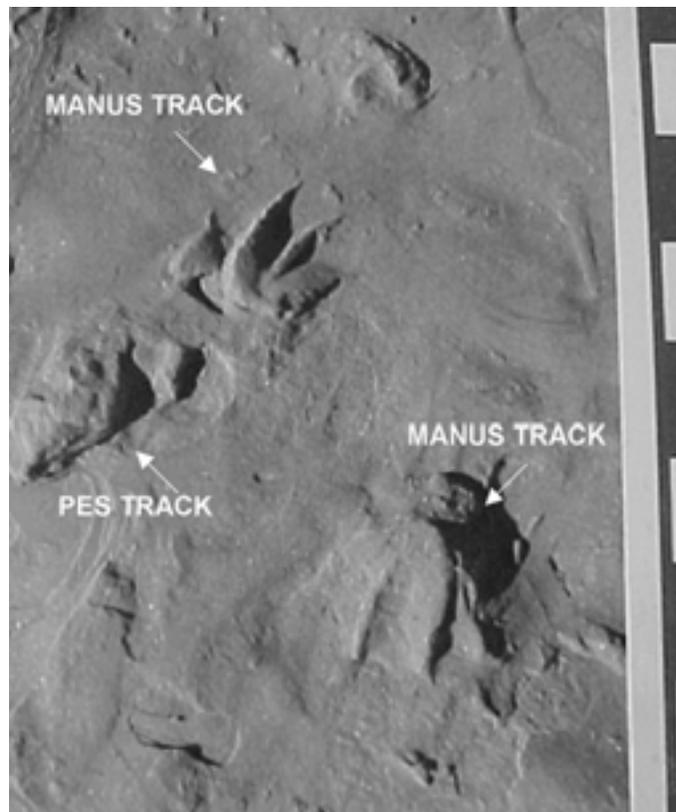


FIGURE 2. An example of ichnogenus *Rhychosauroides* manus and pes set and isolated manus walking footprints, traveling in opposite directions.



FIGURE 3. An example of a medial tail drag mark of ichnogenus *Rhychosauroides*.



FIGURE 4. An example of ichnogenus *Chirotherium* pes print. The footprint is significantly smaller (5 cm.) than any manus or pes footprints found at Capitol Reef (CRNP), Glen Canyon (GCNRA), and San Rafael Swell areas.

Swim Tracks

Randomly oriented swim tracks are the most common type of swim trace. These traces bear no evidence of forward direction in locomotion. The traces are typically preserved as long, linear, swipes or grooves with two to four digits being represented (Fig. 5). These swipes and grooves formed while the animal was partially buoyant (Mickelson et al., this volume). The second most common types of swim tracks are “toe dinks”. These traces are formed at the time the animal was almost fully buoyant and only the tips of their claws were touching the substrate (bottom). These traces suggest that these animals were well adapted to water (Fig. 5; Mickelson et al., this volume).

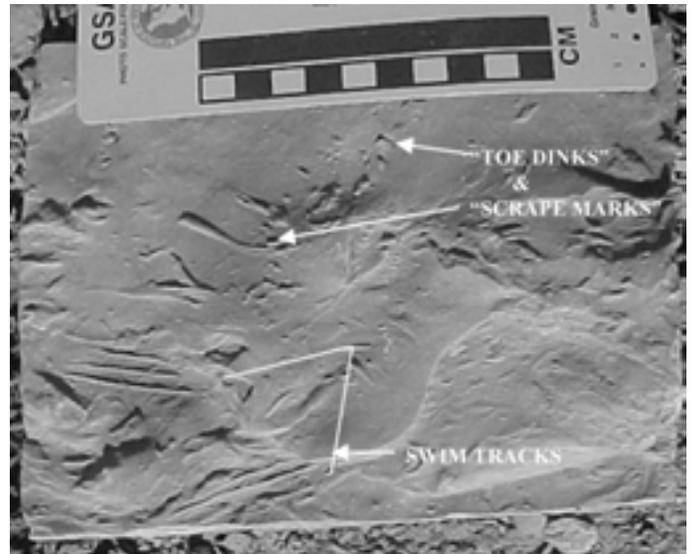


FIGURE 5. An example of ichnogenus *Rhychosauroides* “swim tracks”, “toe dinks”, and “scrape marks”. These types of tracks are dependent upon hip height, water depth and buoyancy of the animal.

DISCUSSION

The vertebrate tracks of the Moenkopi Formation in the Kolob Canyons, Zion National Park all occur within marine regressive deposits of the lower red member. The depositional environment indicates that these organisms were able to tolerate brackish water conditions similar to those of the Capitol Reef National Park and Glen Canyon National Recreation Area vertebrate track localities (Mickelson et al., this volume). More importantly, the lower red member vertebrate tracks are the oldest known Early Triassic footprints in North America. The presence of both terrestrial walking tracks preserved with mudcracks and swimming traces preserved with ripple marks, indicates fluctuating water levels at the time of track deposition. Comparisons of Zion National Park’s Moenkopi track bearing horizons to other Moenkopi track horizons in the region provides us an opportunity for lateral and temporal stratigraphic correlations that will help us understand floral and faunal diversity and animal behavior during the Early Triassic of North America.

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ABLMPALEONTOLOGICAL SITE STEWARDSHIP PROGRAM FOR WASHINGTON COUNTY, SOUTHWESTERN UTAH: THE BEGINNING OF A NATIONWIDE PROGRAM?

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Abstract—Archeological Site Stewardship Programs, sponsored by federal agencies like the U.S. Department of the Interior's Bureau of Land Management (BLM), are well established in the western United States. These Site Steward Programs are designed to utilize volunteers to monitor significant archaeological sites for signs of vandalism, the looting of artifacts, natural impacts, such as erosion and general public activities at each locality. The St. George [Utah] Field Office of BLM is initiating what we believe to be the first Paleontological Site Stewardship Program (PSSP) in the nation to monitor paleontological and will focus on localities on public domain lands in Washington County, Utah. The overall goal of this volunteer program is to monitor significant and irreplaceable fossil localities for signs of erosion, vandalism, theft and general public activities in a similar manner to the Archaeological Site Stewardship Program. Other uses for a PSSP could include utilizing volunteers to aid professionals in the discovery and recording of new localities, preservation and conservation of existing sites and increasing public awareness regarding the preservation of fossil resources.

INTRODUCTION

The discovery of an amazing dinosaur track site within St. George city limits by Dr. Sheldon Johnson in February 2000 resulted in the 1st phase of museum construction over the original locality within Washington County, Utah (Fig. 1). The site has gained worldwide recognition by both researchers and the general public (Hayden, 2000; Kirkland et al., 2002). Since the site's discovery and construction of the on-site museum, now called the St. George Dinosaur Discovery Site at Johnson Farm (SGDS) (Fig. 2A), public interest in the paleontological resources of southwestern Utah has increased dramatically. This has resulted in an increase in volunteers and a rise in the membership of the Southwest Chapter of Utah Friends of Paleontology (UFOP), which is now the largest chapter in the state.

Increased excitement over the SGDS has contributed considerably to the discovery of many new track and body fossil sites in Washington County and surrounding areas (e.g. Iron County, Utah; Clark and Lincoln counties, Nevada; northwestern Utah, etc). These localities are being reported from BLM, Dixie National Forest, the Red Cliffs Desert Reserve, other federal lands, state parks, Utah State Institutional Trust Lands and private properties. All of these new fossil localities are reported to the SGDS, BLM, other landowners and to the State Paleontologist's Office at the Utah Geological Survey (UGS) in Salt Lake City. However, the long-term protection of significant sites, discovered or undiscovered, is of great concern, particularly as Washington County is the fifth fastest growing county in the United States.

THE PROBLEMS

Fossil Theft

Fossil collectors are noticeably on the increase at and around the SGDS since its discovery. The presence of fossil thefts is more noticeable within the area, and some thefts on federal lands have been reported to the BLM and UGS. Additionally, fossil tracks from the area often appear for sale on e-Bay, where, unfortunately, the provenance of these tracks is nearly impossible to discern. Although many examples of fossil thefts are known from throughout the nation and around the world, to keep in focus, we will briefly mention three recent examples of fossil theft in southwestern Utah:

(1) Stolen bones from a metoposaur locality (Figs. 2B-C) in the

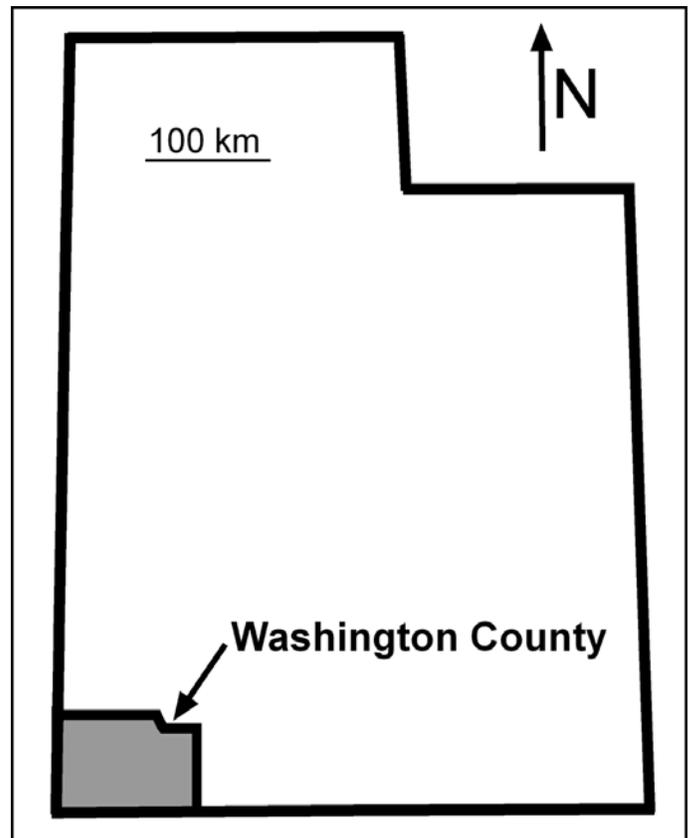


FIGURE 1. Map of Utah showing the location of Washington County.

Petrified Forest Formation, Chinle Group on Hurricane Mesa, along with the disappearance of many fossil trees trunks in the same area (Fig. 2D). This occurred within a three-month period between March and June 2003. This site was discovered by ARCM on June 11, 2002 and reported as a theft by the Yale-Peabody Museum and ARCM in 2003 to the BLM Regional Paleontologist.

- (2) A large dinosaur track was stolen from “The Spectrum Tracksite” on Utah State Institutional Trust Land (SITLA) near Washington, Utah. A large block from an edge portion of the tracksite was pulled out by someone using an ATV and dragged away from the site. SITLA plans on preserving this site, with development of the surrounding property.
- (3) An, as yet, undescribed tracksite north of Kanab, Kane County, Utah located in the Kayenta Formation has been victim of several dinosaur track thefts in recent years (A. Titus, personal commun., 2003). As with most *in situ* track thefts, the person(s) responsible chiseled or saw-cut around the footprints, then splits it out from below. The result of this kind of theft leaves behind a circular hole often in the middle of a pre-existing trackway. A well-documented example of this can be seen at the famous Dinosaur Ridge Tracksite near Denver, Colorado (Lockley, 2001) (Fig. 2E).

By making the public aware of an existing PSSP in Washington County and promoting an awareness that Site Stewards are watching significant fossil localities should act as a deterrent and hopefully reduce further fossil thefts in the county.

A common problem is unintentional removal of significant fossils from federal, state and even private lands without owner permission. On several occasions, dinosaur tracks and fossil bones have been brought into the SGDS museum for identification; however, these persons claim they were not aware that a permit is required to legally collect vertebrate fossils on public lands. At the SGDS, we try to inform the public about what they should and should not do without discouraging or intimidating them. Public awareness is definitely beneficial and can be of considerable assistance in identifying new localities.

Site Vandalism

Graffiti

Like fossil theft from federal lands vandalism, in the form of graffiti, is on the increase in Washington County and surrounding areas. This is also a very common problem at archaeological sites, particularly highly visible aboriginal rock art sites (petroglyphs and pictographs) (Fig. 3A). One such case has recently been reported from west of Ivins, Utah in the Santa Clara River Reserve, where vandalism to a rock art site on BLM-administered lands was successfully prosecuted, resulting in convictions and the levying of fines and restitution costs. Ironically, this very same petroglyph site is adjacent to a recently studied tracksite in the top of the Shinarump Formation of the Chinle Group (Lockley and Milner, in press).

Another recent example involves the vandalism of an important archaeological site associated with a well-known Kayenta Formation theropod dinosaur tracksite in Grand Staircase-Escalante National Monument (GSENM). Here Native Americans painted pictures of the nearby *Eubrontes* tracks on a rock wall. The vandalism took the form of initials carved into the rock wall next to the pictographs (A. Titus, personal commun., 2005). The nearby tracksite, though never properly described, has been briefly mentioned in publication by Hamblin and Foster (2000), featured on the cover of the UGS Survey Notes (anonymous, 2001), and graces the poster promoting Utah Prehistory Week, 2006.

Plaster Casts

Another kind of vandalism can happen either intentionally or accidentally. A common problem associated with dinosaur tracksites occurs when members of the public attempt to replicate tracks by making plaster casts of them. Some people are aware that it is against the law to do this on federal (U.S. Department of the Interior and Bureau of Land Management, 2002) and state lands. A majority of the public is unaware of any laws pertaining to this type of activity. Trying to replicate tracks by directly applying plaster to them can cause extensive damage. Here

are a couple of recent examples from southwestern Utah:

- (1) A well-known dinosaur tracksite in the Late Cretaceous Iron Springs Formation on the east side of Parowan Gap in Iron County preserves many tracks (Milner et al., in press). One particular ornithomimid track often visited by the public, receives at least one attempt at replicating it with plaster each year! Damage to the specimen is becoming more and more obvious (Fig. 3B).
- (2) A second plaster cast was discovered within a *Eubrontes* track in November 2005 by ARCM and Dr. Martin Lockley (Dinosaur Tracks Museum, University of Colorado at Denver) while researching an Early Jurassic tracksite near Washington, Utah (Figs. 3C-E). Before the discovery of the plaster-filled footprints, we noticed the track had been intentionally covered with sand after the person(s) were unable to remove the plaster from the track. Obvious chisel marks can be seen in the plaster, produced in an attempt to extract the plaster cast from the track (Fig. 3C). Lockley, a qualified professional, removed the plaster from the track (Figs. 3D-E). Despite care taken during the removal of the plaster obvious damage to the specimen occurred from the plaster binding to the track surface and infilling pre-existing cracks. Unfortunately, not all of the plaster could be completely removed from the trace fossil, defacing the track (Fig. 3E). This is an excellent example of a criminal action of vandalism to a paleontological site.

Note that latex and silicon molds of tracks can be made safely without damage to the tracks and can help fully document and preserve tracks and tracksites that could eventually be lost to natural erosion and/or vandalism. However, *in situ* track replication should only be attempted by a qualified researcher under permit.

Privatization of Lands, Rapid Development, Population Growth and Tourism

St. George (Figs. 4A-B) was the second fastest growing city, per capita, in the USA in 2005 (Mackun, 2005), and a recent survey shows Washington County is the 5th largest growing county in United States per capita (Canham, 2006). The demand for lands suitable for development has increased dramatically in the past decade. Utah State Institutional Trust Lands within the St. George Basin are being sold off and developed for residential and commercial purposes. Legislation is also poised to be introduced in this Congressional session that could require the sale or transfer of as much as 90,000 acres of BLM-administered public land to the county for future development (“Washington County Public Lands Act”). If legislatively approved federal land disposals do not require compliance with federal environmental protection or heritage preservation laws, such as the National Environmental Policy Act or the National Historic Preservation Act, significant archeological, biological and paleontological resources and values could be destroyed by subsequent development.

Enormous areas of previously unexplored vertebrate fossil-bearing formations are present in Washington County. Untold scientific and interpretative opportunities will be lost to development, possibly with no scientific documentation or any efforts at salvage or preservation. Mesozoic stratigraphy including the Triassic Moenkopi Formation and Chinle Group; Early Jurassic Moenave, Kayenta and Navajo formations; and Late Cretaceous Iron Springs Formation have all produced vertebrate body fossil sites and/or significant tracksites. It is extremely important to locate, document, and preserve fossils from these undiscovered localities before they are lost forever!

Population growth and increasing tourism to the region also place significant fossil localities at greater risk of theft or vandalism. Federal agencies, like BLM, lack adequate staff and law enforcement rangers to effectively monitor remote fossil sites on public lands. Volunteer site stewards can greatly increase the capabilities of the agencies to monitor

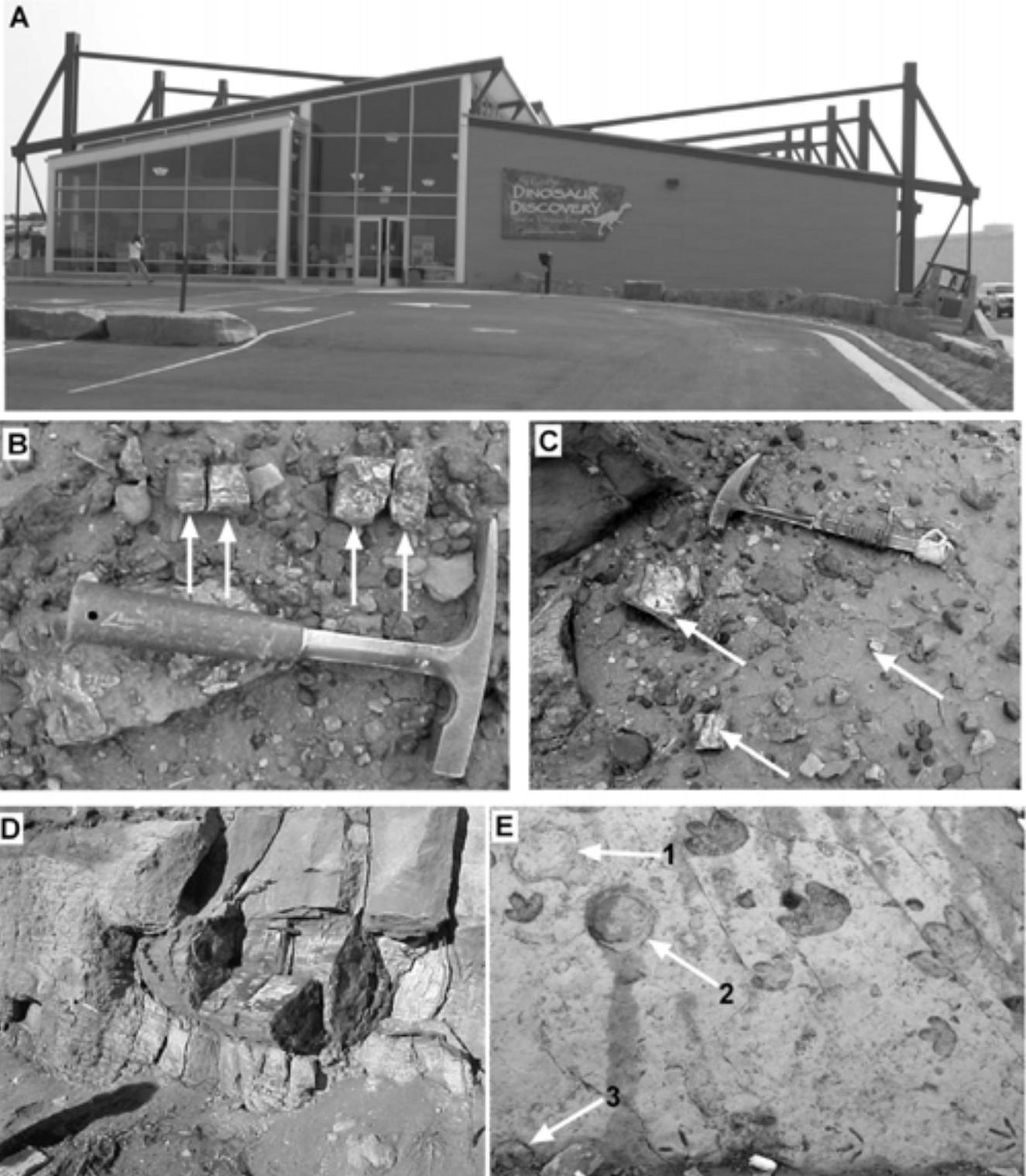


FIGURE 2. **A**, The new museum covering an *in situ* dinosaur tracksite at the St. George Dinosaur Discovery Site at Johnson Farm, St. George, Washington County, Utah. **B**, Arrows point to metoposaur jaw fragments stolen from a Petrified Forest Formation, Chinle Group site on Hurricane Mesa west of Zion National Park in Washington County. **C**, Large skull sections (white arrows) from the same metoposaur as in B, also stolen. **D**, Large petrified tree from Hurricane Mesa – also stolen. **E**, Dakota Group ornithopod and theropod dinosaur tracks at Dinosaur Ridge near Denver, Colorado. 1 points to chisel marks around an ornithopod track; 2 indicated where an ornithopod track was stolen from; and 3 points to a theropod track surrounded by chisel marks from an attempted theft.

