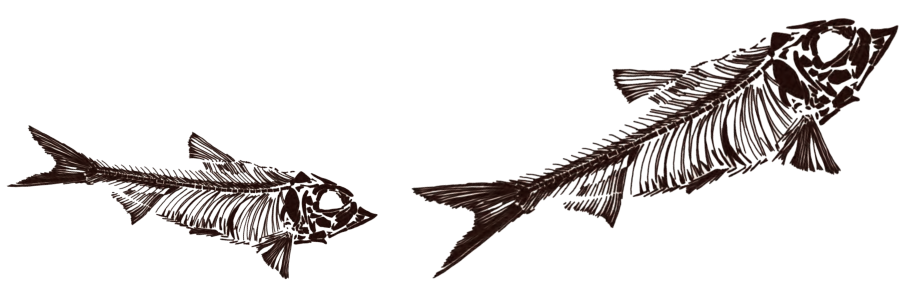
PROCEEDINGS of the
NINTH CONFERENCE on FOSSIL RESOURCES

Edited by
Tyra Olstad and Arvid K. Aase,
Fossil Butte National Monument

With thanks to
William Parker, Petrified Forest National Park
Scott Foss, Bureau of Land Management



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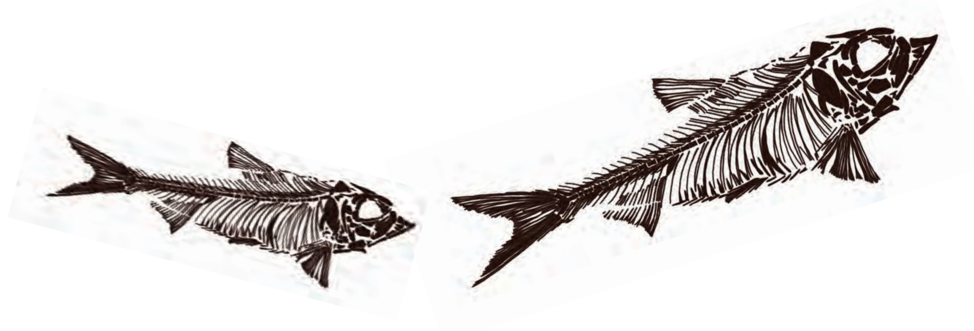

MISSION STATEMENT

The Conference on Fossil Resources provides an opportunity for public land managers, professional scientists and interested amateurs to come together to discuss successes, discoveries and land management policies regarding paleontological resources. Through this collaboration, participants seek to maximize scientific, educational and recreational opportunities on public lands.

HISTORY

The Conference has convened periodically since 1986, when Dinosaur National Monument hosted a gathering focused primarily on issues related to the management of paleontological resources in National Park Service units. Subsequent conferences have expanded in scope to include the management, protection, and interpretation of paleontological resources on all public lands.

Fossil Butte National Monument welcomes attendees back to Kemmerer, Wyoming—site of the third conference.
Previous hosts include:

Dinosaur National Monument
Vernal, Utah (1986)

Petrified Forest National Park
Holbrook, Arizona (1989)

Fossil Butte National Monument
Kemmerer, Wyoming (1992)

Florissant Fossil Beds National Monument
Colorado Springs, Colorado (1994)

Badlands National Park and South Dakota School of Mines and Technology
Rapid City, South Dakota (1998)

Colorado Bureau of Land Management, Gunnison National Forest, and Colorado National Monument
Grand Junction, Colorado (2001)

New Mexico Museum of Natural History and the New Mexico Bureau of Land Management
Albuquerque, New Mexico (2006)

Utah Friends of Paleontology, the Utah Bureau of Land Management, and the Utah Geological Survey
St. George, Utah (2009)