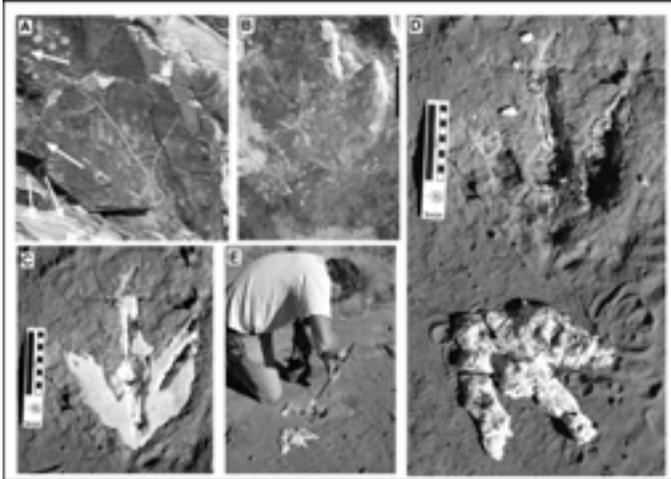


FIGURE 3. **A**, 3,000 year old American Indian petroglyphs on outcrops of Early Jurassic Navajo Sandstone on the west side of Parowan Gap, Iron County, Utah. White arrows point to modern graffiti (i.e. site vandalism). **B**, Beautifully preserved ornithomimid natural cast track in the Upper Cretaceous Iron Springs Formation, Parowan Gap, Iron County, Utah. The white material all over and around this footprint is adhered plaster to the sandstone – another case of site vandalism. **C**, Plaster-filled *Eubrontes* theropod track in the lower Kayenta Formation (Early Jurassic) near Washington, Washington County, Utah. Notice the chisel marks within the solidified plaster in an attempt to remove it by the person(s) responsible for the vandalism. **D**, Dr. Martin Lockley carefully removing the plaster cast infilling the track in **C**. **E**, Photograph of the same track in **C-D** showing the plaster infill removed. Plaster is still attached to the inside of the track and matrix has been pulled away from the track resulting in permanent damage.

sites, document new localities, and assist with public outreach and education.

Erosion

Erosion to significant paleontological sites is a serious problem. Important body fossil sites can usually be collected prior to erosion destroying a site; however, most *in situ* tracksites are at constant risk to weathering. Efforts to preserve tracksites in Washington County and other areas should be seriously considered, especially sites displaying unique features or holding type specimens.

Many body fossil sites in the region and neighboring states still remain uncollected. Several of these localities in Washington County hold vertebrate fossils that are first reports for the area and/or potentially unique taxa. One such example of an “at risk” site is the “Millie Phytosaur Site” in the Petrified Forest Formation of the Chinle Group (Fig. 4C). The locality holds a partially articulated phytosaur skeleton near the base of a steep wash. The skeleton lies in a slumped section of mudstone, and *in situ* bones have been identified in the outcrop above. The site was discovered by UFOP member Kolene Granger in 2005 and represents the first articulated skeleton from the St. George area. The slumped portion of the skeleton is at great risk of being washed away unless collected.

POSSIBLE SOLUTIONS

Site Sensitivity: Should a Site be Monitored or Not?

At present, only localities on BLM-administered lands will be monitored by Paleontological Site Stewards. Before Site Stewards can be assigned localities to monitor, the significance of each site must be assessed on a case-by-case basis. Additionally, the proximity of a site to



FIGURE 4. **A-B**, Excavation for development in and around the St. George area of Washington County, Utah. **C**, The “Millie Phytosaur Site” in Washington County, Utah. This site is contained within the Petrified Forest Formation, Chinle Group. An articulated skeleton of a phytosaur was found on a slumped section of outcrop into the base of the wash. *In situ* bones still remain in the outcrop above where the skeleton was first found. Potential flash-flooding could jeopardize this site.

areas of human activity also needs to be taken into account.

Fossil localities in Utah are managed for their scientific, educational and recreational values (U.S. Secretary of the Interior, 2000; Hayden, 2005; Kirkland et al., this volume). The BLM has suggested three levels of fossil locality classification (Raup, 1987; U.S. Bureau of Land Management, 1998); however, due to the great diversity of fossil-bearing rocks in Washington County, we find the six-tiered classification system ranking the sensitivity of geological formations that contain fossils derived from DeBlieux et al. (2003) and Kirkland et al. (this volume) to be more effective. These formation rankings can be applied to individual sites and are fully explained in Kirkland et al. (this volume).

A list of criteria was created by the BLM and U.S. Forest Service to define “fossils of scientific value” (Raup, 1987; DeBlieux et al., 2003):

- Preservation of soft body parts.
- All vertebrate body fossils and traces
- Preservation of uncommon invertebrate fossils.
- Close or intimate association of plants with animals.
- Preservation of the skull, whole isolated bones or other diagnostic materials.
- A concentration and diversity of plants and animals of restricted geologic or geographic range.
- Fossils poorly known to science.
- Unique or significant geographic, stratigraphic or paleontologic position such as type locality, only known occurrence, reptile-mammal transition, etc.

In order for localities in Washington County or elsewhere to be considered of critical scientific paleontological value, they must exhibit one or more of the above criteria.

Trained Paleontological Site Stewards

Interview and Screening Process

All potential volunteers for the PSSP must go through a four-stage screening process in order to become Site Stewards. The process begins with the completion and submission of an application form. The volunteers must undergo an interview with qualified BLM employees (Site Stewardship Administrator, Geologist and/or Archaeologist), Site Steward Coordinator(s), and/or paleontologist(s) familiar with the program. If accepted, volunteers must become familiar with proper paleontological procedures either by volunteering at the SGDS, or participating in a UFOP Certification program. This will assist the volunteers in gaining a basic knowledge of the regional geology and paleontology, simplified fossil identification, basic understanding of field and laboratory techniques, collections management and an appreciation for the importance of preserving important fossil localities and their surroundings. This will allow the SGDS paleontologist to become more acquainted with candidates and make a final recommendation on their suitability for the PSSP. In addition, the SGDS would benefit from the extra assistance at the museum. This could also benefit the state should the volunteers become UFOP members, resulting in assistance to the local UFOP chapter and potentially to other paleontologist in the state or surrounding states. Volunteers will also receive training in Outdoor Survival Skills, Leave No Trace Principles, Orienteering, use of GPS systems and Personal Safety during site monitoring duties. Those accepted to the PSSP will sign BLM Volunteer Agreements that outline the nature of the volunteer duties and the responsibilities of each volunteer. The acceptance of volunteer services by BLM provides federal legal protection for each volunteer, should they be injured or killed while performing their official volunteer functions.

Monitoring Localities and Locality Records

Once a Site Steward is accepted into the program, he/she will be assigned a locality or localities to monitor periodically, preferably on a monthly basis. Site Stewards will be provided with a site folder with information on each locality they monitor. These site folders are confidential and are the property of the federal government and land manager. These site folders will include:

- A copy of the necessary portion of a 7 1/2 minute topographic map showing the best access to the locality.
- A larger scale map showing land ownership and route into the vicinity of the locality to monitor.
- Written directions on how to find the site.
- Latitude and longitude coordinates or Township and Range of the locality.
- Routine and emergency reporting instructions.
- Site description; type of site; geologic description; list of fossil types found at site; possible tracksite maps.
- Portion of geologic map(s) relevant to the locality.
- Stratigraphic data relevant to the locality and surrounding rock formations.
- Spare data sheets to record information on any new localities discovered while monitoring your site (see below).

This information will assist Site Stewards in identifying the characteristics of the site, becoming familiar with the detailed history of the locality (such as *in situ* fossils or sites they have been found), possible erosion problems and other information specific to that site. The goal is twofold: to deter vandalism or theft and to monitor for other sources of potentially damage (such as erosion). Thorough the early detection of potential hazards to the locality from vandalism, theft or erosion and, in the case of illegal activities, the safeguarding of evidence, important fossil localities can be more effectively protected.

Reporting Locality Problems

Site Stewards will be trained on appropriate site etiquette, the procedure for approaching their site(s), what to look for when at a locality and what to do when encountering people visiting, vandalizing or stealing from a site.

Each site folder will contain a list of the proper contacts, detailed instructions on what to do if problems are encountered, information on the local geology and what would constitute new discoveries (see below). Site Stewards are recommended to carry a camera and GPS unit with them to periodically photograph and record the monitored site, any potential problems with it or to help document new fossils they may encounter.

Site Stewards should not bring other people with them unless they are pre-authorized by the BLM office. They are not authorized to carry or use firearms during volunteer duties or travel off-road or off-trail to the localities by motorized or non-motorized vehicles. If encountering other visitors at the site, they **should not** inform them of their position with the PSSP, provide information on the site or attempt to act in a law enforcement-type manner. These behaviors will NOT be tolerated by the BLM in a Site Stewardship Program.

Volunteer safety comes first! If vandalism or theft is encountered, the appropriate law enforcement officer(s) should be contacted along with the BLM Site Coordinator overseeing the PSSP. If any problems are encountered, the Site Steward should move away without disturbing the site or potential violators and contact the appropriate person(s) as soon as possible.

Volunteers Assist in the Discovery and Recording of New Localities

Searching for New Localities

Training volunteers to assist in monitoring significant paleontological localities on land managed by the BLM is needed. In addition these volunteers could be including in conservation efforts to preserve important tracksites for future generations of researchers to study and for the enjoyment and education of the public.

BLM Site Stewards along with organized/trained groups, such as UFOP, can assist researchers in surveying for potentially significant sites within the region (Fig. 5A-B). The discovery of new sites can also lead to other volunteer opportunities, such as participating in site excavations (Fig. 5C) and fossil preparation training in the lab (Fig. 5D).

Standard for Recording Localities

All Site Stewards will be trained on the proper recording of information on locality data sheets (see Appendix). This will include how to correctly photograph a site and fossils, plotting localities on topographic maps, identification of primary stratigraphic units and using a GPS unit to pin-point exact locality coordinates.

The Washington County PSSP will use locality data sheets developed by the State Paleontologists office at the Utah Geological Survey. Other institutions have also adopted these locality data sheets, including the SGDS (Appendix). Locality data sheets include the following: locality description, types of fossils, with a brief description, an area to sketch specimens, geologic information, map coordinates, GPS and map information, depositional environment, collection date and who found the specimen(s), associated photographs, permit, and repository information, name of the person recording the data and a section for publication information on the specimens that can be added on later to go along with additional specimen information.

All of the recorded information on any localities on public lands will be submitted to BLM's St. George Field Office and to the State Paleontologists office at the UGS. This information is entered into a comprehensive database maintained by the UGS containing most fossil localities within the state of Utah. Access to the information contained in



FIGURE 5. **A**, Volunteers exploring portions of the upper Chinle Group in the St. George area. **B**, UFOP members search outcrops of Moenave Formation for dinosaur tracks and vertebrate body fossils near the SGDS in St. George. **C**, UFOP members assisting UGS staff excavating an iguanodont dinosaur in the Lower Cretaceous Cedar Mountain Formation in 2005 at “Andrew’s Yellow Cat Site”. **D**, David Slauf, an SGDS volunteer and UGS member preparing a fish fossil in the lab.

this database is restricted to qualified researchers and institutions (Kirkland et al., this volume).

***In Situ* Preservation and Interpretation of Sites**

In situ interpreted “public use” fossil sites in Washington County currently include only the SGDS museum and a remote tracksite on BLM-administered public lands, south of St. George in the Warner Valley. At this site, the tracks are located in an ephemeral drainage. Approximately 10 years ago, BLM constructed a low retaining wall in the drainage, in an effort to divert seasonal run-off away from the dinosaur tracksite. This locality occurs in the lower portion of the Early Jurassic Kayenta Formation, which lies unconformably below the Navajo Sandstone. Originally this locality was incorrectly described as being in the Moenave Formation (Miller et al., 1989). The St. George Field Office plans to address the deficiencies in both the protection and interpretation of the Warner Valley site, as funding and staff time permit. Assistance from volunteer Site Stewards could expedite the completion of needed improvements and changes to this public use site.

In the past year, approximately 15 new tracksites have been discovered within 15 km of St. George, most on BLM-administered public lands. Several of these sites are on very delicate surfaces and in order to preserve them for future research and potential public viewing, consolidation of the outcrops through chemical applications may be needed. Certain non-reversible consolidates that have been tested on historic masonry buildings and shown to be successful at preserving the fabric of the buildings may be suitable for this purpose. Ethyl silicate has been tried on natural outcrops and has stood up to the test thus far, but long-term effects are unknown; also it very expensive (Grisafe, 2000, 2001, 2002). Silane-based chemicals have proven reliable in the preservation of historic buildings over the past century (R. Denton, personal commun., 2006). Some of these chemicals may prove valuable in the long-term preservation of dinosaur tracksites (Mason III, 2005). The use of artificial consolidates or preservatives on *in situ* fossil sites will require extensive research and testing. A cadre of trained site stewards could assist BLM with projects to conserve and interpret *in situ* fossil localities.

Another method for documenting dinosaur tracksites involves detailed three-dimensional photogrammetry techniques and remote sensing of sites, a procedure already in use by the BLM in some areas (Breithaupt et al., 2004; Matthews et al., this volume).

Increasing Public Awareness

Site Stewards would also be capable of assisting BLM and other agencies with public outreach and education. Due to their training and experiences gained as volunteers they would be particularly effective at communicating the value and importance of fossil resources to other users of public land. Their passion for the resource and its protection/preservation will enhance their ability to commutate to others. As an example, an Education sub-committee of BLM-St. George Field Office’s Color Country Site [archeological] Steward Program has developed an hour-long Power Point program and script that speaks to the need for young people to practice stewardship for a wide array of public land resources. This “curriculum” is targeted at the 7th grade level and is presented by volunteer Site Stewards in the classrooms of Washington County schools, to very favorable reviews from students and teachers. A module specific to archeological site protection and site etiquette is under development by this group, as part of a series to educate young people about their responsibilities as resource stewards for future generations. This series could easily include a module on paleontology and the legal and ethical reasons for the protection of important fossil localities.

CONCLUSION:

POSSIBLE PALEONTOLOGICAL SITE STEWARDSHIP PROGRAM EXPANSION AND THE FUTURE

The St. George area is now home to many educated and physically active retirees, as well as seasonal residents, “snow-birds”, who enthusiastically seek out volunteer opportunities and donate many volunteer hours to public service. It is anticipated that the PSSP program will be in place within the next few months and will be highly successful as volunteers are already “in line” to be trained as Site Stewards. This program should also prove to be a useful management tool and other federal and state land managers will be interested in having volunteer Site Stewards monitoring resources for them. Strong similarities exist in both the training and functionality for paleontological and archeological Site Stewards, with the difference being mainly in the resource they monitor. Cross-pollination of these two programs could streamline the administrative tasks for BLM and would likely increase volunteers for both programs. We have every reason to believe that the introduction of the Paleontological Site Stewardship Program will make a difference in furthering the protection of paleontological resources in southwestern Utah.

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APPENDIX

An example of the locality data sheets used at the St. George Dinosaur Discovery Site at Johnson Farm.

Date: _____ State: _____

WGSN Locality #: _____

ST. GEORGE DINOSAUR DISCOVERY SITE AT JOHNSON FARM FOSSIL LOCALITY DATA SHEET

State: _____ County: _____ Field #: _____ Found by: _____

Locality Name: _____ Nearest Landmark: _____

Locality Description: _____

Primary Fossil Type: Vertebrate Invertebrate Plant Fossil Micro

Township & Range: _____ Quarter Sec: _____ Sec: _____ Twp: _____ Range: _____

USGS Grid Zone: _____ Easting: _____ Northing: _____ Source: _____

UTM Easting: _____ Northing: _____

UTM Easting: _____ Northing: _____

Elevation: _____

Map Year: _____ Source: _____ Scale: _____ Year: _____

Landform: _____

Group: _____ Formation: _____ Member: _____

Bed: _____ Lithology: _____ Strat. Pos: _____

Env: _____ Period: _____ Epoch: _____

Stage: _____ Substage: _____ Zone (S.A.): _____

Terrestrial Marine Depositional Environment: _____

Preservation Type: _____

Repository: _____ Acronym: _____ Loc. #: _____

Collection Date: _____ Permit #: _____ Accession #: _____

Photo: _____

Parent(s) Recording Date: _____

0101-4

a ST. GEORGE DINOSAUR DISCOVERY SITE AT JOHNSON FARM FOSSIL LOCALITY DATA SHEET

JTS Locality #: _____

Repository: _____ Acronym: _____ Loc. #: _____

Collection Date: _____ Permit #: _____ Accession #: _____

Repository: _____ Acronym: _____ Loc. #: _____

Collection Date: _____ Permit #: _____ Accession #: _____

Repository: _____ Acronym: _____ Loc. #: _____

Collection Date: _____ Permit #: _____ Accession #: _____

Taxa: _____

Holotype Paratype Neotype Replica Micro

Remarks: _____

Publication(s) Referencing Specimen

Journal Book Edited Book Magazine

Article Author(s): _____

Journal/Book Title: _____

Secondary (Series) Title: _____

Book Editor(s): _____

Year: _____ Volume: _____ Issue #: _____ Pages: _____

Journal Book Edited Book Magazine

Article Author(s): _____

Journal/Book Title: _____

Secondary (Series) Title: _____

Book Editor(s): _____

Year: _____ Volume: _____ Issue #: _____ Pages: _____

ADDITIONAL FOSSIL VERTEBRATE TRACKS IN NATIONAL PARK SERVICE AREAS

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Abstract—Fossil vertebrate tracks were first inventoried from National Park Service areas in 1998 and vertebrate tracks ranging in age from the Pennsylvanian through Pleistocene/Holocene were identified in 19 National Park Service areas. Since the completion of that initial inventory, fossil vertebrate tracks have been identified in nine additional NPS areas, for a total of 28 NPS areas preserving fossil vertebrate tracks. The new discoveries include five additional parks with Mesozoic tracks (Aniakchak National Monument, Denali National Park, Manassas National Battlefield Park, Navajo National Monument and Wupatki National Monument) and four with Cenozoic tracks (Agate Fossil Beds National Monument, Chickamauga and Chattanooga National Military Park, Golden Gate National Recreation Area and Oregon Caves National Monument). These new discoveries include the first evidence of Cretaceous dinosaurs in western Alaska (Aniakchak National Monument) and well-preserved claw marks in cave sediments of Oregon Caves National Monument. This paper also highlights new information regarding fossil tracks in parks identified in the initial 1998 inventory including a highly unusual trackway morphology recently discovered in Grand Canyon National Park, a potentially new ichnotaxa from the significant Copper Canyon tracksite in Death Valley National Park and one of the oldest Mesozoic tracksites in North America from Zion National Park. All together the rich fossil record of vertebrate ichnites in National Park Service areas include tracks of amphibians, ornithischian and saurischian dinosaurs, birds, artiodactyls, perissodactyls, carnivores and proboscidians. Continued research into the vertebrate ichnofossils of National Park Service areas will undoubtedly contribute additional discoveries and increased knowledge regarding these important paleontological resources.

INTRODUCTION

An initial inventory of fossil vertebrate tracks from areas administered by the National Park Service was undertaken in 1998 (Santucci et al., 1998). During the original inventory the fossilized tracks of ancient vertebrates were identified in nineteen different units of the National Park Service. This ichnological record in the parks ranged from Pennsylvanian trackways in Grand Canyon National Park, Arizona, through Pleistocene / Holocene tracks in Zion National Park, Utah.

Since the original inventory, fossil vertebrate tracks have been documented in nine additional National Park Service areas. These include Mesozoic vertebrate tracks at Aniakchak National Monument, Alaska; Denali National Park, Alaska; Manassas National Battlefield Park, Virginia; Navajo National Monument, Arizona; and Wupatki National Monument, Arizona. Additionally, Cenozoic vertebrate tracks have been documented at Agate Fossil Beds National Monument, Nebraska; Chickamauga and Chattanooga National Military Park, Georgia and Tennessee; Golden Gate National Recreation Area, California; and Oregon Caves National Monument, Oregon. These additional vertebrate ichnites result in a total of 28 National Park Service areas identified with fossil vertebrate tracks (Fig. 1).

PALEOZOIC TRACKSITES

Introduction

Santucci et al. (1998) reported on Paleozoic vertebrate tracks from two National Park Service areas, Grand Canyon National Park, Arizona and Glen Canyon National Recreation Area, Utah. Since the original inventory, no new parks were identified containing Paleozoic vertebrate tracks.

Grand Canyon National Park, Arizona

A previously undescribed and highly unusual trackway was recently discovered in the Pennsylvanian Coconino Sandstone at Grand

Canyon National Park (C. Bowman, personal communication, 2006). The trackway was found by Dr. John Whitmore (Cedarville University) in the eastern portion of Grand Canyon. The trackway is contained in a downdropped slab and will be collected. The trackway shows overlapping pairs of manus and pes impressions of very large tracks (16 – 18 cm). The large tracks consist of didactyl pairs, which are not previously known from the Paleozoic (Fig. 2). The tracks may reveal actual morphology of the unknown track-maker, but more likely the shape is due to non-preservation of the lateral digits. The track slab also exhibits a smaller tetrapod trackway and appears to have a few tail drags posterior to the large didactyl tracks.