BRIGHAM YOUNG UNIVERSITY
GEOLOGY STUDIES

Volume 49(A), 2011

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ORAL PRESENTATION

COLORADO BUREAU OF LAND MANAGEMENT FOSSILS SINCE 1865: A HISTORY OF FIELDWORK, PERMITS, AND FINDS

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ABSTRACT—General collection of fossils in Colorado predates 1865 and continues today. Scientifically, researchers have used available permissions and permits to collect fossils on public lands now administered by the Bureau of Land Management (BLM) in Colorado for over 150 years, making highly significant finds including taxa new to science that have proven useful in understanding past environments. Modes of exploration and collection for these fossils have included hiking, excavation, drilling, horses and other animals, mechanized terrain travel, aviation, ground sensing, satellite, and computer navigation. More than 250 permits have now been issued for the surface collection, sampling, excavation, and mitigation of impacts on paleontological resources on BLM lands in Colorado. Small to large specimens of plants (pollen and petrified wood, for example), invertebrates (ammonites and insects), vertebrates (dinosaurs and mammals), and trace fossils have been collected by a variety of researchers and their host institutions and are reposited across the nation in many museums, colleges, universities, and geologic surveys. These fossils provide many educational and economic benefits, including added interest for heritage tourism: Colorado BLM currently hosts five fossil-themed trails, highlights fossils in two National Byway auto tours, and locates fossils in at least eleven National Landscape Conservation Areas.

KEYWORDS—Colorado, Bureau of Land Management, Permits, Paleontological, Fossils

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ORAL PRESENTATION

COMPLETION OF THE GENERAL MANAGEMENT PLAN FOR THE SOUTH UNIT OF BADLANDS NATIONAL PARK: THE FIRST TRIBAL NATIONAL PARK IN NATIONAL PARK SERVICE HISTORY

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ABSTRACT—After 3 years of cooperative effort between Badlands National Park, the Oglala Sioux Tribe, and the National Park Service (NPS) Midwest Regional Office, the Badlands General Management Plan (GMP) is nearing completion for potentially the first Tribal National Park in our nation's history. The GMP includes seven management options, ranging from shared management between the NPS and the Oglala Sioux Tribe to deauthorization with management by the Oglala Sioux Tribe as a tribal park. The preferred management option for the new General Management Plan includes the development of a Tribal National Park over a series of stages, beginning with NPS employees mentoring tribal employees in resource management and visitor education. As tribal employees develop the necessary skills to manage a "National" park, they will step into positions previously held by NPS employees and assume responsibility for managing the nation's first Tribal National Park. Five of the proposed management options (including the preferred option) would require congressional legislation for full implementation. In addition to management options, there are four resource and visitor experience alternatives discussed in the GMP. The preferred alternative focuses on resource protection with expanded access and opportunities for visitors. Because of the premier fossil resources preserved within the South Unit, paleontological resources are considered a primary resource under the preferred alternative, with a special emphasis placed on inventory, monitoring, research and salvage collection. A visitor oriented paleontological excavation would also be considered under this alternative. Plans for the development of a Lakota Heritage and Education Center (LHEC) are proceeding in addition to the GMP. The LHEC would serve as a major visitor contact station as well as curatorial space for fossils and artifacts. Museum specimens would continue to be housed in trust for the tribe, in off-site NPS-approved collections. Where feasible, they would be transferred to the new facility. Additionally, the preferred alternative would protect fossils by increasing law enforcement staff, reducing cattle grazing, and increasing visitor education.

KEYWORDS—Vertebrate Paleontology, National Park Service, Oglala Sioux Tribe, Management Policies, Museum Collections

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ORAL PRESENTATION

THE PLANNING AND EXECUTION OF AN OPEN-TO-THE-PUBLIC EXCAVATION OF AN ALLOSAUR FROM THE SAN RAFAEL SWELL

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ABSTRACT—In December 2009, an articulated vertebral column was found during a survey east of Castle Dale, Utah, in the San Rafael Swell. The site was located near the main county road into the Swell, creating a security problem: how to keep the site safe until it could be properly excavated and how to excavate the fossils without attracting the attention of curious onlookers. The solution: open the excavation up to the public. During the five days the site was open, more than 2000 people visited.

From the time the site was found until it was excavated under a permit issued by the Bureau of Land Management (BLM), the Emery County Sheriff's Department regularly monitored the site during routine patrols. Because work at the site could not be concealed, the Prehistoric Museum decided, in conjunction with the state and local BLM offices, to publicize the excavation in order to allow continuous supervision of the site, educate the public about the importance of such discoveries, and highlight the partnership between the Museum and BLM. Parking areas, camping areas, trails, observation areas, vehicle access, crowd control, volunteer help, news releases, and tools and equipment were planned out in advance to deal with the expected crowds..

The success of this project was made possible by the cooperation of the BLM, CEU Prehistoric Museum volunteers, Carbon County Travel Bureau and others. Problems were identified, ideas were shared and solutions were found. The result was a successful, educational and enjoyable experience for everyone interested.

KEYWORDS—Collaboration, San Rafael Swell, excavation, interpretation

*Presenting author.

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Kemmerer, WY, April 2011

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ORAL PRESENTATION

PRESERVATION, MANAGEMENT, AND REINTERPRETATION OF AN EARLY JURASSIC DINOSAUR TRACKSITE IN WARNER VALLEY, WASHINGTON COUNTY, UTAH

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ABSTRACT—The Early Jurassic Warner Valley Dinosaur Tracksite (WVT), situated in the lower part of the Kayenta Formation, is located near St. George, Utah on public land administered by the St. George Field Office of the Bureau of Land Management (BLM). The site was discovered in 1982 and described in a preliminary scientific paper by paleontologists from Brigham Young University (BYU) in 1989. Shortly after its discovery, the BLM set up interpretive signage and opened the site for public educational use (Fig. 1A). Although the WVT has become well known, especially to the local population, it also became a target for vandalism and has been subjected to extensive off-highway vehicle (OHV) use.

Following the establishment of a paleontological site stewardship program by the St. George Field Office in 2007, the WVT received continual monitoring by trained BLM volunteers, who reported damage to the tracksite, OHV use on and around the site (Fig. 1B), and illegal replication of dinosaur tracks (Fig. 1C). The monitoring encouraged the BLM to better preserve and protect the site by erecting site etiquette signs, surrounding the site with range fencing, improving the parking area and access road, and installing new, updated signs (Fig. 1D–E).

In late 2010, the St. George Dinosaur Discovery Site at Johnson Farm (SGDS) was asked to help update the WVT signs. The preliminary map published by BYU documented 161 individual impression (natural mold) tracks pertaining to the ichnotaxa *Eubrontes* and *Grallator* in 23 trackways on two track-bearing horizons. Permission was granted by the BLM to expand the surface area of the WVT to include surfaces between the upper and lower track-bearing beds that previously had been covered. During this new cleaning, excavation, and remapping, many new specimens were discovered that were either covered at the time of the original mapping or consist of previously unrecognized compression tracks that are raised off the surface. At present, the WVT preserves 400 individual tracks and at least 25 trackways on five track horizons, greatly enhancing the significance of the site.

The new, more extensive signage at the WVT will include several items absent from the original signs, including an updated map of the entire tracksite alongside the original map, a paleogeographic map of the Early Jurassic of Utah, information on the original discovery, and generalized information about the kinds of tracks and the animals that produced the tracks, the geology of the area, the Kayenta Formation paleoenvironment, the future of the WVT, and what data may still be obtained with further study and protection.

The southern portion of the tracksite, where many of the better preserved *Eubrontes* tracks are situated, remains to be stabilized and repaired. The tracks in this area are on a thin bed that, when exposed, becomes friable and easy to remove. Hollow sounds under this layer are harbingers of future damage or, worse yet, theft of tracks that have broken free. Also, concrete residue from illegal and improper replication has yet to be removed. The BLM and the SGDS are jointly exploring the best options for both proper replication and possible stabilization of the tracksite with ethyl silicate. Photogrammetry may be used to record track data about specimens that may be damaged or destroyed (Fig. 1F).