Of particular interest, the new trackslab shows excellent preservation of sediment splays or fans posterior to the individual tracks. These appear to consist of the sediment (sand) grains that have been pushed posteriorly as the individual feet impact and withdraw from the ground surface. The sediment splay patterns for the manus are small semicircles with an approximate diameter one half the length of the manus impression. The sediment splay patterns for the pes are larger in size and sediment volume and form a “L-shaped” distribution. This sediment distribution is interesting in that it shows angulations that appear to coincide with the oblique gait of the large quadrupedal trackmaker. The sediment splays associated with the tracks may yield valuable information related to the sediment substrate

MESOZOIC TRACKSITES

Introduction

Santucci et al. (1998) reported on Mesozoic vertebrate tracks from twelve National Park Service areas including: Arches National Park, Utah; Big Bend National Park, Texas; Canyonlands National Park, Utah; Capitol Reef National Park, Utah; Colorado National Monument, Colorado; Dinosaur National Monument, Colorado and Utah; Gettysburg National Military Park, Pennsylvania; Glen Canyon National Recre-



FIGURE 1. Map of National Park Service areas that have documented fossil vertebrate tracks. White dots indicate parks identified during the original vertebrate tracks inventory (Santucci et al., 1998). Black dots indicate new parks identified in this paper. 1. Agate Fossil Beds National Monument, Nebraska; 2. Aniakchak National Monument, Alaska; 3. Arches National Park, Utah; 4. Badlands National Park, South Dakota; 5. Big Bend National Park, Texas; 6. Canyonlands National Park, Utah; 7. Capitol Reef National Park, Utah; 8. Chickamauga / Chattanooga National Military Park, Georgia and Tennessee; 9. Colorado National Monument, Colorado; 10. Death Valley National Park, California; 11. Denali National Park and Preserve, Alaska; 12. Dinosaur National Monument, Colorado and Utah; 13. Gettysburg National Military Park, Pennsylvania; 14. Glen Canyon National Recreation Area, Arizona and Utah; 15. Golden Gate National Recreation Area, California; 16. Grand Canyon National Park, Arizona; 17. John Day Fossil Beds National Monument, Oregon; 18. Manassas National Military Park, Virginia; 19. Mojave National Preserve, California; 20. Montezuma Castle National Monument, Arizona; 21. Navajo National Monument, Arizona; 22. Oregon Caves National Monument, Oregon; 23. Petrified Forest National Park, Arizona; 24. Pipe Spring National Monument, Arizona; 25. Rainbow Bridge National Monument, Utah; 26. Scotts Bluff National Monument, Nebraska; 27. Wupatki National Monument, Arizona; 28. Zion National Park, Utah.

ation Area, Utah; Petrified Forest National Park, Arizona; Pipe Spring National Monument, Arizona; Rainbow Bridge National Monument, Utah; and Zion National Park, Utah. Five new parks have been identified with Mesozoic fossil vertebrate tracks and are presented below. In cases where new data, discoveries, or other information related to fossil vertebrate tracks within parks that were previously reported by Santucci (1998), this new information is also presented.

Aniakchak National Monument, Alaska

During a paleontological resource survey at Aniakchak National Monument in 2002, a hadrosaur (duckbilled dinosaur) footprint (Fig. 3) was found within the tidal flat or near shore deposits of the Upper Cretaceous Chignik Formation along the Aniakchak River. In addition to the footprint, two “hand” (manus) prints may also be present. This fossil is significant, not only because it represents the first evidence of dinosaurs found within Aniakchak, but because it represents the first evidence for Cretaceous dinosaurs in western Alaska, some 1,290 kilometers (800 miles) from the well-known North Slope dinosaur localities (Fiorillo, 2002). The track also indicates the excellent potential for more dinosaur fossils both within Aniakchak and within the Chignik Formation in general. As part of the Aniakchak paleontological resource survey, a CD-ROM has been created (Koch and Santucci, 2002) with additional information about the track and hadrosaurs in general. Fiorillo (personal communication, 2003) also reports the discovery of additional dinosaur footprints in the Chignik Formation. In addition, 13 upright tree stumps, a large quantity of leaf litter and some leaves with evidence of insect herbivory were found (T. Fiorillo, personal communication, 2003).



FIGURE 2. Unusual new vertebrate track slab from the Coconino Sandstone in the eastern portion of Grand Canyon National Park, Arizona.

Arches National Park, Utah

A paleontological resource inventory at Arches National Park identified a number of new vertebrate track localities in the park (Swanson et al., 2005). Tridactyl tracks occur in the Late Triassic Chinle Formation from the southern margin of the park along the state highway. Two theropod tracks and many other tracks have been found within the Jurassic Kayenta Formation in the park. These tracks occur in deposits that have been interpreted as interdunal oases deposits. An isolated reptile track (*Dromopus?*) was identified in the Salt Wash area of the park (Swanson et al., 2005).

A small theropod trackway, unusual feeding traces and subaqueous crocodile tracks are also found within the Ruby Ranch Member of the Cedar Mountain Formation (Early Cretaceous) (Swanson et al., 2005). Lockley et al. (2004) reports tridactyl theropod tracks, didactyl theropod tracks and sauropod tracks as well as tracks from ornithischian dinosaurs from within Arches National Park. Some of these tridactyl tracks may have been made by the coelurosaur theropod *Nedcolbertia*. The didactyl tracks may be attributable to dromeosaurs (*Deinonychus?*). The sauropod (possibly *Pleurocoelus* or *Venenosaurus*) trackways are similar to the classic “wide-gauge” sauropod trackway *Brontopodus*. The two types of ornithischian tracks were likely made by an ornithopod (potentially cf. *Tennontosaurs*) and an ankylosaur (possibly *Sauropelta*), respectively. The lower track-bearing surface contains a much less complex assemblage of theropod tracks and what may be sauropod track underprints (Lockley et al., 2004). Theropod tracks on this surface display two morphologies, one narrow-footed and the other, a more common morphology suggesting a medium-sized theropod.

Colorado National Monument, Colorado

Intensive paleontological resource inventories were initiated during the past five years yielding nearly 75 paleontological localities within Colorado National Monument. At least 79 theropod tracks identified as



FIGURE 3. Cretaceous hadrosaur track from the Chignik Formation at Aniakchak National Monument, Alaska.

the ichnogenus *Grallator* were reported from five localities in the Upper Triassic – Lower Jurassic Wingate Sandstone within the Monument (King et al., 2004). Trujillo and Walker (2005) also report several localities with numerous theropod tracks in the Wingate Sandstone. Lucas et al. (2006, fig. 4C) reported a manus imprint identified as *Pteraichnus* from the Summerville Formation of Colorado National Monument.

Lockley and Foster (2006) reported on fossil vertebrate tracks from two horizons in the Upper Jurassic Morrison Formation at Colorado National Monument. The tracks occur in fluvial sequences of the Salt Wash Member. The tracks include a theropod, small ornithomimid dinosaur (ichnogenus *Dinehichnus*) and turtles (ichnogenus *Chelonichnium*) (Lockley and Foster, 2006). A few isolated sauropod pes casts are reported from the Salt Wash Member in the Monument (Foster and Lockley, 2006). Sauropod and theropod tracks were reported by Trujillo and Walker (2005) from the Salt Wash Member at Colorado National Monument.

Denali National Park and Preserve, Alaska

On June 27, 2005, a tridactyl dinosaur track (Fig. 4) was discovered in a Cretaceous unit at Denali National Park. The track was found by a student from the University of Alaska, Fairbanks, participating in a geology and geophysics field camp held in Denali. The footprint is a cast within coarse sandstone of the lower Cantwell Formation. The rock unit represents a fluvial sequence including alluvial fans, braided streams and some lacustrine deposits (Phil Brease, personal communication, 2006). The track morphology indicates a theropod dinosaur track-maker from the Late Cretaceous of Alaska.

During August 2005, the footprint was measured, photographed and molded. The track-bearing block was carefully removed and transported to be placed on display for the public. This discovery will likely prompt further paleontological field work in the Cantwell Formation at Denali.

Gettysburg National Military Park, Pennsylvania

Santucci et al. (1998) reported on the occurrence of *Atreipus* dinosaur manus and pes in the building stone of the South Confederate Avenue bridge over Plum Run. In 2006, additional footprints were reported from other stones in the same bridge (J. Jones, personal communication, 2006). A single *Anchisauripus* track and a possible poorly preserved *Otozoum* track were confirmed by the authors.



FIGURE 4. Theropod dinosaur track from the Cretaceous Cantwell Formation in Denali National Park and Preserve, Alaska.

Manassas National Battlefield Park, Virginia

Vertebrate ichnofossils are known from the Triassic Bull Run Formation (“Balls Bluff Siltstone”) within Manassas National Battlefield Park, Virginia (Kenworthy and Santucci, 2004). These ichnofossils include *Gwyneddichnium majore* (Weems and Kimmel 1993). The *Gwyneddichnium* tracks were collected in the early 1990s by Weems during geologic mapping in and around Manassas. The tracks themselves were collected under permit and are currently at the U.S. Geological Survey headquarters in Reston, Virginia (R. Weems, personal communication, 2004). Gore also collected *Gwyneddichnium majore* tracks from Manassas, although they were identified as *Rhynchosauroides* (Gore 1988a, 1988b). In 1992, an additional track (referred to *Grallator* sp.) (Fig. 5) was found along the banks of Bull Run Creek near Manassas (Weishampel and Young 1996). This has recently been reassigned to *Atreipus milfordensis* (R. Weems, personal communication, 2004).

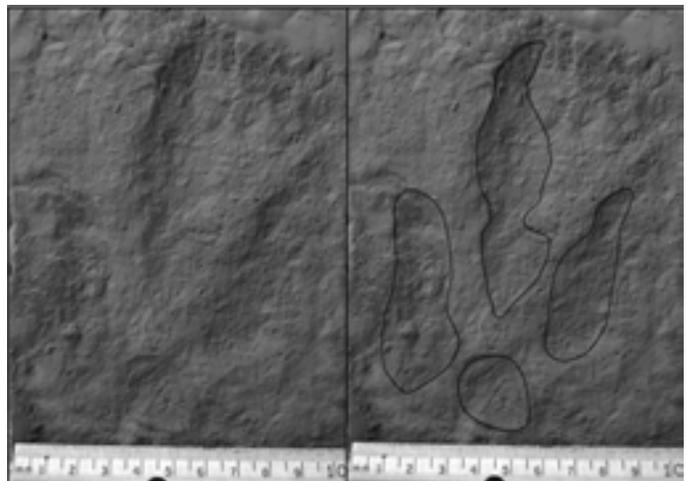


FIGURE 5. Tridactyl dinosaur track from the Triassic at Manassas National Military Park, Virginia.

Navajo National Monument, Arizona

Two tridactyl tetrapod tracks (Fig. 6) are preserved in blocks of Jurassic Navajo Sandstone at Navajo National Monument, Arizona (Hunt et al., 2005). Santucci et al. (1998) originally reported that the tracks were found in 1933, about a mile from the Keet Seel archeological site. Mellberg (personal communication, 2005) indicated that the tracks probably originated from a site about 10 miles outside the monument boundary near Tall Mountain.

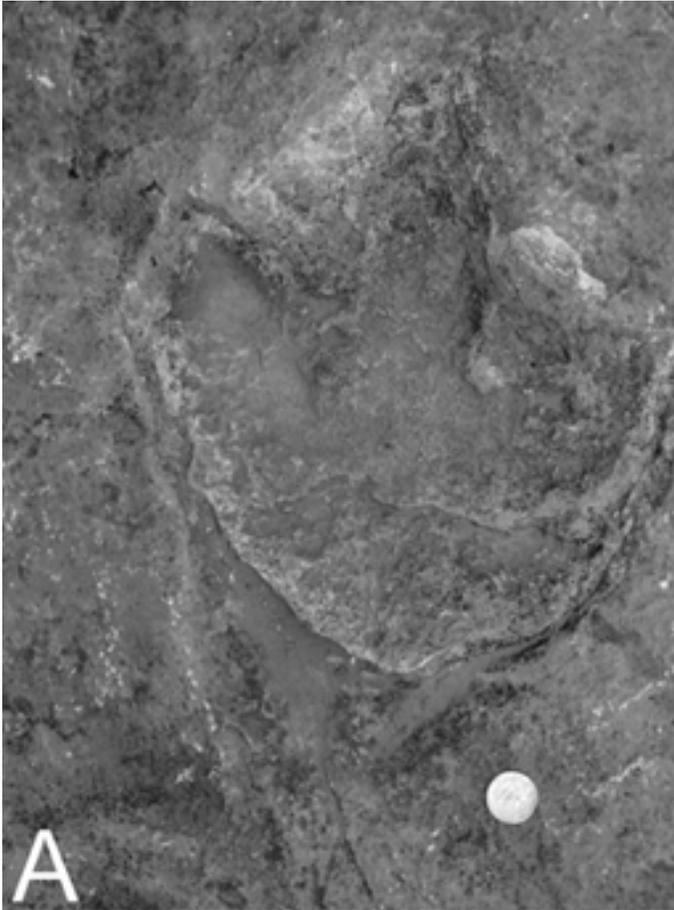


FIGURE 6. Tridactyl vertebrate tracks within blocks of Jurassic Navajo Sandstone on display at Navajo National Monument, Arizona.

Petrified Forest National Park, Arizona

Tetrapod tracks are identified from three localities at Petrified Forest National Park, Arizona (Hunt, et al., 2005). The first track locality is within a sandstone in the Teepees area of the park. Martin and Hasiotis (1998) report this unit as the Monitor Butte Member of the Chinle Group, while Heckert and Lucas (2002) refer to this unit as the Blue Mesa Member. Several pedal impressions of *Rhynchosauroides* sp., indeterminate swimming traces and an indeterminate large trackway (Santucci and Hunt, 1993; Santucci et al., 1995; Martin and Hasiotis, 1998). A dinosaurian track from this locality represents a right pes impression identified as *Grallator* sp. (Martin and Hasiotis, 1998; Hunt et al., 2005).

The second locality is in the Rainbow Forest area of the park from the Agate Bridge Bed of the Sonsela Member of the Chinle Group (Hunt et al., 2005). The ichnofauna includes *Rhynchosauroides* sp., cf. *Grallator* and *Brachychirotherium* sp. (Martin and Hasiotis, 1998; Hunt et al., 2005).

Martin and Hasiotis (1998) report another vertebrate track locality in the Flattops area of the park. The tracks at this locality are indeterminate, medium-sized reptile tracks. The track-bearing unit is in the Agate Bridge Bed of the Sonsela Member of the Chinle Group (Hunt, et al., 2005).

Wupatki National Monument, Arizona

The Early-Middle Triassic Moenkopi Formation is extensively exposed at Wupatki National Monument, Arizona. Kirby (1987) reports amphibian swimming traces from the Moenkopi Formation at Wupatki National Monument. In 2003, geologic intern K. Alden Peterson began to investigate the occurrence of vertebrate trace fossils within Wupatki National Monument. During June of 2004, Alden discovered a vertebrate track locality that included large *in situ* *Chirotherium* tracks. Part of the locality included tracks observed in some down-dropped blocks adjacent to the *in situ* tracks. In addition to a *Chirotherium* trackway (Fig. 7), approximately twenty track large archosauromorph-like tracks along with some smaller tetrapod tracks were discovered at the locality (Peterson, 2004; Hunt et al., 2005).

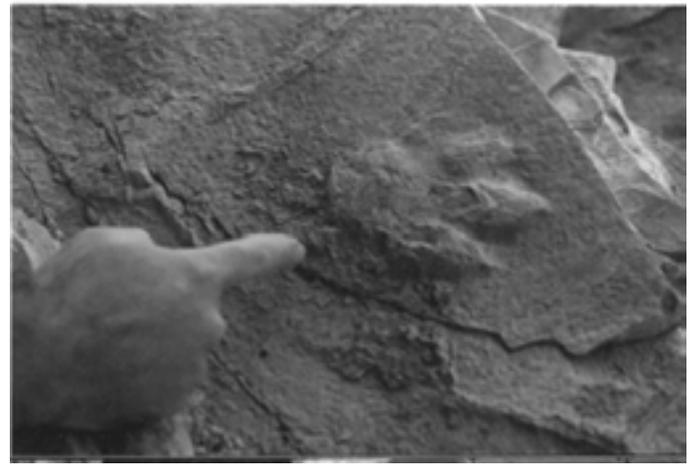


FIGURE 7. Tridactyl track tentatively referred to as "cf. *Tapripeda* n. sp." from the Miocene Copper Canyon Formation at Death Valley National Park, Nevada.

Zion National Park, Utah

During 2002 and 2003, staff from the Utah Geological Survey intensified paleontological field activities coordinated by the National Park Service since 1997 in Zion National Park. Through this work over 120 new fossil localities were documented in the park, including many new vertebrate track sites (DeBlieux et al., 2005).

An important vertebrate track locality was discovered in the Early Triassic Moenkopi Formation within the Kolob Canyon District of Zion. Small reptile and possible therapsid (mammal-like reptile) tracks were found in a gray siltstone unit below the Virgin Limestone Member of the Moenkopi Formation. This locality may represent one of the oldest Mesozoic tracksites in North America (DeBlieux et al. 2005).

Additional vertebrate track localities were located in all three members of the Late Triassic – Early Jurassic Moenave Formation exposed in Zion National Park. The basal Dinosaur Canyon Member contains primarily tridactyl dinosaur tracks. The Whitmore Point Member contains large numbers of dinosaur tracks and trackways (Smith and Santucci, 1999; Smith et al., 2002; DeBlieux et al., 2003). The three-toed dinosaur tracks are assigned to the ichnogenera *Eubrontes* and *Grallator*. Tracks appear concentrated in a greenish-gray dolomitic bed in the Whitmore Point Member (DeBlieux et al., 2005). The uppermost member of the Moenave Formation is the Springdale Sandstone. Dinosaur tracks are

rare in this unit and may actually occur at the contact with the overlying Kayenta Formation.

The Early Jurassic Kayenta Formation has the greatest concentration of fossil vertebrate tracks in Zion National Park. The ichnogenera of the Kayenta are primarily *Eubrontes* and *Grallator*. One four-toed track was also located in the Kayenta Formation at Zion National Park (DeBlieux, et al. 2005).

Santucci (2000) reported several dinosaur footprints from the Early Jurassic Navajo Formation along the trail to Observation Point in Zion Canyon. A second vertebrate track locality was located in the Navajo Sandstone near Parunuweap Canyon. The prints of several different animals are preserved on a weathered surface of a large rock-fall boulder (DeBlieux et al., 2005).

CENOZOIC TRACKSITES

Introduction

Santucci et al. (1998) reported on Cenozoic vertebrate tracks from seven National Park Service areas including: Badlands National Park, South Dakota; Death Valley National Park, California; John Day Fossil Beds National Monument, Oregon; Mojave National Preserve, California; Montezuma Castle National Monument, Arizona; Scott's Bluff National Monument, Nebraska; and Zion National Park, Utah. Four new parks have been identified with Cenozoic fossil vertebrate tracks and are presented below. In cases where new data, discoveries, or other information related to fossil vertebrate tracks within parks that were previously reported by Santucci (1998), this new information is also presented.

Agate Fossil Beds National Monument, Nebraska

A number of tracks are visible in vertical profile at Agate Fossil Beds National Monument (Hunt, 1992; M. Hertig, personal communication, 2002). The vertical profile tracks are documented at Carnegie Hill, University Hill and at the *Stenomylus* Quarry. A wayside exhibit panel along the Fossil Hill Trail suggests these tracks may have been made by entelodonts.

Chickamauga/Chattanooga National Military Park, Georgia and Tennessee

Nine caves have been documented at Chickamauga/Chattanooga National Military Park (Sanatucci et al., 2001). Many caves are cut into the limestones associated with Lookout Mountain, some of which have entrances outside park boundaries, however, the subsurface features of the caves may extend into the Park. The Bangor Formation (Mississippian) and Mont Eagle Formation are two Paleozoic limestones exposed in the park. Both formations are prominent throughout the park and contain numerous large pits.

Two caves, Kitty City and 27 Spider, are solution caves in the Cumberland Plateau Cave Area. Kitty City Cave has casts of big cat paw prints and claw marks on the walls. Preliminary assessment of the fossil remains suggests the cats apparently fell into the pit, attempted to climb out, and subsequently died. 27 Spider Cave is located three miles (5 kilometers) north/northeast of Kitty City Cave and is the longest cave in the park with a 1,000 foot (305 meter) passage. The lower part of the cave was mapped by the National Speleological Society. 27 Spider Cave contains a large cat skull and vertebral column which are partially exposed in a mud bank. There are also felid canines exposed in the cave wall. In 1995, a large oil spill in the park forced the closure of all of the caves (D. Curry, personal communication, 2001).

Death Valley National Park, California

Death Valley National Park preserves four Cenozoic track localities within its boundaries. All three track localities are preserved within fluvial-lacustrine deposits associated with Cenozoic tectonics that down-

dropped the present day Death Valley and uplifted the Black and Funeral Mountains. Tracks consist of bird and mammal tracks preserved in fine-grained lacustrine sediments usually found associated with shoreline features such as ripples, raindrops and mudcracks.

The most abundant and diverse locality in the Park for bird and mammal tracks is within the Copper Canyon Unit (CCU) where lakeshore deposits preserve twelve *Avipeda*, five *Felipeda*, five *Ovipeda*, three *Hippipeda*, one tridactyl track "cf. *Tapirpeda* n. sp.," (Fig. 8) and one *Proboscipeda* ichnospecies (Santucci and Nyborg, 1999). These tracks are especially important because they represent a diverse fauna of large terrestrial mammals, many of which have no known body counterparts in the immediate area. In addition, the CCU preserves a unique record of lake dynamics in association with animal behavior. The CCU sequence includes over 3000 meters of lake basin sediments. New age constraints taken from three interstitial volcanic flows confirm that the CCU was deposited approximately between 6 to 3 Ma, with track bearing units deposited approximately between 5 to 4 Ma (Nyborg and Buchheim, 2005). Due to the number of tracks, (literally hundreds exposed within the lacustrine facies of the Copper Canyon basin) and over sixty track site localities known thus far, there is a unique opportunity to study the variations among these tracks and track bearers. There is also the opportunity to set a standard for description of mammal tracks in the fossil record.

Within unnamed sediments near Cow Creek very large avian tracks (*Avipeda*), a panel with three carnivore tracks (*Felipeda*) and two types

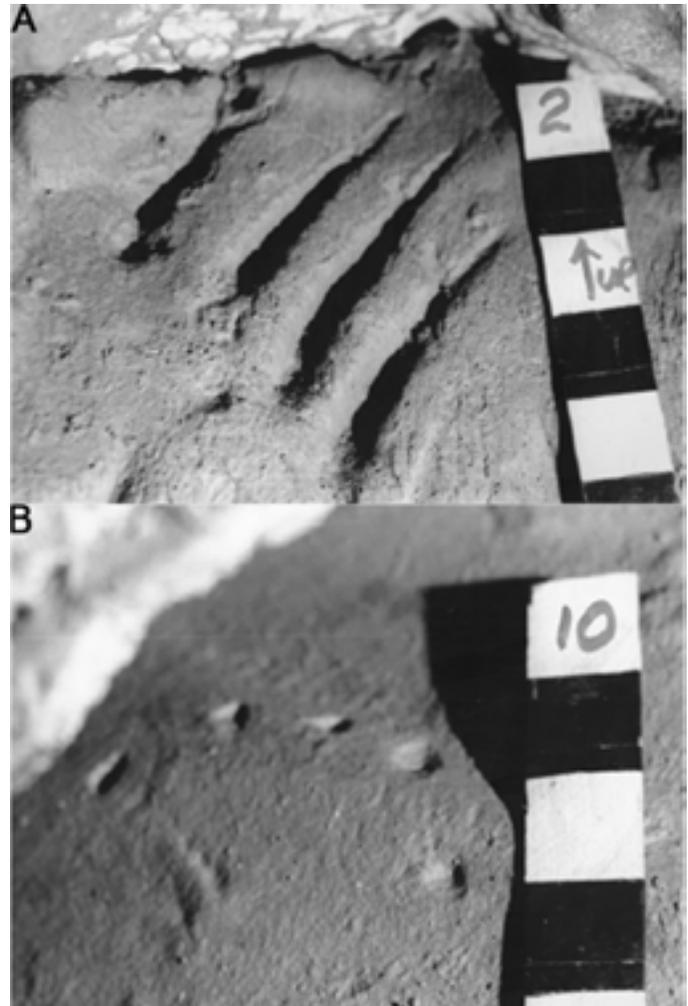


FIGURE 8. Bear claw and scratch marks in cave walls at Oregon Caves National Monument, Oregon.

of artiodactyl tracks (*Ovipeda*) are preserved along several bedding planes representing intermittent fine-grained lacustrine sediments within an overall medium-grained sandstone unit (Santucci and Nyborg, 1999). Although the age of this track locality has not been determined, it appears to be contemporaneous with the Copper Canyon Track Locality due to its similar track fauna.

Also within unnamed sediments an isolated outcrop in the Central Death Valley Playa near Salt Creek preserves avian, artiodactyl, perissodactyl and possible proboscidian tracks (D. Curry, personal communication, 1998). The track-bearing unit is contained within fluvial-lacustrine deposits in an overall conglomerate unit.

Two poorly preserved artiodactyl tracks within lacustrine sediments believed to be associated with the Furnace Creek Formation were collected from Twenty Mule Canyon Track Locality in the 1980s. No additional tracks have been found in this region however this discovery reveals the potential of the region, which is dominated by fluvial-lacustrine deposits.

Cenozoic fossil vertebrate tracks can be found outside of the boundaries of Death Valley National Park however the abundance, diversity and most importantly the quality of preservation of these tracks within the park surpass all other track localities in North America and perhaps the world. The mammal tracks of Death Valley can be biostratigraphically applied, greatly enhancing our knowledge of Cenozoic mammal and bird evolution in southwestern United States and in the reconstruction of the depositional and tectonic history of this playa-lake environment within the context of the Cenozoic basin and fill deposits of Death Valley.

Golden Gate National Recreation Area, California

Hunter et al. (1984) report moderately well preserved bilobate depressions probably formed by split-hoofed ungulates and excellently preserved pawprints probably formed by canids. Claw impressions in some of the tracks reinforce the canid identification.

Oregon Caves National Monument, Oregon

Vertebrate trace fossils have also been documented in Oregon Caves. A single 4.5 inch (11 centimeter) bear paw print is preserved in the cave sediments. There are at least 20 distinct claw scratch marks in the sediments, tentatively identified as bear claws. One such trace is exceptionally preserved, showing five claw points pushed into the mud (Santucci, et al, 2001) (Fig. 8A-B).

TRACKSITE MANAGEMENT AND PROTECTION

Fossil vertebrate tracks and trackways are generally fragile resources and typically studied and maintained *in situ*. Natural conditions and processes, such as weathering, erosion, freeze-thaw temperature changes, will act directly upon surficially exposed *in situ* vertebrate ichnofossils. Such conditions will contribute to the deterioration and eventual destruction of these surficial trace fossils.

Growing scientific and public interest in fossil vertebrate tracksites is paralleled by the increasing documentation of their theft and vandalism. During 2001, over two dozen incidents of either theft or vandalism of *in situ* fossil vertebrate tracks were documented (Santucci, 2002). These incidents range from damages resulting from poor or inappropriate casting techniques to the unauthorized collecting of tracks in units of

the National Park Service. A well-known dinosaur tracksite in a Utah state park was vandalized by members of a Boy Scout group and received considerable national and local media attention. Fossil vertebrate tracks are becoming more visible on the commercial fossil market.

The management and protection of *in situ* fossil vertebrate tracksites has become challenging. Human impacts to vertebrate ichnofossils include incidents of damage or destruction through intentional vandalism, casual theft and systematic theft. Sound management and protection strategies employed for *in situ* fossil vertebrate tracksites include: tracksite inventories, site mapping, photodocumentation, track replication, specimen collection, site stabilization, burial, site closure, construction of maintenance barriers / fencing and a variety of site monitoring strategies.

CONCLUSIONS

Continued paleontological fieldwork and research in National Park Service areas will likely yield new occurrences of fossil vertebrate tracks in the future. A new Cenozoic fossil vertebrate track locality has been identified directly adjacent to the boundary of Lake Mead National Recreation Area. The fossil producing unit is well exposed in Lake Mead and future field inventories may yield the presence of similar vertebrate tracks in the recreation area (M. Kissel-Jones, personal communication, 2003). The Eocene Green River Formation is extensively exposed in Colorado, Utah and Wyoming. Fossil vertebrate tracks, including large concentrations of bird tracks and a few mammal track localities, are known from various nearshore and shallow water facies of the Green River Formation. One possible reptile swimming trace was discovered at Fossil Butte National Monument, Wyoming, and is in the park collection. A bird track slab was discovered in a quarry located just outside Florissant Fossil Beds National Monument. This specimen was on loan and exhibited at the monument for a short time. The specimen is now in the collections at the Denver Museum of Natural History (H. Meyer, personal communication, 2006).

New track localities are also likely to be discovered in parks that these resources are already identified. The extensive exposures of late Paleozoic deposits in Grand Canyon, Mesozoic exposures in Glen Canyon National Recreation Area and the Cenozoic lacustrine track-bearing deposits of Copper Canyon in Death Valley National Park, will all likely yield new vertebrate ichnofossils in the future.

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PLANNING FOR THE FUTURE: A PROGRAM FOR PRESERVING AND INTERPRETING PALEONTOLOGY AND GEOLOGY IN JOSHUA TREE NATIONAL PARK

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Abstract—The Pinto Basin in Joshua Tree National Park is a recognized but largely unexplored site for Quaternary fossil remains. Sediments in this area have yielded abundant but fragmentary Pleistocene vertebrate fossils. Remains consist primarily of isolated dental and distal appendicular elements. Large and small horses and camels are most commonly represented, but specifically diagnostic fossils are rare. New investigations initiated by the San Bernardino County Museum, in cooperation with Joshua Tree National Park and the Joshua Tree National Park Association, focus on renewed recovery and preservation of vertebrate fossils as well as their geologic, stratigraphic and taphonomic contexts. More than 80 fossil localities have been identified since early 2003. Global Positioning System data were acquired for all new localities, for inclusion in the park's digital overlay. New discoveries include remains of *Anas* (duck), *Canis* (wolf-sized canid), *Mammuthus* (mammoth) and *Odocoileus* (deer), as well as probable records of Accipitridae (hawk or eagle), *Lepus* (jackrabbit), *Taxidea taxus* (badger) and *Capromeryx* (dwarf pronghorn), all new records for the fauna. The presence of *Mammuthus* demonstrates a Pleistocene age for the fauna, although previous suggestions of a late Pleistocene (Rancholabrean North American Land Mammal Age) date for the assemblage are not currently supported. Recommendations for future efforts to manage, conserve and interpret fossil resources adequately include the creation of a park-wide paleontology sensitivity overlay, cyclic field inspection, ongoing laboratory analysis, long-term curation in the park and implementation of interpretive programs in paleontology.

INTRODUCTION

Joshua Tree National Park (JOTR) is located in the southern Mojave and western Colorado Deserts, at the eastern extent of the Transverse Ranges (Fig. 1). Established in 1936 as Joshua Tree National Monument, then expanded and redesignated as a national park in 1994, JOTR is bordered by the communities of Joshua Tree and Twentynine Palms to the north, the Coxcomb Mountains to the east, the Cottonwood Mountains and the Eagle Mountains to the south and the San Andreas Fault Zone to the west. The eastern part of JOTR incorporates the Pinto Basin, a large desert drainage bordered and fed by the Pinto Mountains to the north, the Coxcomb Mountains to the east and the Eagle Mountains along the south (Scharf, 1935). Quaternary alluvial sediments, including fossiliferous alluvium, and Tertiary basalts in the region are discussed in this paper.

Fossils, particularly vertebrate fossils, have been among the least understood resources in JOTR. The disciplines of geology, biology and archaeology have all been well represented in studies conducted within the boundaries of JOTR and resources pertinent to those disciplines have been collected, analyzed and preserved. But fossils and the fossil record within the boundaries of JOTR have received comparatively little attention over the past several decades. Further, rather than considering the fossils as significant resources in their own right, these investigations were directed primarily at determining whether or not early humans may have coexisted with Pleistocene megafauna (Campbell and Campbell, 1935; Scharf, 1935).

Paleontological resources are critical for a comprehensive understanding and interpretation of the natural history of JOTR and the significance of its geological, biological and archaeological resources. The study of vertebrate fossils provides data helpful in elucidating the timing of geologic events. Biologically, fossils are important because present-day ecosystems are essentially points in an ecological and evolutionary continuum stretching back thousands and millions of years. Fossils provide a glimpse of ancient environments, providing a unique and irreplaceable perspective on living biological communities. Finally, given that

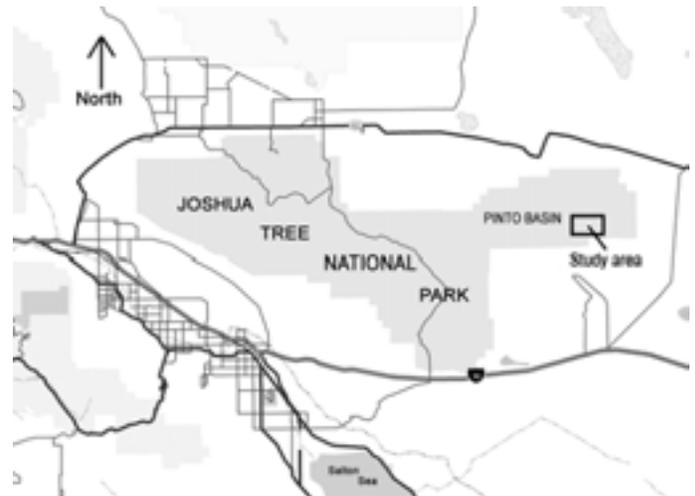


FIGURE 1. Map showing the boundaries of Joshua Tree National Park in southern California. The Pinto Basin and the study area are labeled.

past studies on the archaeology of JOTR suggested that human artifacts were demonstrably associated temporally as well as geographically with extinct Pleistocene megafauna in the Pinto Basin (Campbell and Campbell, 1935; Scharf, 1935), a more thorough study of the megafauna in question, its associated microfauna, and the times at which these animals lived and died would be highly significant.

Section Ia9A of the National Park Service (NPS) Strategic Plan for Fiscal Years (FY) 2001-2005 called for determining the condition of paleontological localities in national parks, requiring that 20% of known localities be in "good condition". As of early 2002, the status of paleontological investigations at JOTR was such that the park could not reach this goal. The full extent of fossil-bearing rock units within the boundaries of JOTR, particularly sediments present in the eastern Pinto Basin, had not been precisely determined. The nature of the fossil fauna from

this region was also poorly understood. Given the abundance and diversity of other large vertebrates elsewhere in the Mojave and Colorado Deserts such as mammoths, ground sloths, dire wolves, sabre-toothed cats, American lions, and bison – not to mention relatively large numbers of rabbits, rodents, squamates, birds, and fish – the fossil record of JOTR required more detailed exploration.

During a visit to the eastern Pinto Basin region in April 2001, NPS vertebrate paleontologist H. Gregory McDonald identified a distal metapodial of a small camel (*?Hemiauchenia*). During a subsequent January 2003 field excursion by San Bernardino County Museum (SBCM), paleontologists located, but did not collect, an additional four localities in a single afternoon. In February of 2003, the SBCM conducted a surface survey for paleontological resources conducted under Federal permit, as part of the JOTR “Geoscientists in the Park” program. More than two dozen previously unrecorded vertebrate fossil localities were found. Fossils recovered ranged from fragmentary to relatively complete, representing animals known from the fossil record of JOTR as well as previously unrecorded taxa.

Based upon this demonstrated paleontological potential, and in keeping with the recommendations of the NPS Strategic Plan for FY2001-2005, the SBCM implemented a detailed paleontological survey and analysis of paleontological resources from JOTR. The new study, conducted in cooperation with the Joshua Tree National Park Association, focused on renewed recovery and preservation of vertebrate fossils as well as their geologic and taphonomic context. The study also included an assessment of the condition of existing collections of fossils previously recovered from JOTR. This focus was proposed to advance the science of paleontology in JOTR as well as to enhance management practices and interpretive activities with the public.

BACKGROUND

The presence of vertebrate fossils in Pinto Basin was first documented by Campbell and Campbell (1935), who briefly mentioned the presence of mineralized vertebrate bones – mainly horse and camel. These authors noted that the fossils appeared to be derived from somewhat older fluvio-lacustrine sediments (named the Pinto Formation by Scharf (1935)) than the cultural materials, but nevertheless proposed that the artifacts and the vertebrate fossils might potentially be coincident temporally as well as geographically. However, paleontologist George T. Jefferson conducted a more focused study of the region in the late 1960s and early 1970s and proposed a depositional hiatus between the cultural deposits and the older bone-bearing fluvio-lacustrine sediments (Jefferson, 1973, 1986). This interpretation suggested that sedimentary surfaces were deflated by eolian processes, bringing Holocene artifacts into apparent association with Pleistocene fossils.

In the Pinto Wash region of the eastern Pinto Basin, Holocene lithic artifacts are found in association with fragmented, wind abraded and occasionally burned bone debris (Jefferson, 1973). These bones represent a relatively modern xeric fauna including *Gopherus* sp. cf. *G. agassizii* (desert tortoise), *Dipsosaurus dorsalis* (desert iguana), *Sauromalus obesus* (chuckwalla), Aves (birds), *Sylvilagus* sp. cf. *S. audubonii* (desert cottontail), *Lepus* sp. (jackrabbit), *Spermophilus* sp. (squirrel), *Neotoma* sp. (wood rat), *Canis* sp. cf. *C. latrans* (coyote), *Vulpes* sp. (fox), *Urocyon cinereoargenteus* (grey fox), *Lynx* sp. cf. *L. rufus* (bobcat) and *Ovis* sp. cf. *O. canadensis* (bighorn sheep) (Jefferson, 1991a). In contrast, the Pleistocene fauna from the Pinto Basin consists primarily of extinct large mammals, particularly equids and camels. These fossils are also fragmented and wind abraded, but are dark in color and frequently heavily permineralized; the latter condition clearly distinguishes many fossil bones from the more recent Holocene bones associated with cultural materials (Jefferson, 1991a).

Pleistocene fossils have been reported (Scharf, 1935; Jefferson, 1973, 1986, 1991a) in generally horizontal, well-bedded claystones, sandstones and siltstones exposed in low bluffs along Pinto Wash. In the

northeastern Eagle Mountains, vesicular basalt layers of Tertiary (Miocene) age (Carter et al., 1987; Trent and Hazlett, 2002) overlie sediments of unknown age. Where in contact with the overlying Miocene flows, these sediments are red in color, indicating a baked zone (Jefferson, 1991a). Previously, the sediments in the northeastern Eagle Mountains were thought to be laterally correlative with the fossil-bearing basin-floor sediments (Jefferson, 1991a). Because the fossils reported from the Pinto Basin date to the Pleistocene Epoch (Jefferson, 1973, 1986, 1991a; this report), the older sediments beneath the Miocene basalts are neither part of, nor do they correlate with the Pinto Formation. As will be demonstrated herein, there are at least three sedimentary packages recognized from the study area: Pleistocene basin-floor fluvio-lacustrine sediments; fossil-bearing alluvial fan sediments perched above the Tertiary basalts; and older, fine- to medium-grained sediments interfingering with and underlying the basalts.

Taxa previously reported from the Pleistocene Pinto Formation include *Equus* sp. cf. *E. conversidens* (extinct small horse), *Equus* sp. (extinct large horse), *Camelops* sp. (extinct large llama-like camel), *Hemiauchenia* sp. (extinct North American llama) and *Ovis* sp. (sheep) (Jefferson, 1991a). As noted by Scott (1997), many of the records of *Equus conversidens* from the Mojave Desert are based upon insufficiently complete or diagnostic fossils, and so several of these records – including those from the Pinto Basin – are better referred to “*Equus* sp. (small)” with no species assignment. Extinct *Bison* has also been reported from the Pinto Basin (Jefferson, 1992), but the sole specimen is a large camelid, likely *Camelops* (Scott and Cox, 2002).

METHODS

The intent of the present study was twofold: to assist JOTR in assessing the paleontological potential of the park and to determine the status of fossils already recovered from the park. Both of these goals accorded with the recommendations of the NPS Strategic Plan for FY2001-2005 regarding fossil resources in national parks. With information provided by this study, management personnel at JOTR would be able to document, preserve and interpret paleontological resources and their geologic context more effectively. Evaluating the percentage of fossils or paleontological localities from JOTR in “good” condition would therefore be accomplished more readily. Further, the ability of JOTR personnel to consider which rock units in the park were likely to yield fossils would be improved. These data would be available in a GIS-based sensitivity overlay for the JOTR resource map.

The SBCM’s initial field survey was conducted in February 2003; several subsequent field efforts were conducted in 2004, 2005 and 2006. New paleontological resource localities were assigned field numbers, described geologically, mapped and photodocumented in the field. Data for each locality were recorded through use of Global Positioning System (GPS) receivers. Taphonomically important positional data were also recorded, particularly the orientation of the fossil(s) relative to magnetic north.

Recovered specimens were cleaned, stabilized and hardened where necessary with Vinac thinned with acetone. The fossils were then housed in the collections of the Division of Geological Sciences, SBCM, stored in standard museum steel geology cabinets and trays. All data pertaining to the recovered fossils were entered into the SBCM’s ARGUS® computer database for permanent storage, including locality information downloaded from GPS receivers into the SBCM’s GIS database. Archival data slips generated from the ARGUS® database are associated with each specimen. The fossils and their data will be transferred to JOTR for permanent storage.

In addition to fossil documentation and recovery, SBCM paleontologists reconsidered the complex geologic relationships of rock units present in the eastern Pinto Basin region of JOTR. Future studies will be directed at establishing the correct relationship between fossil-bearing fluvio-lacustrine beds, alluvial fan deposits and basalt layers and interbedded sediments.