Joint BLM-SGDS reevaluation of the WVT has provided the opportunity to raise public awareness about the importance of preserving this nonrenewable resource through interpretive signage that explicitly discusses the continuous, destructive conditions to which the site is subjected and the measures undertaken to counter them. This project demonstrates that a mutually beneficial agreement between the BLM and the scientific community can result in a well-maintained, well-protected, and educational public resource.

KEYWORDS—Warner Valley, Kayenta Formation, Dinosaur Tracks, Utah, Bureau of Land Management

*Presenting author

FIGURE 1. **A,** Original wooden sign at the WVT full of bullet holes and incorrect information based on 1989 misinterpretation of the site. **B**, Motocross rider driving across the WVT surface. **C**, *Grallator* footprint surrounded by concrete residue from illegal replication of track. **D**, New BLM sign at entrance to parking area at the WVT. **E**, New metal signage frame next to the tracksite surface. **F**, Neffra Matthews photographing a *Grallator* footprint for photogrammetric purposes at the WVT.

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ORAL PRESENTATION

PALEONTOLOGICAL RESOURCES IN THE VERMILION CLIFFS NATIONAL MONUMENT AND PARIA CANYON-VERMILION CLIFFS WILDERNESS: THE USE OF PHOTOGRAMMETRIC ICHNOLOGY IN THE 21ST CENTURY

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ABSTRACT—The Vermilion Cliffs National Monument and the Paria Canyon-Vermilion Cliffs Wilderness encompass nearly 400,000 acres of land managed by the BLM in Coconino County, Arizona and Kane County, Utah. In Early Jurassic times (~190 million years ago), a vast (~350,000 sq. km) sea of sand (erg) covered this area. Today, these sands, preserved as the Navajo Sandstone, create the picturesque geology of these National Landscape Conservation System (NLCS) units. In addition, this region contains a little-known record of thousands of fossil tracks preserved as underprints in convex hyporelief and concave epirelief on dune foreset beds and interdune bounding surfaces. Fossil footprints include tridactyl (*Grallator*) and tetradactyl (*Batrachopus* and *Navahopus*) forms, as well as unique invertebrate traces. These ichnites preserve a variety of interesting preservational and behavioral features related to a desert fauna of theropods, prosauropods, crocodylomorphs, protomammals, and arthropods moving up, down, and across dunes during the monsoonal summer season. Although the discovery of fossil tracks is on the rise worldwide, the general understanding of the complexities of vertebrate ichnology and significance of trace fossils remains remarkably low, resulting in misinformation and mismanagement. Fortunately, photogrammetric documentation incorporated with GIS can assist in the proper documentation, preservation, and assessment of these resources. In these NLCS units, valuable insights and interpretations can be made from these data, providing an ideal opportunity for the successful synergy of management, science, technology, interpretation, and recreation. Photogrammetrically derived 3D image datasets are providing valuable information for the understanding of the Early Jurassic desert ecosystem in the region, as well as understanding the kinematics of footprint formation in arid, eolian environments.

KEYWORDS—Trace Fossils, Photogrammetry, Navajo Sandstone, Vermilion Cliffs National Monument, Paria Canyon-Vermilion Cliffs Wilderness