Intermittently during the study, previously collected fossil resources were located, reviewed and photodocumented, again as part of assisting JOTR in meeting the obligations of Section Ia9A of the NPS Strategic Plan for FY2001-2005. To accomplish this task, the SBCM conducted a search of repositories likely to have fossils originating from JOTR in their collections. Institutions consulted included: the Natural History Museum of Los Angeles County (LACM); the Riverside Municipal Museum (RMM); the San Diego Museum of Man (SDMM); the San Diego Natural History Museum (SDNHM); the Southwest Museum, Autry National Center (SWM); and the Museum of Paleontology, University of California, Berkeley (UCMP). These institutions were queried because of their demonstrated or potential involvement with paleontological resources from JOTR. Additionally, the Division of Anthropology at the SBCM was also queried to determine if any paleontological resources might be included in archaeological collections recovered from JOTR.

RESULTS

The renewed field survey confirmed the continued fossiliferous potential of the eastern Pinto Basin region of JOTR. Every field excursion conducted by the SBCM to date has resulted in the identification of additional localities and/or the recovery of additional fossils and most have added previously unrecorded taxa to the fauna.

SBCM paleontologists recovered a total of more than 200 discrete fossil specimens (>2000 total specimens, including fragments) from 48 *in situ* and 33 “float” resource localities. These fossils are presently housed in the collections of the Division of Geological Sciences, SBCM, where additional preparation and analyses are currently underway. Fossils represented were similar to previously published faunal lists for the Pinto Basin (Jefferson, 1973, 1986, 1991a), while four and possibly six previously unrecorded genera – *Anas*, *Canis*, cf. *Taxidea*, *Mammuthus*, *Odocoileus* and cf. *Capromeryx* – were also identified (see “Discussion”).

The surveys to document regional geology had one important consequence: the identification of vertebrate fossils eroding out of alluvial fan deposits along the northern flanks of the Eagle Mountains. These discoveries documented for the first time the presence of significant fossil resources at JOTR from sediments other than the classic “Pinto Formation”. These fossils are currently under study at the SBCM.

SBCM staff photodocumented catalogued fossils and their accompanying data from JOTR in the collections of the LACM. Fossils examined in the collections of the LACM were assigned to five genera: *Gopherus* (desert tortoise), *Equus* (horse), *Camelops* (large camel), “*Tanupolama*” (= *Hemiauchenia*) (llama) and *Bison* (bison). As discussed previously, the fossil assigned to *Bison* (LACM 3414/47255) has been reidentified, and is actually a camelid, likely *Camelops* (Scott and Cox, 2002). Fossils identified to the species “*Tanupolama stevensi*” (LACM(CIT) 208/47358 through 47362) are now referred to the species *Hemiauchenia macrocephala*, as the former species name has been subsumed into the latter (see Kurtén and Anderson, 1980). All of these fossils were derived from two localities: LACM (CIT) 208 and LACM 3414. Field photographs in the collections of the LACM will be helpful in future field investigations for relocating and further delineating these original collecting sites. These data have been provided to JOTR personnel.

SBCM paleontologists also documented vertebrate fossils in the Janish collection from JOTR, housed in the Division of Anthropology at the SBCM. Although these fossils consisted primarily of nondiagnostic large mammal bone fragments, some identifiable fossils of jackrabbit (*Lepus*) and small horse (*Equus*) were present. The bones of *Lepus* include tooth, jaw and limb elements; some of these remains have a relatively modern appearance and their status as fossils is questionable. The remains of small *Equus* include a partial right metatarsal (hind foot) and a left ectocuneiform (ankle bone). Both elements compare favorably

in size with bones of present-day small horses, but are thoroughly mineralized and clearly fossil in nature. All of these fossils remain with artifacts from the Janish collection in the Division of Anthropology, SBCM.

Curatorial staff at the SWM reviewed site records from in and around JOTR to determine if paleontological resources might be present or if archaeological site records might contain mention of bones or teeth. Several records were identified from JOTR that mentioned the presence of bones. It is not known at the time of this writing whether these bones are modern, historic, prehistoric or fossil.

The present review did not locate any fossils from JOTR in the collections of the RMM, the SDMM, the SDNHM or the UCMP.

DISCUSSION

As with previous investigations, and as documented for much of the Mojave Desert (Jefferson, 1991b), camels and horses dominated the Pleistocene fauna from Pinto Basin. Despite a general lack of specific identity, many of the vertebrate fossils were diagnostic to the family or genus level. These identifications not only provided clues as to the nature of the animals represented, but also provided information pertinent to determining the geologic age of the assemblage. This last was an important point to establish. Earlier studies (Jefferson, 1992) suggesting the presence of *Bison* at Pinto Basin implied a later Pleistocene age (Rancholabrean NALMA) for the assemblage, but because the sole fossil assigned to *Bison* from the region is a large camelid, likely *Camelops* (Scott and Cox, 2002), this age assessment cannot be confirmed.

The field surveys in 2003 and 2004 did not yield indisputable index fossils. However, a tooth fragment (JOTR-789-27799) assigned to cf. *Mammuthus* was suggestive of a Pleistocene age, because this genus is exclusively Pleistocene in continental North America (Kurtén and Anderson, 1980; Lundelius et al., 1987; Bell et al., 2004). Additionally, the morphology of equid fossils recovered during these surveys, as well as of equid fossils collected previously and housed at the LACM, was strongly indicative of a Pleistocene age for the fossil assemblage. Equid fossils from several localities exhibited tall, straight cheek teeth, with mesiodistally long protocones on the upper teeth (Fig. 2), characteristic of Pleistocene and later horses. Late Tertiary North American horses such as *Dinohippus* have short, longitudinally curved cheek teeth that are distinctly different from those observed in the sample from the Pinto

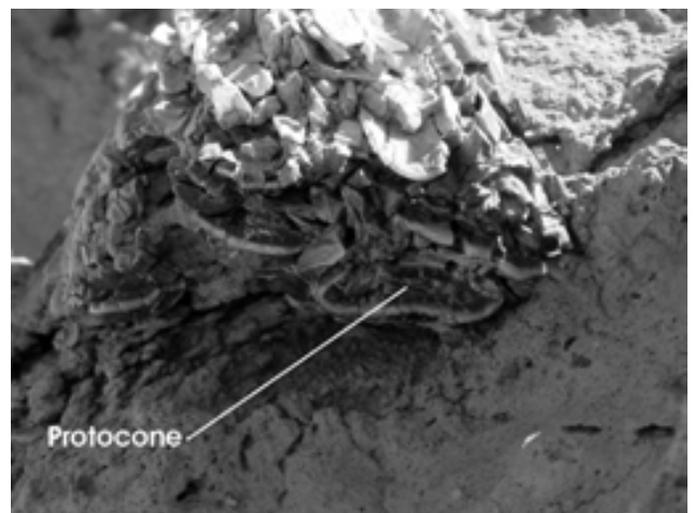


FIGURE 2. Upper left premolar of *Equus* (large horse; specimen JOTR-789-27824) exposed in the field, Joshua Tree National Park, oblique occlusal view. Anterior is to the left. The mesiodistal length of the protocone (labeled) suggests a Pleistocene age for this and associated fossils. Tertiary equids generally exhibit shorter, more rounded protocones. Mesiodistal length of protocone = 19.99 mm.

Basin. Latest Tertiary horses including *Equus (Plesippus) simplicidens* have taller cheek teeth than their forebears, but generally have small, rounded protocones; long protocones are more often a hallmark of Pleistocene horses. The presence of tall, longitudinally straight cheek teeth with mesiodistally long protocones in the horse fossils from the Pinto Basin is strongly suggestive of a Pleistocene age.

The 2005 field survey did result in the recovery of Pleistocene index fossils. Diagnostic molar teeth and associated tusk portions of *Mammuthus* (Fig. 3) were recovered from the "Pinto Formation"; tusk midshaft portions were also recovered from an additional two localities. These finds are highly significant for helping to confirm the Pleistocene age of the sediments.

Remains of extinct mammoths were not the only new records for

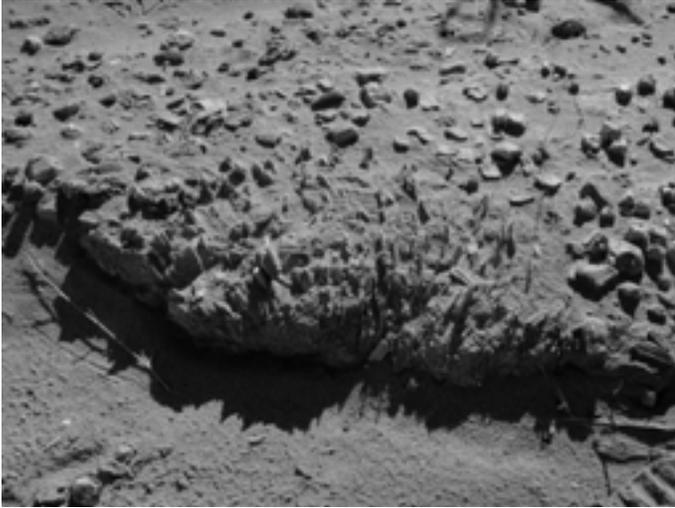


FIGURE 3. Molar tooth of *Mammuthus* (mammoth) eroding out of sediments of the "Pinto Formation", Joshua Tree National Park. The recovery of remains of *Mammuthus* from the "Pinto Formation" confirmed the Pleistocene age of these fluvio-lacustrine sediments. Approximate length of tooth (field estimate) = 36 cm.

the vertebrate fossil fauna. An eroded proximal tibiotarsus (JOTR-789-28371) from float locality SBCM 5.10.33 is assigned to cf. Accipitridae. This avian family encompasses the diurnal birds of prey, including hawks and eagles. Fossils of birds are generally rare in fossil assemblages, because bird bones are often thin, hollow and delicate and do not fossilize well as a consequence. The recovery of bird fossils from the Pinto Basin demonstrates the potential for recovering even very fragile bones from the fossil record of this region. This record and the find of remains of *Anas* mentioned later represent the first records of any bird fossils from the Pinto Basin.

A partial innominate (JOTR-789-27796) from locality SBCM 5.10.25 and a dentary with teeth (JOTR-789-28387) from locality SBCM 5.10.67, are assigned to cf. *Lepus*, the jackrabbit. Although a new record for the Pleistocene record from the Pinto Basin, *Lepus* is abundantly represented in the Holocene fauna from the site. The genus is also common in Pleistocene localities throughout southern California, including the Mojave and Colorado Deserts (Jefferson, 1991b).

A partial carnivoran incisor (JOTR-789-27812; Fig. 4) from locality SBCM 5.10.18, and a carnivoran scapula fragment (JOTR-789-28425) from locality SBCM 5.10.48 were also recovered. The incisor exhibits the dark mineralized color common to Pleistocene fossils from the Pinto Basin and so is interpreted to be a Pleistocene specimen. The tooth closely resembles like elements from large individuals of the genus *Canis*. The tooth is larger than comparable specimens of modern *Canis latrans* (coyote) in the collections of the SBCM and is similar in size to elements of modern wolf (*Canis lupus*). The specimen is not complete and it cannot be determined whether it represents *Canis lupus* or an extinct



FIGURE 4. Incisor of *Canis* sp. (wolf size; specimen JOTR-789-27812) from Joshua Tree National Park, lateral view. This fossil is the first record of Pleistocene carnivorans from the Park. Scale = 1 cm.

wolf such as *Canis armbrusteri* or *Canis dirus*. For the purposes of this study, it is considered "*Canis* sp. (wolf size)". No carnivorans were previously recorded from the Pinto Basin and wolves are extremely rare from the fossil record of the Mojave Desert (Jefferson, 1991b), so this specimen is an important addition to the fossil record of both the local area and the broader geophysical region.

A proximal left radius (JOTR-789-27789) of a small carnivoran, from float locality SBCM 5.10.34, is assigned to cf. *Taxidea taxus* (badger). Badgers have not previously been reported from the Pleistocene fossil record of the Pinto Basin, although they are known from other Pleistocene localities in the Mojave and Colorado Deserts (Jefferson, 1991b). Carnivorans are generally rare in fossil mammalian assemblages, because such these animals are outnumbered by herbivores in biological communities. The recovery of the remains of both wolf-sized canid and badger from the fossil record of the Pinto Basin is therefore important in documenting the potential richness of the fauna.

A distal right humerus (JOTR-789-28383), also from float locality SBCM 5.10.40 is assigned to the genus *Odocoileus* (deer). This genus is not previously recorded from the fossil record of the Pinto Basin. Fossils of deer have been reported from elsewhere in the Mojave and Colorado Deserts, although these remains are usually less common than those of larger mammals such as horse, camel and mammoth (Jefferson, 1991b).

A left naviculocuboid (JOTR-789-28405) and a fragment of mesoectocuneiform (JOTR-789-28406) of a very small artiodactyl were

identified from locality SBCM 5.10.64. These elements resemble the dwarf pronghorn genus *Capromeryx* in size and morphology and are assigned to cf. *Capromeryx* for this reason. *Capromeryx* has not previously been reported from the Pinto Basin.

The fossils recovered during the field survey were generally found as isolated elements, an observation in agreement with previous studies (e.g., Jefferson, 1973, 1986). However, locality SBCM 5.10.21 yielded several bones and bone fragments from a single individual of juvenile small camel. This important finding suggests that other localities as yet unexposed and/or unrecognized in the eastern Pinto Basin region may also have potential to yield significant concentrations of fossils rather than isolates. Re-examination of this locality in early 2006 resulted in the recovery of multiple fossils of *Anas*, another new record for the vertebrate fauna, as well as a fragment of mammoth tooth.

The confirmation of a Pleistocene age for the vertebrate fauna necessitates a continuing re-evaluation of the relationship of the fossil-bearing “Pinto Formation” to the basalts and underlying sediments exposed in the Eagle Mountains to the south (Fig. 5). As stated previously, earlier studies (Scharf, 1935; Jefferson, 1971, 1991a) proposed that the “Pinto Formation” deposits “interdigitate with vesicular basalt flows” (Jefferson, 1991a), with baked sediments underlying the basalts. Because these basalts were originally interpreted to be Pleistocene in age (Hope, 1966), this relationship was not questioned. However, more recent studies (Carter et al., 1987) proposed an age of approximately 7.8 Ma (Late Miocene) for the Eagle Mountain basalts, substantially predating the Pleistocene (beginning approximately 1.8 Ma). The confirmation of a Pleistocene age for the vertebrate fossils from the “Pinto Formation” demonstrates that this unit is not laterally continuous with those sediments interfingering with, and underlying, the basalts.

Field examination by the SBCM in 2004 and 2005 distinguished



FIGURE 5. Aerial view of the eastern Pinto Basin and northeastern Eagle Mountains, Joshua Tree National Park. The sediments discussed in the text and their approximate spatial relationships are labeled. Base map courtesy United States Geological Survey.

at least three sedimentary units in the Pinto Basin and northeastern Eagle Mountains: 1) fluvio-lacustrine beds in the Pinto Basin floor; 2) uplifted and dissected fossil-bearing alluvial fan deposits, overlying Tertiary basalts, in the Eagle Mountains; and 3) uplifted sediments stratigraphically below the basalts in the Eagle Mountains (Fig. 6). The lateral relationship of the sediments above the basalts to the fluvio-lacustrine beds in the basin floor has yet to be resolved.

The stratigraphic position of the sediments below the Tertiary basalts demonstrates that they are a separate lithologic unit, predating the Pleistocene and having a different depositional history. Sampling to determine the fossil-bearing potential of these older sediments is planned

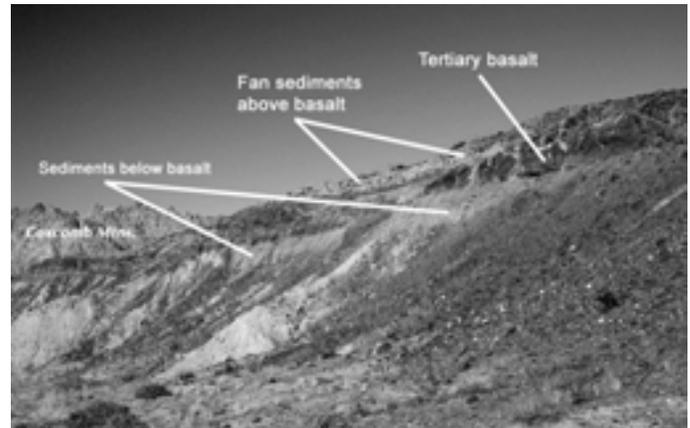


FIGURE 6. Tertiary basalts exposed in arroyos in the northeastern-most Eagle Mountains, Joshua Tree National Park. The presence of sediments perched atop the basalts, as well as older sediments below the flows, are clearly visible. View is north-northeast, with the Coxcumb Mountains in the distance.

for future field excursions. Further biostratigraphic and geologic mapping are warranted in this area to establish definitive corroboration of these field observations.

These findings are important for advancing scientific inquiries, in geology and paleontology – both regionally and throughout the Mojave and Colorado Deserts – as well as in regional archaeology and biology. These findings are also highly significant for helping JOTR effectively manage and accurately interpret its increasingly rich paleontological record. Management personnel will benefit from knowing where fossils occur and in what geologic context. The determinations advanced herein – that more sedimentary packages are present in the eastern Pinto Basin that have been previously recognized, that these sediments yield fossils from more areas that have been earlier explored and that these span a greater range of geologic ages that previously thought – enables resource managers to more effectively plan for the recovery and conservation of fossil remains.

Interpretation of natural resources is an important component of public outreach for any national park or monument. This interpretation requires accurate and up-to-date information on those resources in order to be truly effective, which is facilitated by both ongoing field studies and continuing review of available, carefully conserved natural history collections. The present study provides a wealth of data illustrating this point effectively. For example, the reidentification of remains assigned to *Bison* from the Pinto Basin as a large camelid (Scott and Cox, 2002), based upon a review of available collections, necessitated a reconsideration of the age of the fossils from the region. The field examinations demonstrating that the known fossil-bearing sediments from JOTR were not laterally continuous with sediments located stratigraphically below Tertiary basalts effectively rejected interpretations that the fossils were necessarily of Tertiary age, while the recovery of definitive remains of *Mammuthus* from the basin floor “Pinto Formation” confirmed a Pleistocene age for the fossils (although not necessarily a late Pleistocene age). All of these data are critical for correctly interpreting the geologic and paleontological history of JOTR and conveying those interpretations to the general public. Park personnel can now explain to interested park visitors that the known fossils from JOTR are of Pleistocene age, that the fossil record from the region is much richer than previously documented, that records of *Bison* previously on the books are in error, that mammoths were present in the region, that fossils are now known from more areas in the Pinto Basin that previously recognized and that more sedimentary packages remain to be explored for fossil remains. All of these findings will help JOTR interpretive personnel provide accurate information to park visitors, which in turn will foster a deeper apprecia-

tion of the natural history of JOTR as well as of the importance of both responsible collection and careful conservation of park resources.

CONCLUSIONS

Recent paleontological investigations in JOTR by the SBCM have focused on further documenting the nature and extent of resources and fossiliferous outcrops within the boundaries of the park, including both new field excursions and examination of existing collections. The field studies have confirmed the continued fossil-bearing potential of the "Pinto Formation" in the eastern Pinto Basin region of JOTR and have firmly established a Pleistocene age for the fossil assemblage with the identification of *Mammuthus*. These studies have also demonstrated that the full paleontological potential of this region remains to be tapped; short-term field surveys yielded taxa not only previously unrecognized from the fauna (*Anas*, cf. *Accipitridae*, cf. *Lepus*, *Canis*, cf. *Taxidea taxus*, *Mammuthus*, cf. *Capromeryx*), but also multiple elements from single individuals – a finding suggesting that more complete remains may be present in the subsurface. Additionally, previously unrecognized fossil-bearing dissected fan sediments along the southern border of the Pinto Basin were identified; these sediments, as well as the fluvio-lacustrine "Pinto Formation" require fuller exploration and mapping. The examinations of existing collections assessed and documented the condition of previously recovered fossil remains. Previously unrecognized vertebrate fossils were also identified in archaeological collections.

The data generated by these studies will enable JOTR personnel

to better document, manage, conserve and interpret fossil resources present in the park. Future studies by the SBCM in JOTR will focus on more detailed geologic mapping throughout the park, on further delineation of the nature and extent of fossil-bearing sediments in and around the Pinto Basin, on recovery and conservation of fossils exposed in the park and on comparing these data in the broader framework of Pleistocene vertebrate faunas throughout the Mojave Desert.

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THE NEW MEXICO MUSEUM OF NATURAL HISTORY AND SCIENCE GEOSCIENCE COLLECTION: AN OVERVIEW

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Abstract—The New Mexico Museum of Natural History and Science (NMMNH&S) has an important and extensive collection of fossils that has served as a resource for students and researchers from around the globe. The most scientifically significant portions of the collection are the NMMNH&S holdings of Permian tracks, Late Triassic vertebrates and Paleocene mammals, all of which are world-class collections. Ongoing projects include collaborations with the Bureau of Land Management (BLM) for the excavation of New Mexico's only Morrison Formation bonebed, the Peterson Quarry, and the integration (with BLM support) of portions of the orphaned University of Arizona fossil vertebrate collection into the NMMNH&S collection. Recently, the wealth of information on the NMMNH&S fossil collection has reached beyond its' walls and is now available to anyone via a searchable online database.