POSTER SESSION

WYOMING'S RED GULCH DINOSAUR TRACKSITE: PUBLIC PARTICIPATION, CONSERVATION, AND MANAGEMENT

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ABSTRACT—Public lands of the Rocky Mountain West contain some of the most important vertebrate paleontological remains of North America. Because these fossils are public resources, it is vital for the public to be activity involved with research projects when possible. An example of this type of partnership was the work done at the Red Gulch Dinosaur Tracksite (RGDT). Beginning in 1997, this project brought researchers, students, and volunteers from around the country to northern Wyoming, where they were responsible for determining the paleontological significance of a previously unknown dinosaur tracksite. The RGDT, located on readily-accessible land managed by the Bureau of Land Management (BLM), contains more than 1000 footprints from a population of theropod dinosaurs that walked across an ancient tidal flat 165 million years ago. Its size and complexity presented an opportunity for assistants of all ages to practice their data gathering skills in observation, description, critical thinking, and "footprint sleuthing." A variety of both classical and state-of-the-art documentation methodologies were tested, making this one of the most intensively documented dinosaur tracksites in the world. Through a partnership with the BLM, the needs of students, public, and media were accommodated without negatively impacting scientific research. The RGDT 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.

KEYWORDS—Red Gulch Dinosaur Tracksite, Public participation, Dinosaur tracks, Bureau of Land Management, Resource Management

*Presenting author

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ORAL PRESENTATION

SCIENCE IN CONTEXT: PALEONTOLOGICAL METHODS IN THE NATIONAL PARKS

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ABSTRACT—National Park Service units play an important role in society by demonstrating the entirety of the scientific process in action. Well-managed paleontology parks and monuments afford a visitor experience unattainable virtually anywhere else. This is due largely to an under appreciated element of paleontology—that of context. The exact three-dimensional spot in the ground where a fossil is found is the most basic and crucial data point. The paleontological resource is more completely understood interpreted in context, in the park. However, the importance of a designated park diminishes to the extent that fossils and the science are often outsourced—removed, conserved, curated, and housed elsewhere.

Ideally, a protected locality would be fully equipped with facilities and management plans that would enable preservation and conservation of the fossil resource by highly experienced content specialists. In-house expertise is best equipped to coordinate the research necessary to provide the understanding required to care for fossil resources. By serving as self-contained research stations, these installations provide critical training to future generations of scientists, fulfill the mandate of the park service to educate the general public, generate scientific research, and most importantly, address the intent of the enabling legislation for the individual park or monument.

ORAL PRESENTATION
Article, p. 40–42

PALEONTOLOGICAL RESOURCE MANAGEMENT AND THE OGLALA SIOUX TRIBE'S TRIBAL HISTORIC PRESERVATION OFFICE

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ABSTRACT—The Oglala Sioux Tribe has historically delegated responsibility for cultural/historic preservation and paleontological resource management to various Tribal agencies through Tribal Council Resolutions and Ordinances based on the need of each specific situation. In April 2008, a Tribal Council Ordinance established a Tribal Historic Preservation Office (THPO). This office was directed to: 1) develop a Tribal Historic Preservation Plan and Program, 2) obtain National Park Service (NPS) Historic Preservation Program approval for official status as a nationally recognized THPO, as provided by the National Historic Preservation Act, 3) negotiate a Memorandum of Agreement (MOA) with the NPS to acquire funding necessary to implement the Program, 4) assist in developing a paleontological resource management plan, and 5) create an Advisory Council to serve as an elder advisory group for all cultural and historical management. Since its inception, the Advisory Council has been called upon to address paleontological resource management issues on the Pine Ridge Reservation. Based on traditional teachings, it is believed that everything is connected. This connection means that anytime the earth is disturbed, a human-related and/or fossil item may be uncovered, so there is no real distinction between archaeological and paleontological resources. Currently, the Oglala Sioux Tribe has a nationally recognized THPO, program funding and personnel, consultants, a Tribal Historic Preservation Plan, and a MOA with the NPS assuming certain functions previously conducted by the State Historic Preservation Office. The THPO is working collaboratively with several other Tribal and Federal entities as well as educational institutions to address ongoing needs for protecting and preserving cultural/historic properties and paleontological resources. There are plans in place to make Oglala Lakota College, through its Department of Math, Science & Technology, the official repository and archival warehouse for Oglala Sioux Tribal paleontological resources.