INTRODUCTION

The New Mexico Museum of Natural History and Science (NMMNH&S) began a fossil collection in 1983, and fossils continue to be collected by museum staff, scientific associates and volunteers to this day. Over the years the collection has grown to become one of the most important collections of fossils in the United States, with certain portions of the collection, most notably the Permian tracks, being among the scientifically most significant such collections in the world. Here, we summarize the holdings of the NMMNH collection, its strengths, its layout and note its current long-term projects.

MISSION STATEMENT

The mission of the NMMNH&S geoscience collection reads as follows: "To protect and provide access to fossil and mineral specimens from state and federal lands in New Mexico, the American Southwest, and beyond". The NMMNH&S mission explicitly states that the Museum "pursues scientific inquiry, [and] develops focused collections..." The geoscience collections are a "three-dimensional library of the history of life in New Mexico."

COLLECTION LAYOUT

The NMMNH&S geoscience collection is housed in a separate building (referred to as the "Annex") from the museum proper and the public exhibits. Along with the collection, the Annex currently contains portions of the education and exhibits departments, the primary fossil preparation lab and the various paleontology curators and geoscience staff offices. The collection itself is a large (~6,500 ft²) temperature- and climate-controlled room that is only accessible via limited keypad access (Fig 1).

The collection is divided into three sections based on the storage needs of the specimens: the oversize shelving, track shelving and cabinets (Fig 2). The oversize shelving is heavy-duty steel shelving that can support thousands of pounds and is used for any specimens that are too large to fit comfortably in the available cabinetry. Specimens on the oversize shelving are arranged by geological time interval and are spaced for ease of viewing and removal (Fig. 2A). The track shelving is also open metal shelving and is used for housing the small to medium-sized track slabs. These tracks are also arranged by geological time interval and are spaced closely together to allow for maximum storage. In order to aid researchers in navigating the track sites a number of labels have been placed on the shelving to make locating a locality or specimen as easy as possible (Fig 2B). The cabinetry is used to house the majority of the collection specimens (Fig. 2C). Each cabinet is filled with drawers and in

each drawer is a number of archival trays that house the specimens. Each specimen is accompanied by a computer-generated label with its basic catalogue information.

VARIETY OF SPECIMENS AND LOCALITIES

The NMMNH&S collection began in 1983, three years prior to the opening of the Museum building. Since 1983, the collection has grown considerably, currently including over 50,000 specimens from 6,700 fossil localities. Thus, the NMMNH has averaged over 2,100 new specimens and over 290 localities catalogued each year. Most of these specimens (~80%) and localities (~90%) are from New Mexico, with the rest coming from Texas (~5% of specimens and ~1% of localities), Arizona (~1% of specimens and ~2% of localities), other areas of the United States and a handful of international specimens and localities.

The NMMNH&S collection contains a diverse array of specimens ranging in size from the dorsal block of the holotype of *Seismosaurus hallorum*, which is a 2.3 m x 1.5m x 1.0 m block containing a partial dorsal series of vertebrae that weighs 11,600 lbs, to various tiny mammal teeth that each fit easily on the head of a pin. Fossil mammals are the largest class of specimens represented in the collection (over 18,000 specimens representing ~37% of the collection), followed by reptiles (over 11,000, ~23%), invertebrates (over 6,000, ~12%), trace fossils (over 4,500, ~9%), osteichthyans (over 2,000, ~4%), chondrichthyans (over 1,100, ~2%), Plants (over 600, ~1%) and birds (~90, ~2%).

The NMMNH&S localities are no less diverse with localities ranging from sites where a handful of bone fragments were surface collected to sites like the Peterson Quarry, where excavations have been ongoing for nearly two decades. The Cenozoic is the best-represented Era in the locality catalogue (with over 3,100 localities, ~47% of all localities catalogued) followed by the Mesozoic (over 2,900, 45%), the Paleozoic (over 480, ~7%) and miscellaneous localities (~1%). Among geologic time intervals, the Paleogene is the best represented in the locality catalogue (with over 2,090 localities, ~31% of all localities catalogued) followed by the Cretaceous (over 2,000, ~30%), Triassic (~900, ~13%), Neogene (over 800, ~12.5%), Permian (over 280, ~4%), Pennsylvanian (over 130, ~2%), Jurassic (over 70, ~1%), Mississippian (14, ~0.2%), Devonian (13, ~0.2%), Ordovician (5, ~0.07), Cambrian (3, ~0.04%) and Silurian (1, ~0.01%).

COLLECTION STRENGTHS

While the entirety of the geoscience collection is routinely being studied by both NMMNH&S curators and visiting researchers, three portions of the collection deserve special mention for their world-class

GUIDE TO THE NMMNH&S GEOSCIENCE COLLECTION

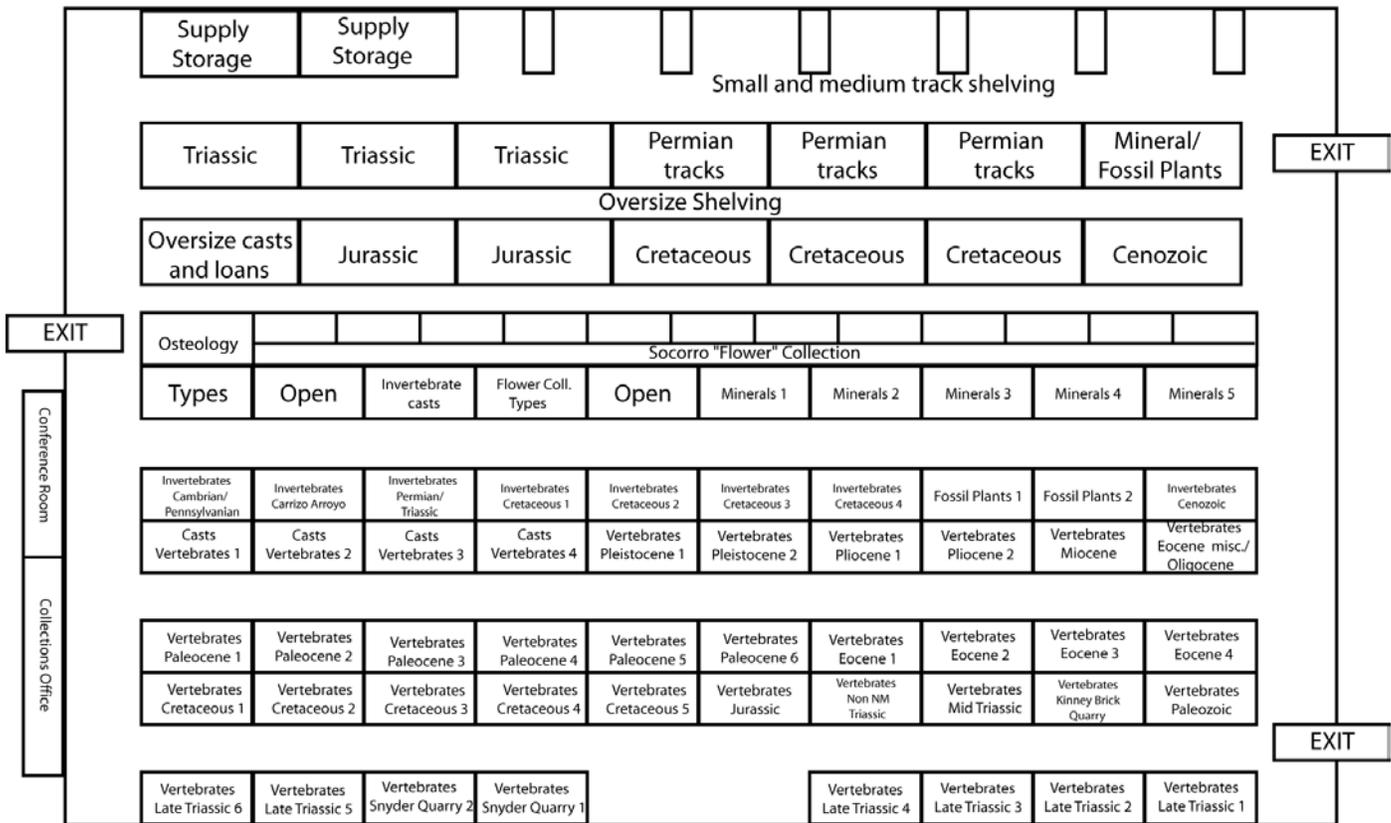


FIGURE 1. Schematic guide to the NMMNH&S geoscience collection.

status and ability to attract researchers from around the globe. These are the Permian track collection, the Late Triassic vertebrate collection and the Paleocene mammal collection.

Permian Track Collection

The holdings of Permian tracks in the NMMNH&S collection represent the largest single collection of Permian tracks in the world. Nearly all of these tracks come from localities in the Robledo Mountains of southern New Mexico (Fig. 3). Many of the track slabs from these sites preserve numerous extensive trackways on a single surface. The exquisite preservation of these tracks show numerous amphibians and early reptiles traversing a variety of substrates. Because of the quality of preservation and copious amounts of tracks, the Robledo Mountains localities have been referred to as a “Rosetta Stone” for understanding Permian tracks. This collection served as the impetus for major revisions of ichnotaxonomy, including boiling down over 100 different poorly down ichnotaxa to approximately a dozen well-understood ichnotaxa.

Late Triassic Vertebrates

The Late Triassic vertebrates in the NMMNH&S collection come from New Mexico, Arizona and Texas. These specimens include everything from partial and nearly complete skeletons of phytosaurs, aetosaurs and early theropod dinosaurs to a variety of microfossils recovered from screenwashing sites. The extensive collections made by the NMMNH&S helped serve as the basis for curators and staff here at the museum establishing the land vertebrate faunachron (lvf) system for dividing Late Triassic time using vertebrate fossils, a system that is recognized worldwide.

Highlights of the Late Triassic collection include: *Adelobasileus*, the oldest known mammal; a fully prepared block from the Ghost Ranch

Coelophysis quarry containing a complete three dimensionally preserved *Coelophysis* skull with sclerotic ring; and an extensive collection of material from the Snyder Quarry, an assemblage caused by a paleowildfire and including over a dozen skulls of the phytosaur *Pseudopalatus buceros* (Fig. 4).

Paleocene Mammals

The Paleocene mammal collection consists predominantly of microfossils, especially teeth, from the San Juan Basin of northwestern New Mexico. These mammal fossils represent some of the first mammals to repopulate the North American landscape following the extinction of the dinosaurs. The collection is copiously documented and thus serves as a primary basis for understanding the North American Puercan and Torrejonian land mammal “ages.”

ONGOING PROJECTS

At any given time dozens of projects are being undertaken on the NMMNH&S collection, however, two projects deserve special attention: the excavation, preparation and study of the Jurassic Peterson Quarry and the integration of the University of Arizona collection.

The Peterson Quarry

The Peterson Quarry is New Mexico’s most prolific, and currently only active, Morrison Formation bonebed. Since 1989, the Peterson Quarry has been excavated by NMMNH&S volunteers, including Ronald and Rodney Peterson, the original discoverers of the quarry, who collectively have spent over 6,000 hours excavating the quarry. The quarry itself is located on land administered by the Bureau of Land Management (BLM). The BLM, notably BLM paleontologist Patricia Hester, has been instrumental in assisting the NMMNH&S with permitting and



FIGURE 2. Fossil storage in the NMMNH&S geoscience collection. **A**, oversized shelving, **B**, track shelving and **C**, specimen cabinets.

logistical support needed for such a large and long-term excavation. The flow of information has been reciprocal with the BLM advising the NMMNH&S on how best to remove the fossils while maintaining the integrity of the surrounding landscape, and the NMMNH&S removing, preparing, studying and publicizing the specimens from this important quarry. Currently, one of the major specimens from the site, a partial skeleton of the theropod *Saurophaganax*, is on display in the Jurassic

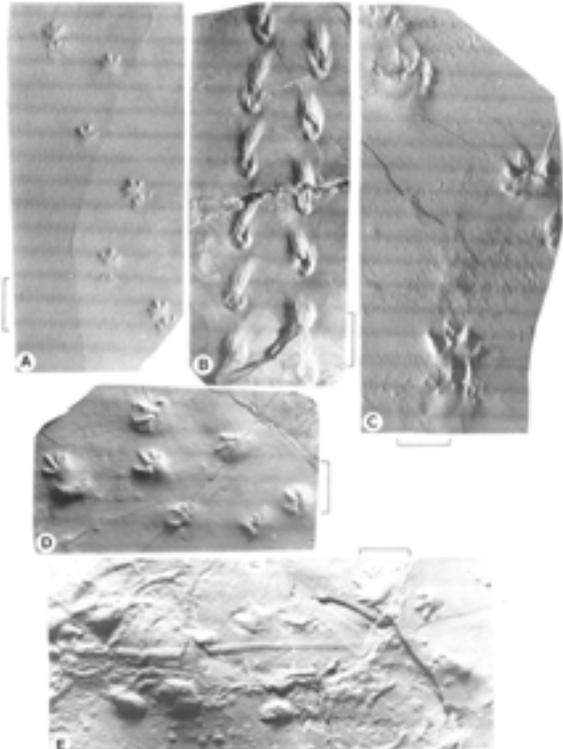


FIGURE 3. Examples of Permian tracks collected from the Robledo Mountains housed in the NMMNH&S geoscience collection. From Hunt et al., 1995.



FIGURE 4. A phytosaur skull (NMMNH P-31292) from the Late Triassic Snyder Quarry. From Zeigler et al., 2002.

Hall of Supergiants at the NMMNH&S.

The Integration of the University of Arizona Collection

In the late 1970s and early 1980s the University of Arizona in Tucson had an active field paleontology and research program in the San Juan Basin, New Mexico. This fieldwork included collecting Cretaceous dinosaurs and Paleocene and Eocene mammals. Unfortunately, as the priorities of the University shifted away from the paleontology collection all the specimens, including the fossils collected from New Mexico, were kept in storage spaces that were not conducive to their study or long-term preservation. Thus, with the administrative and financial as-

sistance of the BLM, the NMMNH&S was able to have the New Mexico portion of the University of Arizona collection transferred to the NMMNH&S. The physical moving of over 10, 000 specimens from Tucson to the NMMNH&S in Albuquerque took place in the fall of 2005. Since the initial move, the UA collection has been systematically catalogued into the NMMNH&S database, including retaining all the original UA specimen numbers in our database for cross-referencing purposes. The process of integration is ongoing, as the collection is currently being physically integrated into the existing collection. This integration is being accomplished with the aid of BLM funding, which was used to purchase additional collections cabinets and specimen trays for the curation of this large influx of specimens. At the current pace, the UA collection should be entirely catalogued and integrated into the NMMNH&S collection by the end of May 2006, less than nine months after the initial transfer.

ONLINE DATABASE

The latest innovation to the NMMNH&S collection is the ability of our specimen database to reach out and have an internet presence. In late 2003, www.nmfossils.org was launched which included a

link to a searchable version of the NMMNH&S fossil database, under the "Paleo-Database" link. This database provides specimen numbers, descriptions and taxonomic information for nearly all the specimens housed at the NMMNH&S. The search engine allows a varied array of search types, including searches by New Mexico county, by any of the major taxonomic groups, by time period, etc. Accompanying the information are illustrations and over 2,000 photographs of actual fossil specimens. This tool is useful not only for researchers who are preparing for a visit to our collection but also to any New Mexicans who are curious about what can be found in their own backyards.

CONCLUSION

The NMMNH&S geoscience collection is one of the significant fossil collection in the United States and has many specimens that are world-renowned. Various ongoing projects are adding to the collections' utility and depth on a daily basis. And, while the physical collection is available to aid all collection visitors in locating specimens and data, with the advent of the internet version of the NMMNH&S paleo database, the physical building is no longer the only source for information on New Mexico's fossil record.

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AH-SHI-SLE-PAH WILDERNESS STUDY AREA (SAN JUAN BASIN, NEW MEXICO): A PALEONTOLOGICAL (AND HISTORICAL) TREASURE AND RESOURCE

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Abstract—The Ah-shi-sle-pah Wilderness Study Area ranks as one of the most important regions in the San Juan Basin for Late Cretaceous vertebrates from both a scientific and historical viewpoint. The venerable field paleontologist Charles H. Sternberg collected the holotype skull (PMU.R200) of *Pentaceratops fenestratus* and a post-cranial skeleton with lower jaws (PMU.R268) from the south branch of Ah-shi-sle-pah Wash (formerly Meyers Creek). These and numerous other fossil vertebrates collected by C. H. Sternberg were sold to the University of Uppsala, Sweden in the early 1920's. More recently, this region has been intensively collected by field crews of the State Museum of Pennsylvania, which have recovered 280 specimens of fossil vertebrates (fishes, turtles, crocodilians and dinosaurs), along with invertebrate and plant specimens, from numerous sites (many of them new) in the upper Fruitland (Fossil Forest Member) and lower Kirtland (Hunter Wash Member). The fossil vertebrates from these strata comprise the Hunter Wash local fauna, which are characteristic of early Kirtlandian time.

INTRODUCTION

The Ah-shi-sle-pah Wilderness Study Area (WSA), San Juan Basin, New Mexico (Fig. 1) is located about 80 kilometers south of Farmington, New Mexico and 3.2 kilometers north of Chaco Culture National Historic Park. It takes its name from the principal drainage, Ah-shi-sle-pah Wash (formerly Meyers [Meyer's] Creek), which drains to the southwest where it becomes confluent with the Chaco River. The Ah-shi-sle-pah WSA consists of 6563 acres of public land, which was initially set aside for wilderness consideration in November 1979 and has since been deemed as non-suitable for Wilderness designation. The Navajo Nation has selected approximately 3094 acres of the Ah-shi-sle-pah WSA as part of an exchange for lands relinquished in the Navajo-Hopi relocation settlement. The final disposition of the land has not been acted upon by Congress. The lands that have been selected by the Navajo Nation contain some of the most important paleontological sites in the San Juan Basin, both from a scientific and historical perspective.

The Ah-shi-sle-pah WSA was first collected by Charles H. Sternberg in early 1921, and specimens from this area form a significant part of the fossil vertebrate collection at the Museum of Evolution, University of Uppsala, Sweden (PMU). The WSA has been intermittently collected between 1924 and 1995, with a brief surge in 1977 as the result of a paleontological survey for the BLM (Kues et al., 1977). This survey documented the paleontological importance of the region, assessing it as an area "where substantial mitigation is essential." It has since been collected by field crews from the New Mexico Museum of Natural History and Science (NMMNH) and The State Museum of Pennsylvania (SMP) over the last 20 years. Intensive collecting has been accomplished by the latter institution over the last decade. To date, 280 specimens of fossil vertebrates from Ah-shi-sle-pah WSA have been collected and catalogued into the collections of the State Museum of Pennsylvania. Many of these specimens are significant and are presently being studied.

The purpose of this paper is to: (1) discuss the historical significance of the Ah-shi-sle-pah WSA in the annals of American vertebrate paleontology; (2) record the current collecting and research being conducted by the State Museum of Pennsylvania (Harrisburg); and (3) discuss the scientific importance of this paleontological resource.

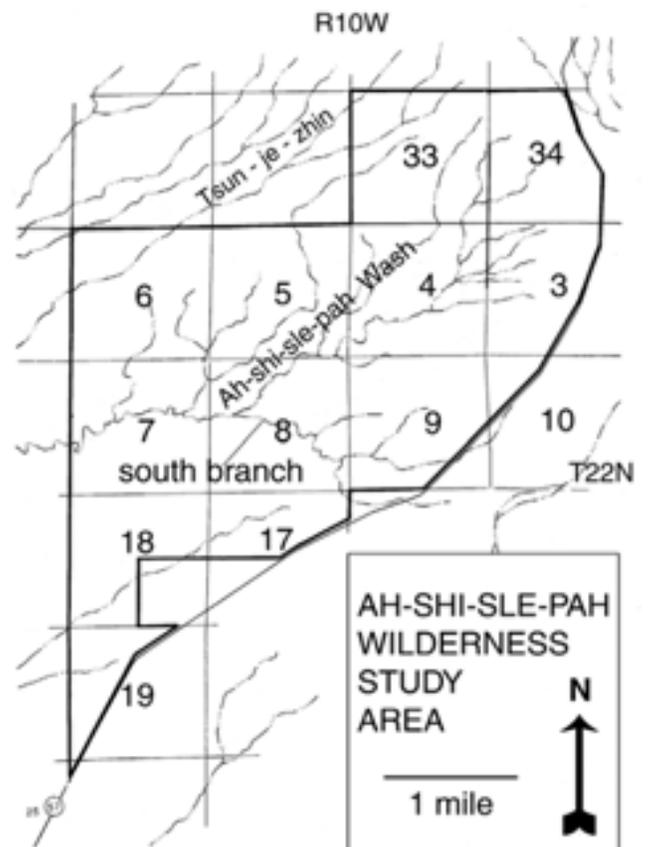


FIGURE 1. Map of Ah-shi-sle-pah Wilderness Study Area, San Juan Basin, New Mexico.