KEYWORDS—Tribal, Oglala, Resource Management

*Presenting author

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ORAL PRESENTATION

SITE CONDITION ASSESSMENTS OF FOSSILS IN THE NATIONAL CAPITAL REGION

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ABSTRACT—Using paleontological resource inventory and geologic resource evaluation reports, site condition assessments were completed at three parks in the National Capital Region: Manassas National Battlefield Park, Fort Washington Park, and the Chesapeake and Ohio Canal National Historical Park. At Manassas National Battlefield Park, fossil-bearing outcrops are well-constrained in unpublished maps by Dr. Robert Weems (USGS) and other researchers. At Fort Washington Park, fieldwork revealed multiple exposures of the shell-rich Aquia Formation in steep ravines. The discovery of accelerated erosion in one ravine causing destruction of fossil casts and molds led to a successful NPS Geologic Resource Division technical assistance request. Subsequent training workshops raised awareness among regional staff, and prepared interpreters to tell the story of Fort Washington's ancient history. At the Chesapeake and Ohio Canal National Historical Park, fossils Cambrian to Devonian in age (540 to 460 million years old) were described at five sites within the Valley and Ridge Province. Site condition assessments revealed the differences between carbonate rock sites in the Great Valley and shale exposures in the western part of the park. Limestone and dolomite outcrops were in good condition, with stable rock faces, few fossils visible and little evidence of visitor impacts on the sites. In contrast, Devonian-age shale exposures along the Western Maryland Railroad grade present resource concerns due to accelerated erosion rates, increased fossil visibility, and possible impacts on fossils by park visitors. A year-long paleontological inventory of C & O Canal National Historic Park will expand on this work in 2011. This six-month Geoscientist-in-the-Park internship raised awareness about fossils—a resource for which eastern parks are not traditionally known.

KEYWORDS—Manassas National Battlefield Park, Fort Washington Park, Chesapeake and Ohio Canal National Historical Park, Paleontological resources, Site condition assessments

ORAL PRESENTATION

LEAFY THERMOMETERS AND RAIN GAUGES: USING FOSSIL LEAVES TO TEACH ABOUT EOCENE CLIMATE IN THE CLASSROOM

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ABSTRACT—The National Park Service encourages incorporating the history and science of our parks into the classroom. This affords an opportunity for middle and high school teachers, particularly in the sciences, to offer concrete, relevant examples from iconic American landscapes to engage students and aid them in mastering abstract principles. Fossil Butte National Monument uses an inquiry-based, integrated learning approach in the activity *Leafy Thermometers and Rain Gauges*. Using a suite of 37 fossil leaf photographs from the Green River Formation, students conduct leaf margin analysis (LMA) and leaf area analysis (LAA) to produce estimates of mean annual temperature (MAT) and mean annual precipitation (MAP) for the Early Eocene in a classroom setting. In essence, students do climate science. Students test the robustness of the model by collecting local leaves and comparing the result of LMA and LAA with an observational weather database.

Beyond the basic methodology and testing, a comparison of temperature and precipitation estimates from fossil leaves with observational climate records for southwestern Wyoming allows students to make general statements about how climate has changed since the Early Eocene and brainstorm potential causes. Further, contrasting a graph of the temperature trend for SW Wyoming based on two data points (52 million years ago and today) with other graphs of temperature change over various time intervals facilitates a discussion of how and why climate has changed and whether or not the evidence presented rejects a hypothesis of human-induced climate change.

KEYWORDS—Climate change; Interpretation; Eocene; Leaf Margin Analysis; Leaf Area Analysis

*Presenting author

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ORAL PRESENTATION

A PALEONTOLOGICAL RESOURCE INVENTORY OF BUREAU OF LAND MANAGEMENT WILDERNESS LANDS IN WASHINGTON COUNTY, UTAH

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ABSTRACT—The Washington County Wilderness Bill, which is part of the Omnibus Public Lands Bill signed into law in 2009, designates 129,300 acres of public land administered by the Bureau of Land Management (BLM) as wilderness. As part of the planning process, the BLM funded the Utah Geological Survey (UGS) to conduct a paleontological inventory of wilderness areas, providing an opportunity for input into critical land-use and management decisions. This marks the first time that paleontological resources have been included in an initial natural resource inventory for a new public wilderness area.