Geology

Strata within the Ah-shi-sle-pah WSA include most of the upper Fruitland Formation (Fossil Forest Member) and lower part of the Kirtland Formation (Hunter Wash Member). As such, the area is one of the few places in the San Juan Basin where the contact between the two forma-

tions is visible. The contact is placed at the base of the Bisti Bed (Lucas et al., 2006), a persistent sandstone complex that crops out locally (Fig. 4A-B). The strata are dominated by mudstones and intermittent sandstones and occasional resistant channel sandstones.

The Sternberg Years (1921-1924)

The well-known fossil collector and field paleontologist Charles H. Sternberg (Fig. 2) collected fossil vertebrates from the Fruitland, Kirtland and Ojo Alamo formations beginning in the summer of 1921 and ending in 1924. Among his important discoveries during this period were three nearly complete skulls, an incomplete frill and postcranial skeleton of *Pentaceratops* from various localities within the San Juan Basin.

In 1921, Sternberg collected the holotype of *Pentaceratops fenestratus* (PMU.R200) and the postcranial skeleton (PMU.R268), and both were sold to the University of Uppsala. In 1922, Sternberg collected the holotype of *P. sternbergii* (AMNH 6325), presumably from what is now referred to as the Fossil Forest (Hunt, 1991). In early June of 1923, Sternberg discovered another skull (AMNH 1624), subsequently referred to as *P. sternbergii*. A fourth specimen, AMNH 1625 (nearly complete frill, consisting of the posterior part of the parietal and right squamosal) was discovered later that same month. Unfortunately, the provenance of both AMNH 1624 and AMNH 1625 is not known.

Sternberg (1932) reported that he discovered the crushed skull of *Pentaceratops fenestratus* (PMU.R200) "in a bit of badlands" 1 mile south of Mr. Tyler's (at Kimbeto Wash). Wiman (1930) and Lull (1933) recorded the locality of this specimen as "1 mile south of Kimbetoh Wash, on the south branch of Meyers Creek..." Rowe et al. (1981, p. 32) re-assessed the locality data based on Wiman's and Lull's papers and concluded that the holotype *P. fenestratus* was collected from the Kirtland Formation "one mile (1.6 km) north of Kimbeto Wash, on the south branch of Ah-shi-sle-pah Wash (Meyers, Wash)." This would probably have been from either sections 8 or 9 (T22N, R10W) as this area is known to produce fossils, near the site of Sternberg's last camp of 1921 (on the south branch of Meyers Creek) and other collecting localities. Mateer (1981) reported that the postcranial skeleton of *Pentaceratops* (PMU.R268) was recovered from T22N, R11W. However, based on his autobiographical account (Sternberg, 1932), it is all but certain that the postcranial skeleton came from near Sternberg's "hoodoo locality" described below. Consequently, this places the site of PMU.R268 (Fig. 2)



FIGURE 2. Charles Sternberg collecting the *Pentaceratops* skeleton (PMU.R268) in Ah-shi-sle-pah Wash (Meyer's Creek) in 1921. The photograph was taken by Wesley Bradfield, a photographer from the American School of Research of Santa Fe. He spent part of the day with C. H. Sternberg documenting his collecting in Ah-shi-sle-pah Wash. The photograph was originally published in Sternberg (1932).

in the same township and range, also on the south branch of Ah-shi-sle-pah Wash. Indeed, a survey of the fossils collected by Sternberg and sold to the University of Uppsala show that many of the specimens were collected in this area.

VERTEBRATE FOSSIL LOCALITIES

To date, 19 regional fossil localities have been identified within the Ah-shi-sle-pah WSA by the State Museum of Pennsylvania. These localities vary in size, and each has been given name and assigned a locality number with their respective borders outlined on a master 7.5 minute USGS topographic map (Pueblo Bonito NW). At the end of each field season a duplicate map is made plotting each specimen (by hand for specimens collected prior to 2000; GSP coordinates [UTMs] for specimens collected from 2001 and beyond). Below is a brief list by locality of some of the more important specimens that have been recovered from within the Ah-shi-sle-pah WSA.

Fruitland Formation (Fossil Forest Member)

Bob's Bloody Bluff and Bob's Bloody Bluff (North Side) (SMP Localities 396 and 401)

Bob's Bloody Bluff (Fig. 3A) is prominent mesa capped by the Bisti Bed of the Hunter Wash Member (Kirtland Formation). The underlying stratum is the upper Fruitland Formation (Fossil Forest Member). On the west side of the bluff are the sites of Eagle's Nest and Eagle's Nest Flat; and to the north are Bob's Bloody Bluff (north side) (locality 401) and to the east Bob's Microsite (locality 409). Some of the more significant fossils collected from Bob's Bloody Bluff (locality 396) include: SMP VP-1592, nearly complete right maxilla with teeth (cf. *Kritosaurus navajovius*); VP-1623, a nearly complete (indeterminate) hadrosaurid femur; and VP-1685, incomplete xiphilastron (*Plastomenus* sp.). From Bob's Bloody Bluff (north side) (locality 401): SMP VP-1619, incomplete right humerus (cf. *Parasaurolophus crytocristatus*); and VP-1621, incomplete osteoderm (Ankylosauridae indet.).

Eagle's Nest/Eagle's Nest Flat (SMP localities 397 and 398)

Eagle's Nest was named for the abandoned eagle's nest resting atop a pinnacle on the west side of Bob's Bloody Bluff (Fig. 3B). The nest sits on the capping Bisti Bed. The site of Eagle's Nest is immediately to the east of the base of the pinnacle, in a cul-de-sac of the bluff. Numerous weathered skeletal elements were visible, but only diagnostic specimens were collected. Eagle's Nest Flat is a vast flat surface that extends out from the west side of the bluff and Eagle's Nest (Fig. 4b). The flat is largely a lag deposit.

From Eagle's Nest (locality 397): SMP VP-1658, two isolated tyrannosaurid teeth (cf. *Daspletosaurus* sp.).

From Eagle's Nest Flat (locality 398): SMP VP-1669, incomplete crocodylian scutes and frags; VP-1593 (Fig. 3C), nearly complete pes phalanx (cf. *Daspletosaurus* sp.); VP-1596, skull fragments, including the distal end of a quadrate, partial ?jugal, fragments of epoccipitals (cf. *Pentaceratops sternbergii*); VP-1598 and 1605, isolated teeth of *Myledaphus bipartitus*.; VP-1610, carapace of cf. *Denazinemys nodosa*; VP-1662, upper margin of right maxilla (cf. *Kritosaurus navajovius*); VP-1664, distal end of a metatarsal (cf. Ornithomimidae indet.); VP-1667, incomplete nuchal, right and left xiphiplastra and associated fragments (*Plastomenus robustus*); and VP-1668, nearly complete plastron, carapace fragments (*Denazinemys nodosa*).

Bob's Microsite (SMP locality 409)

Bob's Microsite is a rich microsite that has yielded fish (scales and teeth), turtle, crocodylian (osteoderms and teeth) and dinosaur remains. It is located northeast of Bob's Bloody Bluff. Some of the more

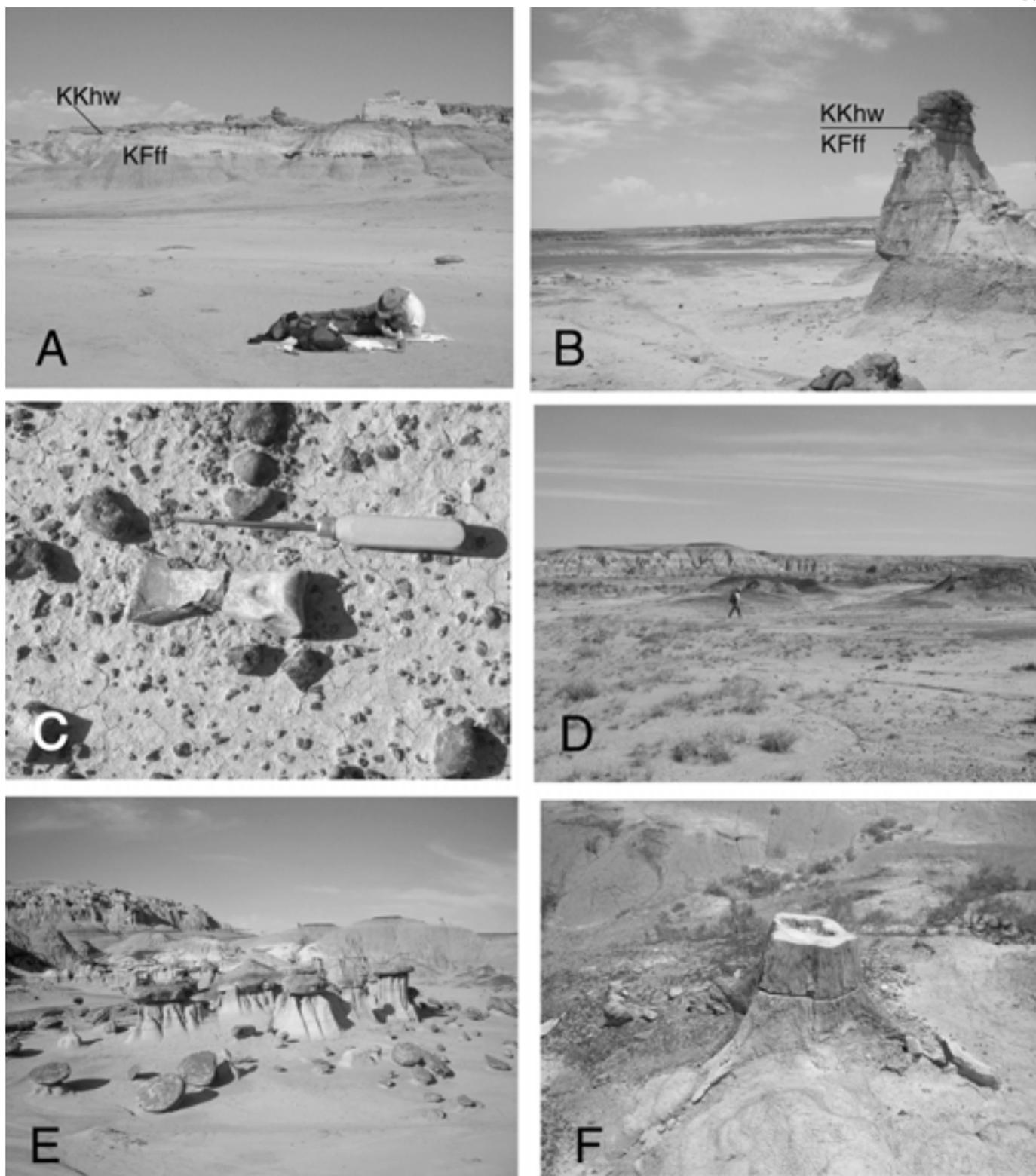


FIGURE 3. Localities and fossils in the Ah-shi-sle-pah Wilderness Study Area. **A**, Bob's Bloody Bluff (background), exposures of the upper Fruitland Formation (Fossil Forest Member), darker cap rock is the Bisti bed of the Kirtland Formation (Hunter Wash Member); **B**, Eagle's Nest and Eagle's Nest Flat, looking west across the lag surface of Eagle's Nest Flat (upper Fruitland Formation). The abandoned eagle's nest is visible atop the pinnacle (right); the locality of Eagle's Nest is located further to the right, out of view; **C**, nearly complete pes phalanx (SMP VP-1593) of *cf. Daspeltosaurus* sp. found at Eagle's Nest Flat; **D**, Denver's Blowout, low-lying exposures of the Kirtland Formation (Hunter Wash Member from center to right of photo); **E**, channel sandstones forming "toadstools" are numerous along the south branch of Ah-shi-sle-pah Wash (west); and **F**, fossil tree stump *in situ*, one of many such stumps in the Kirtland and Fruitland formations of Ah-shi-sle-pah WSA. Abbreviations: KFff = Fruitland Formation, Fossil Forest Member; KKhw = Kirtland Formation, Hunter Wash Member.

important specimens recovered from this site include: SMP VP-1668, scute fragments (*Denazinosuchus kirtlandicus*); VP-1686, very small and incomplete frontal (Crocodylidae indet.); and VP-1704, incomplete and weathered carapace and plastron (? *Denazinemys nodosa*).

Turtle Terrace (SMP locality 400)

“Turtle Terrace” was named for the many turtle fragments that were found weathering out of the formation. Among the more significant fossils recovered are: SMP VP-1615 and 1616, two large coprolites; VP-1680, nearly complete radius (Hadrosauridae indet.); and VP-1698, large humerus (Testudines indet.).

KIRTLAND FORMATION (HUNTER WASH MEMBER)

Denver’s Blowout (SMP locality 281)

Denver’s Blowout (Fig. 3D) was discovered by Denver Fowler in the Summer of 2002. The site consists of low-lying exposures of the lower Kirtland Formation (Hunter Wash Member) and at the time of its discovery it was the richest site found in the Ah-shi-sle-pah WSA. A number of important specimens have been recovered from Denver’s Blowout, including: SMP VP-1445 proximal end of left ulna and two ?radius fragments (Theropoda: ?Ornithomimidae or Dromaeosauridae); VP-1485, incomplete skull and lower jaws of *Melivius chauliodous* (the most complete known); VP-1488, portion of jugal with orbital rim of *Pentacerasatops sternbergii*; VP-1500, nearly complete parietal, incomplete squamosals, jugal and epoccipital of *Pentacerasatops sternbergii*; and VP-1522, carapace and plastron fragments (*Basilemys nobilis*).

Ah-shi-sle-pah Wash (west) (SMP locality 228) (includes Sternberg’s hoodoo site)

This locality covers 1295 square kilometers and there are numerous collecting sites within its boundaries. It is from this general area that Sternberg collected his postcranial skeleton of *Pentacerasatops sternbergii* (PMU.R268) in the fall of 1921 and a number of turtles.

Noteworthy specimens from Ah-shi-sle-pah Wash (west) include: SMP VP-742, plastron fragments (*Aspideretes* sp.); VP-1508, two complete dorsal vertebrae and lower half of a centrum of another (*Pentacerasatops sternbergii*); VP- 1712, left jugal and quadratojugal (*Pentacerasatops sternbergii*); and VP- 1789, complete left femur (*Ornithomimus* sp.).

The hoodoo site, which is located within SMP locality 228, was collected by C. H. Sternberg and his Navajo assistants Dan Padilla and Ned Shouver in 1921. A photograph of them at this site was published by Sternberg (1932) and is reproduced here (Fig. 4). We recognized this site in 2003 and published a note briefly describing the site as Sternberg’s hoodoo, not a Palmetto, as indicated by Sternberg (Lucas and Sullivan, 2003).

In the manifest of specimens collected and sold to the University of Uppsala, Sternberg lists a turtle (no. 107) identified by him as “*Adocus*. This fine turtle, injured in taking it up under a high pilar. I could not get behind it without tumbling over the pilar.”

Sternberg (1932) mentions that the hoodoo site was a locality where his two Navajo assistant discovered and collected a number of turtles. The base of the hoodoo bears a scar that is consistent with a small quarry site, the size of a common fossil turtle (~ 40 cm). The photograph, taken by Wesley Bradfield in 1921, clearly shows the chiseled base of the hoodoo and rock debris strewn across the surface, to the left of the base, suggesting that it was an excavation site.

Ah-shi-sle-pah Wash (east) (SMP locality 365)

SMP VP-1086, centrum (*Melivius chauliodous*); VP-1090, incomplete skull of a juvenile *Parasaurolophus* sp. (this specimen was pub-



FIGURE 4. Sternberg’s hoodoo site in 1921 (top) and 2003 (bottom). Note the excavation scar and debris at the based of the hoodoo in the 1921 photo. This is probably the site of specimen (no. 107) sold to the University of Uppsala. Today, the scar of Sternberg’s collecting is still evident (below).

lished by Sullivan and Bennett, [2000] as coming from the Fruitland Formation but has since been determined to be the Kirtland Formation); VP-1440, distal end of a right femur (Hadrosauridae indet.); VP-1144, axis vertebra (?*Pentacerasatops sternbergii*); VP-1145, a large unidentified ?skull element (dubbed the “mystery bone”) possibly pertaining to an ankylosaurid; VP-1146, terminal phalanx (Trionychidae indet.); VP-1473, skull and scute fragment (Crocodylidae indet.); and part of the edge of a carapace (*Basilemys nobilis*).

FOSSIL INVERTEBRATE LOCALITIES

To date only one invertebrate fossil specimen (SMP IP-8335), an incomplete internal mold of a large bivalve (presumably *Unio* sp.), has been recovered from Ah-shi-sle-pah WSA. The specimen was found in association with the numerous fossil vertebrates from Denver’s Blowout (locality 281).

FOSSIL PLANT LOCALITIES

During the course of our fieldwork, we have, on occasion, come across sites that are of paleobotanical interest. These sites produce petrified wood (stumps and logs), leaves and palynomorphs (from lignites). Overall, fossil plants have received little attention. Knowlton (1916) was the first to study the flora from the Fruitland and Kirtland formations of the San Juan Basin, but none of the material he reported on came from Ah-shi-sle-pah WSA. Later, a summary of the Cretaceous and

Tertiary floras of the San Juan Basin was presented by Tidwell et al. (1981). In recent years there has been a renewed interest in the macrofloras and trees of the Fruitland and Kirtland formations (Boucher and Wing, 1997; Boucher et al, 1997; Boucher, 2000; Vollum-Davies et al., 2000).

WOOD

Petrified wood is common throughout most of the Ah-shi-sle-pah WSA. Wood is known from both the Fruitland and the Kirtland formations and occurs mostly as broken material. However, there are a few areas where large logs and stumps are preserved. There is also a significant stump field along the western edge of the Ah-shi-sle-pah WSA. *In situ* stumps occur in both formations.

Two specimens of petrified wood have been collected. SMP PB-1009 and PB-4602 are from localities 386 and 228, respectively, and both are from the Hunter Wash Member (Kirtland Formation). The taxonomic identity of these specimens has not been determined.

LEAVES

Two incomplete and unidentified specimens of fossil leaves have been recovered from Ah-shi-sle-pah WSA. SMP PB-4601 is a small incomplete leaf impression from locality 396 (Fruitland Formation, Fossil Forest Member). SMP PB-4432 is an incomplete leaf impression from locality 406 (Kirtland Formation, Hunter Wash Member).

PALYNOMORPHS

Lignites are encountered in the upper part of the Fruitland and lower Kirtland formations. One lignite sample, SMP PB-1042 (locality 365), from the Kirtland Formation (Hunter Wash Member) was processed and yielded palynomorphs of *Baculatisporites* sp., *Cicatricosisporites* sp., *Cyathidites minor*, *Cycadopites fragilis*, *C. sp.*, *Ephedrites* sp., *Faveotrilletes* sp., *Frauxinoipollenites constrictus*, *Gleichmeiidites delicatus*, *Klukisporites* sp., *Liliacidites* sp., *Pityosporites constrictus*, *Proteacidites retusus*, *P. thalmani*, *Pseudoplicapollis newmanii*, *Retitriletes* sp., *Taxodiaceapollenites hiatus*, *Tricolpites hians*, *T. sp.* and *Varirugosisporites* sp.

FUTURE WORK AND THE FATE OF THE AH-SHI-SLE-PAH WSA

All fossil vertebrates from Ah-shi-sle-pah WSA belong to the Hunter Wash local fauna, a vertebrate fauna known from the upper Fruitland and lower Kirtland Formation (Fossil Forest Member and Hunter Wash Member, respectively). The fauna is based mostly on lower vertebrates (fish, turtles, crocodylians and dinosaurs). While mammal teeth have been collected in Hunter Wash (Clemens, 1973) and the Fossil Forest (Rigby and Wolberg, 1987), none are known from Ah-shi-sle-pah WSA. A preliminary list of fossil vertebrates is presented in Table 1.

Our understanding of the paleontology, fauna and flora, of the Ah-shi-sle-pah WSA is presently in its infancy. Although it has been intensively collected for macrovertebrate fossils in recent years, more sites need to be discovered and collected. Presently, the majority of the fossils from this region are housed in the collections of the State Museum of Pennsylvania and the Museum of Evolution, University of Uppsala. Only a handful of specimens (12, mostly dinosaur) from Ah-shi-sle-pah WSA are catalogued in the collections of the New Mexico Museum of Natural History and Science.

In addition to collecting macrovertebrate fossil sites, the microvertebrate sites (many of them co-occur with the macrovertebrate sites) are numerous throughout the Ah-shi-sle-pah WSA and need to be intensively collected. These sites have yet to be screened *en masse*. To date, all microfossils from this area have been picked-up from the outcrop. Thus, an increase sample of both the micro and macrovertebrate

TABLE 1. A preliminary list of fossil vertebrates from Ah-shi-sle-pah WSA based on collection data from NMMNH, PMU and SMP. **FF Mbr** = Fossil Forest Member; **HW Mbr** = Hunter Wash Member.