To create potential fossil yield classification (PFYC) maps for the wilderness areas, we used data from UGS 1:24,000 and 1:100,000-scale geological maps of the region to prioritize paleontological data collection in the field. Based on the location of important fossil-bearing strata—the Chinle, Moenave, and Kayenta formations and, to a lesser degree, the Navajo Sandstone and Carmel formations—and their proximity to developed areas, the BLM selected the Cottonwood Canyon, Red Mountain, and Canaan Mountain wilderness areas for field inventory.

Field work began in the fall of 2010 at Red Mountain and Cottonwood Canyon. Numerous sites with tracks attributed to *Grallator*, *Eubrontes*, and *Brasilichnium* were discovered in the Navajo Sandstone along with several tracksites in the Kayenta Formation. We will continue our field survey during the spring of 2011, concentrating on Canaan Mountain, which has the highest potential for significant body fossils.

KEYWORDS—Fossil Resource Management, BLM wilderness, PFYC maps, Washington County, Navajo Formation

ORAL PRESENTATION

DEVELOPING A POTENTIAL FOSSIL YIELD CLASSIFICATION MAP FOR GLEN CANYON NATIONAL RECREATION AREA

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ABSTRACT—Utah Geological Survey (UGS) has been using GIS to integrate existing digital geologic maps with the UGS Paleontological Locality Database to generate Potential Fossil Yield Classification (PFYC) 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.

The Bureau of Land Management has defined 6 levels of sensitivity for map units for the purpose of developing paleontological sensitivity maps, which the UGS has adopted. This sensitivity scale starts at five for the most sensitive map units and decreases to zero for map units that do not preserve fossil resources. This scale is: (5) Significant fossils are known and widespread; (4) Significant fossils are present; (3) Common fossils may be abundant, but significant fossils are rare (This category includes most Paleozoic formations and Pleistocene deposits.); (2) Significant fossils are rare; (1) Fossils are unlikely to occur; (0) Map units represent water and human-made features.

Distribution of fossil resources is typically first assessed by a thorough literature review, followed by fieldwork. Paleontological resources correlate with the distribution of geological units, so paleontological sensitivity maps may be constructed based on literature reviews and field data.

The PFYC map produced for the Glen Canyon National Recreation Area (GLCA) was based on geological maps published and under development by the UGS for the GLCA at 1:100,000 scale or greater. Only a general sense of the distribution of significant fossil resources can be made at the scale figured here (Fig. 1), as the size of the polygons defined in the GIS data are often smaller than the pixel size. However, the 1/125,000 scale map exhibited in this poster provides a tool that we hope will prove useful for National Park Service resource managers at GLCA. Future geological mapping at 1/24,000 scale would provide a basis for significantly better management tools.