TAXON GROUP	SUBGROUP	GENUS/SPECIES	Fruitland (FF Mbr)	Kirtland (HW Mbr)
Chondrichthyes	Rhinobatidae	<i>Megastoma spartus</i>	X	X
Actinopterygii	Actinidae	<i>Melurus chelonius</i>		X
Testudines	Batracheidae	<i>Dorsatemys robusta</i>	X	X
		<i>Neuronyx sp.</i>	X	X
		<i>Thesoclis hemiphratica</i>	X	X
		<i>Adocus sp.</i>	X	X
		<i>Nankungchelyidae</i>	<i>Euclemys robusta</i>	X
Torturoidae	Torturoidae	<i>Apollonia sp.</i>	X	X
		<i>Platanoclis robusta</i>	X	X
Crocodilia	"Mesosuchia"	<i>Dorsosuchus kirtlandi</i>		X
		<i>Dorsosuchus agilis</i> cf. <i>Lepidochelys</i> sp.	X	X
Dinosauria	Tyrannosauridae	<i>Deplatorius sp.</i>	X	X
		<i>Omlonius sp.</i>		X
		<i>Dromaeosaurus</i> indet.		X
		cf. <i>Kritosaurus neogivus</i>	X	X
		<i>Parasaurornithomimus</i> sp.		X
		<i>Arkyosaurus</i> indet.	?	X
Ceratopsia	Ceratopsidae	<i>Pentaceras sternbergi</i>	X	X

faunas is highly desirable in order to properly assess the taxonomic diversity of the Hunter Wash local fauna in this and nearby areas.

Little is known regarding the paleobotanical realm in this region. The stump field needs to be studied in detail. The *in situ* stumps need to be mapped, sampled and thin sectioned. Comparison of the plants with those from the Dinosaur Provincial Park (Oldman and Dinosaur Park formations) reported by Koppelhus (2005a,b) needs to be made in order to determine how, and if, these floras differ both latitudinally and biostratigraphically.

In summary, a thorough study of the fossil faunas (vertebrate and invertebrate) and floras from Ah-shi-sle-pah WSA is an essential part of the completing the paleontological picture for the early Kirtlandian age in North America. It is imperative that this region remain in the public domain in perpetuity because of its historical and paleontological importance.

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THE FEEDING MECHANICS OF *LEPTAUCHENIA DECORA* BASED ON SPECIMENS FROM THE WHITNEYAN (OLIGOCENE) OF BADLANDS NATIONAL PARK, SOUTH DAKOTA

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Abstract—*Leptauchenia* is a common fossil mammal found in late Oligocene strata exposed in Badlands National Park, South Dakota. The life habits of this small ungulate have been the subject of much speculation. Proposed life histories have ranged from a semi-aquatic beaver like existence to a semi arid lifestyle similar to African rock hyraxes. In this study we apply biomechanical analyses to interpret the cranial and dental specializations of *Leptauchenia* compared to the basal morphotype, *Prodesmatochoerus*. The results from distortion grid, quadrant analysis, dental indices and vector analysis of reconstructed adductor musculature indicate that *Leptauchenia* was adapted to a more abrasive diet than normal for oreodonts. The vector for the masseter/pterygoideus complex is shifted anteriorly and is increased in magnitude relative to the temporalis compared to basal oreodonts. Dental characters of *Leptauchenia* compare most closely with modern selenodont artiodactyls that are mixed feeders in closed habitats. We believe the cranial morphology of *Leptauchenia* is the result of a selective shift in the feeding niche of this oreodont from browsing on succulent vegetation to mixed feeding on more fibrous plants in response to climatic shifts that resulted in more xeric vegetation.

INTRODUCTION

Merycoidodontids were a common part of the North American paleofauna during the transitional period between the decline of primitive mammalian herbivores (e.g., phenacodontids) in the Eocene and the rise of modern pecoran groups in the Miocene. Merycoidodontids and the less diverse and more primitive Agriochoeridae, make up the Oreodontoidea, commonly referred to as “oreodonts.” Oreodonts are small to medium sized selenodont artiodactyls that are endemic to North America with a stratigraphic range from the early Uintan to late Hemphillian NALMA (46.7-5.2 Ma). Oreodonts exhibit a unique combination of suiform and ruminant features. They are distinguished from other selenodont artiodactyls by the absence of a diastema, a primitive pig-like tarsus and a derived dental condition in which p1 is enlarged and caniform while the lower canine is reduced and incisiform. The basic oreodont body plan is pig-like in form having a dense robust cranium, short neck, and short limbs.

The subfamily Leptaucheniiinae, an enigmatic group with unusual facial features and an early trend toward hypsodonty, are among the most common Whitneyan and early Arikarean mammals found in the White River sediments exposed in Badlands National Park (BADL), South Dakota. Opinions on the life habits of leptaucheniians have ranged from semi-aquatic beaver-like animals (Scott, 1929) to inhabitants of rocky habitats where they may have formed social groups similar to hyraxes (Lander, 1998). Joeckel (1992) examined the auditory bullae of *Leptauchenia* using CAT scans and concluded that the enlarged bullae were an adaptation for increased low frequency hearing. Most opinions about the possible life habits of leptaucheniians are based on either comparative anatomy or depositional geology. The purpose of this paper is to present a biomechanical analysis of feeding adaptations in *Leptauchenia decora* from the Poleslide Member of the Brule Formation (Whitneyan NALMA) in BADL.

MATERIALS AND METHODS

Specimens

The classification scheme and phylogenetic interpretation for *Leptauchenia* used in this paper is that of Cobabe (1996) for genus and species level taxonomy and Lander (1998) for higher level taxonomy. All

of the *Leptauchenia* specimens utilized in this study were collected in BADL in Whitneyan aged exposures that are referred to in the geologic literature as “the *Leptauchenia* Beds.” We used specimens of *Prodesmatochoerus periculatorum* (= *Merycoidodon culbertsoni*) from the Orellan beds in BADL as a functional out group for our biomechanical analysis of the feeding apparatus in *Leptauchenia decora*. All the specimens used in this study are housed in the Georgia College & State University Vertebrate Paleontology collection (GCVP). Of the 104 catalogued specimens of *Leptauchenia* in the collection, we only used specimens identified as young adults (m3 fully erupted but relatively little wear on the molars).

Biomechanical Analysis

Skeletal Analysis

Distortion grids (Thompson, 1961) of lateral and ventral views of *Leptauchenia* were performed using *Prodesmatochoerus* (the likely primitive morphotype for merycoidodontids, Wall and Shikany, 1995) as a template. A quadrant analysis was performed on mandibles of *L. decora* and *P. periculatorum* (see Mead and Wall, 1998 for a similar study).

Dentition

Hypsodonty Index (HI) is the height of m3 divided by its width. Molar height was measured from the tip of the protoconid to the crown/root interface directly below it on the labial side. Molar width was the maximum distance between the protoconid and the entoconid. Lengths of the lower molar and premolar series were measured at bone height to produce a premolar/molar ratio. Average values for all ratios were obtained from ten specimens of *L. decora* and ten of *P. periculatorum*. Wear facets of *L. decora* were examined and compared to those described by Greaves (1973). All linear measurements were taken with Mitutoyo digital calipers, accurate to within 0.01 mm. A two factor analysis of variance (ANOVA) was performed using the SAS® program on the quantitative measurements to determine statistical significance of differences between the two taxa. Comparative data on modern herbivores is from Wall and Collins (1998).

Adductor Musculature

Our estimates for vector direction and magnitude for the temporalis and masseter/pterygoideus complex are based on reconstruction of the jaw adductor musculature in ten *Leptauchenia* specimens and then averaging the results. Modeling clay was used to estimate the muscle mass for each of the jaw adductor muscles (see technique in Turnbull, 1970). Six muscles were evaluated in this study, the dorsal Temporalis (Td), ventral Temporalis (Tv), Zygomaticomandibularis (Zm), Masseter (M), internal Pterygoideus (Pi) and the external Pterygoideus (Pe). Dissections of heads of *Sus scrofa* and *Odocoileus virginianus* were made to familiarize the authors with this musculature in modern artiodactyls. Muscle descriptions provided by Greaves (1972) also influenced our reconstruction of *Leptauchenia* adductor musculature.

RESULTS

Skeletal Analysis

The *Leptauchenia* skull is highly modified from the primitive oreodont morphotype (Fig. 1). *Leptauchenia* has a shortened rostral portion of the skull, enlarged dorsally displaced orbit and a dorsoventrally expanded temporal and mandibular angle region. With respect to skull width versus length, *Leptauchenia* is clearly more brachycephalic than *Prodesmatochoerus*. *Leptauchenia* also has a more slender muzzle relative to palatal width than *Prodesmatochoerus*.

Leptauchenia is different from *Prodesmatochoerus* with respect to the distribution of bone in the region of the mandible sculpted by the insertion of the adductor musculature (Fig. 2). In *Leptauchenia* the percentage of bone falling within each quadrant is: I 17.4%; II 16.1%; III 31.7%; and IV 34.8%. The distribution of bone in the four quadrants for *Prodesmatochoerus* is: I 18.8%; II 6.8%; III 14.5%; and IV 59.8%. Seventy-four percent of the mandibular angle lies beneath the occlusal

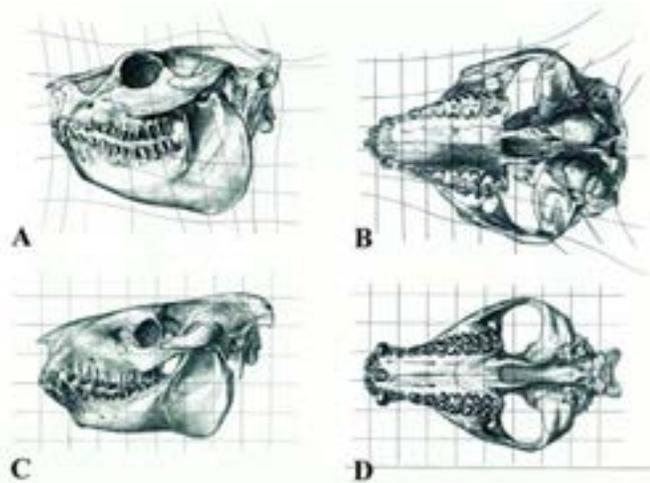


FIGURE 1. Distortion grid analysis of the A, lateral and B, ventral view of *Leptauchenia decora* using *Prodesmatochoerus periclorum* (C and D) as the template. Modified from Scott (1940).

plane in *Prodesmatochoerus*. Only 66.5% of the mandibular angle lies below the occlusal plane in *Leptauchenia*.

Dentition

The ratio of unworn height to width of m3, the hypsodonty index, revealed significant differences between *L. decora* and *P. periclorum*. The average hypsodonty of *Leptauchenia* was 2.01 while *Prodesmatochoerus* averaged 1.40 (the statistical difference between the two samples has a P value of 0.0001). Measurements of molar and premolar series revealed a higher premolar ratio in *P. periclorum* (0.87) than *L. decora* (0.74) (with a P value of 0.0075).

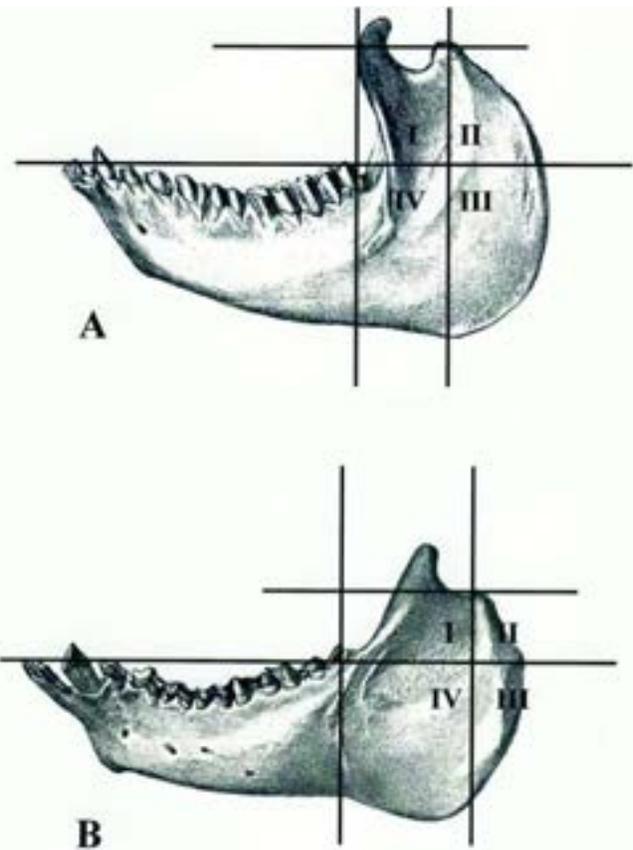


FIGURE 2. Lateral view of the mandibles of A, *Leptauchenia decora* and B, *Prodesmatochoerus periclorum* illustrating quadrant analysis of the mandibular adductor region. Modified from Scott (1940).

Adductor Musculature

A vector diagram of the major jaw adductor musculature is provided in Figure 3. The jaw musculature of oreodonts is peculiar among ungulates due to the well-defined separation of the dorsal and lateral temporalis and the presence of a distinct zygomaticomandibularis. The temporalis group originates on the braincase bordered by the sagittal and nuchal crests. The dorsal and lateral temporalis are separated by a large diagonal ridge that tends to follow the parietosquamosal suture from the middle of the braincase to the pterygoid crest in *Prodesmatochoerus* and to a protuberance at the level of the posterior root of the zygomatic arch in *Leptauchenia*. *Leptauchenia* also exhibits one or two smaller, more anterior ridges that run parallel to the main ridge. The lateral temporalis inserts on the coronoid process and likely functioned in a similar manner to the standard artiodactyl temporalis. The dorsal temporalis inserts on a boss found just posterior to m3 on the lingual side of the dentary. The diagonal groove in the temporal region of the skull keeps the dorsal temporalis isolated from the lateral temporalis.

Oreodonts differ from most other ungulates in having a well-defined masseteric fossa and a medial muscle attachment site on the zygomatic arch. In many pecorans, the zygomaticomandibularis is fused to the deep masseter, however, it is likely that this muscle retained its independence in oreodonts. The masseter muscle group in ungulates is commonly separated into the deep and superficial masseter muscles, however, we concur with Greaves (1972) assessment that these muscles are not separate in oreodonts.

The pterygoid group is made up of the internal and external pterygoid muscles. The origin of this group is concentrated on the pterygoid process but includes most of the pterygoid bone as well as the connecting palatal bone. The internal pterygoid is the larger of the two muscles. It inserts on the medial side of the angular process of the dentary. The

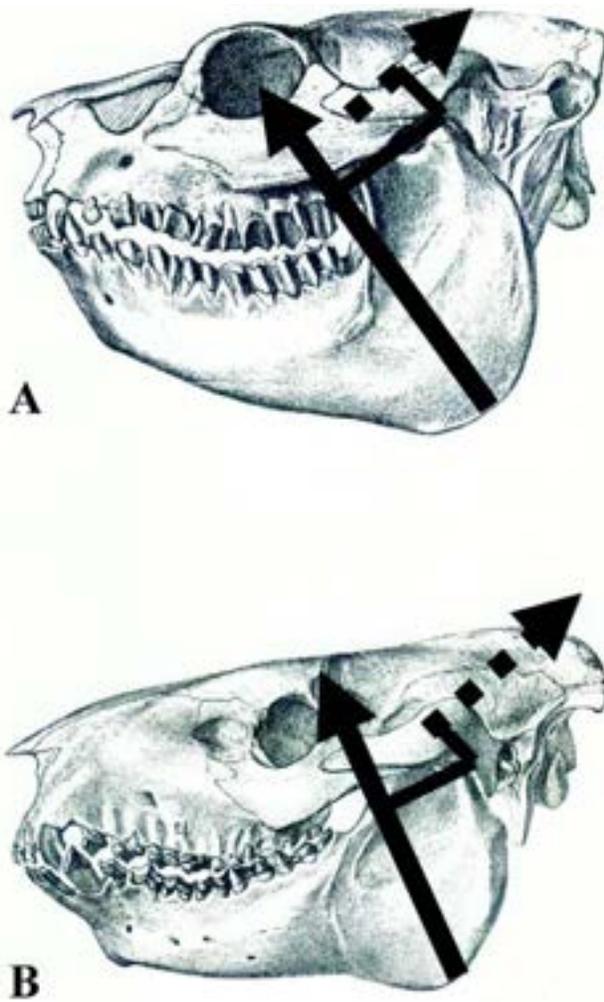


FIGURE 3. Lateral view of the skull and mandible of **A**, *Leptauchenia decora* and **B**, *Prodesmatochoerus periclorum* illustrating vector analysis of the mandibular adductor musculature. The temporalis group is represented by a dashed vector and the masseter/pterygoideus group is depicted with a solid vector. Total vector lengths are drawn to the same scale for the two taxa. Modified from Scott (1940).

external pterygoid is much smaller than the internal portion. Its origin is posterior to that of the internal pterygoid on the lateral surface of the pterygoid process. The insertion of this muscle is immediately below the mandibular condyle on the medial side of the jaw. As is common among ungulates, the pterygoid and the masseter are the largest two muscle groups. They act synergistically as the main muscles in transverse and anterior movement of the jaw.

Our estimates for the percentage of total adductor muscle mass in *Leptauchenia* are: masseter and zygomaticomandibularis 41.5%, pterygoideus complex 29.4% and dorsal and lateral temporalis 29.1%. The corresponding percentages for *Prodesmatochoerus* are: 38%, 23.9% and 38.1%. These percentages are reflected in the lengths of the vectors illustrated in Figure 3.

DISCUSSION

Many features of the *Leptauchenia* cranium, a typical representative of the subfamily Leptaucheniinae, are the result of a marked departure from other lineages of oreodonts with respect to the feeding component of the niche. Not only are leptaucheniinae among the smallest of oreodonts (Schultz and Falkenbach, 1968), they are also the first selenodont artiodactyl group to evolve any degree of hypsodonty. *Leptauchenia* displays the following characteristics associated with mastication that

distinguish this lineage of oreodonts: smaller and more brachycephalic skull; anteroposteriorly shortened braincase; reduced rostrum; relatively higher sagittal and nuchal crests; massive zygomatic arch; expanded mandibular angle; relatively narrow muzzle; reduced caniniform teeth; small, peg-like incisiform teeth that exhibit wear facets; relatively high hypsodonty index; significant increase in molar surface area relative to premolars; submolariform p4; anterior shift in the orientation of the masseter/pterygoideus vector; and increase in the mass of the masseter/pterygoideus relative to the temporalis.

These morphological differences correlate closely with dietary differences. The hypsodonty index and relative premolar row length for *Leptauchenia* correlate most closely with modern herbivores occupying a mixed feeding, closed habitat niche (whose HI mean equals 2.07 with a mean premolar ratio of 0.73), while *Prodesmatochoerus* compares favorably with modern selective browsers with respect to these dental parameters (mean HI of 1.5 and premolar ratio of 0.86). The anterior expansion of the zygomatic arch (Fig. 1) and the posterior expansion of the mandibular angle in *Leptauchenia* (Fig. 2) indicate a significant anterior shift in orientation of the masseter (and pterygoideus with respect to the mandibular angle) in this taxon (compare vector directions in Fig. 3). The mass of the masseter/pterygoideus has also increased relative to the temporalis (compare vector lengths in Fig. 3). The anterior shift in muscle orientation increases the horizontal vector component of these muscles. The horizontal vector is most important in the lingual phase (jaw moves forward and downward) of the chewing cycle during which the molars are used to grind food. The rearrangement of the masseter/pterygoideus musculature also results in an increase in size of the lever arm, and therefore the out force, of these muscles. Increased brachycephaly in *Leptauchenia* also correlates with greater side to side movement during mastication (a direction of movement only important during grinding activity). Mastication in *Prodesmatochoerus* reflects more of a compromise between the buccal (jaw movement is forward and upward during which shearing is emphasized) and lingual phases of mastication in this basal oreodont.

It is possible that the cranial and dental modifications evident in *Leptauchenia* reflect the small size of these oreodonts. Body size and metabolic rate are inversely related in mammals. It is therefore possible that these modifications could be due to the demands associated with quantity of food required relative to body size. Janis (1988) noted another complicating factor in that hypsodonty index may more accurately reflect feeding at ground level rather than actual dietary preference. However, we believe the totality of the cranial, dental and adductor muscle adaptations evident in *Leptauchenia* support the hypothesis of a dietary shift in this group. If an increase in the quantity of food intake was the primary selection factor in leptaucheniinae, then a behavioral response that increased foraging time is a more likely solution to the problem. The weight of evidence indicates that *Leptauchenia* fed on a diet that required more thorough mastication than typical for oreodonts. We believe *Leptauchenia* was adapted to feeding on a diet consisting of more fibrous, less succulent vegetation, possibly even some early grasses. Prothero (1994) came to a similar conclusion based on paleoclimate evidence. While our data show that the dentition of *Leptauchenia* compares most favorably with modern artiodactyls that are mixed feeders in a closed habitat, we keep open the possibility of a more open habitat niche since the auditory features of *Leptauchenia* appear to be adapted to a more open environment (Joekel, 1992).

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