KEYWORDS—Potential Fossil Yield Classification, Mapping, Glen Canyon

*Presenting author

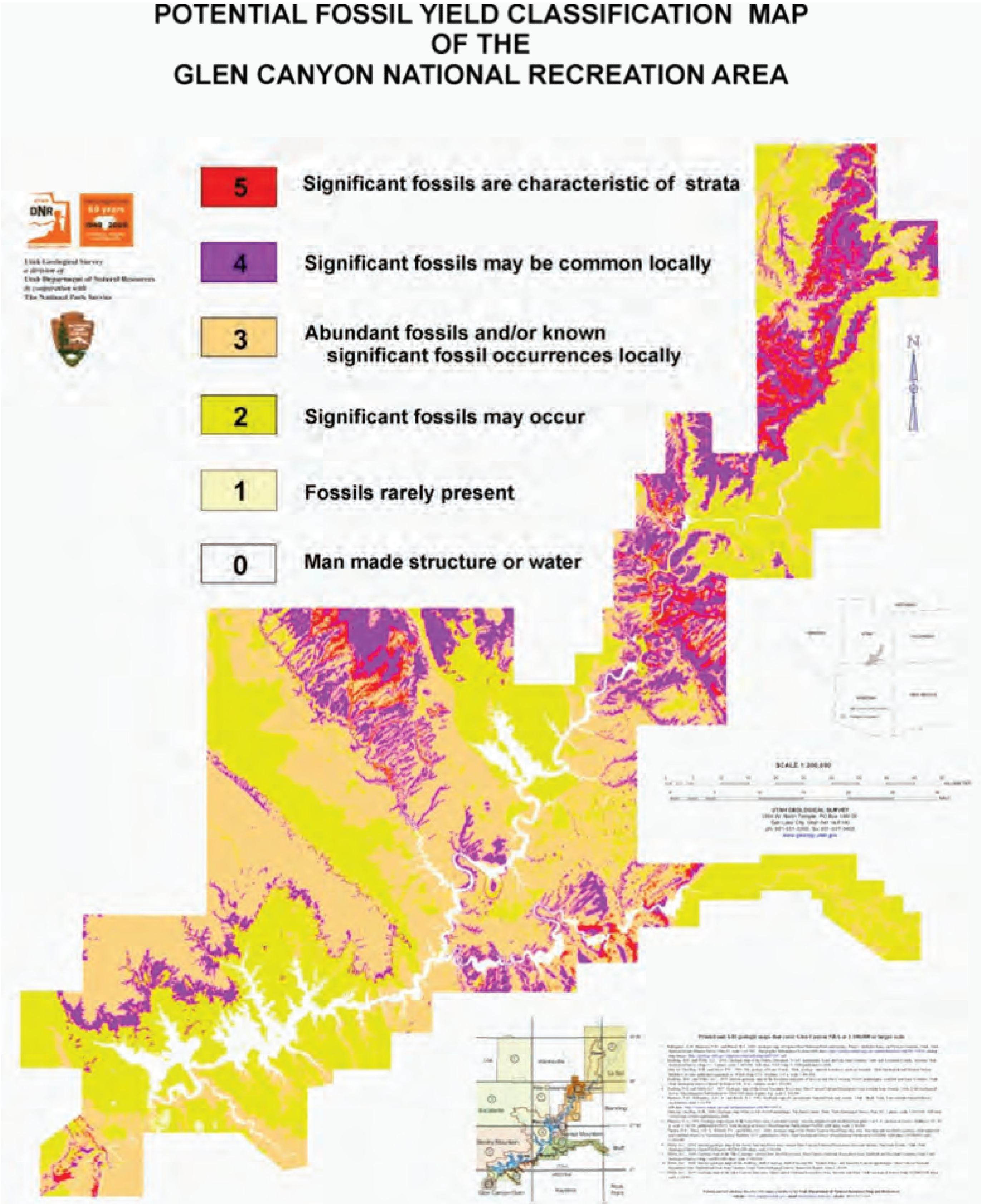

FIGURE 1. Potential Fossil Yield Classification (PFYC) for GLCA based on data collected during the course of this investigation.

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ORAL PRESENTATION

UPDATE ON THE STATUS OF THE SVP STANDARD GUIDELINES FOR THE ASSESSMENT AND MITIGATION OF ADVERSE IMPACTS TO PALEONTOLOGICAL RESOURCES

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ABSTRACT—In 1995, the Society of Vertebrate Paleontology (SVP) published “Standard Guidelines” for the “Assessment and Mitigation of Adverse Impacts on Nonrenewable Paleontologic Resources.” In the 15 years following their introduction, these guidelines functioned well, becoming *the* standard against which the adequacy of paleontological resource impact assessments and mitigation programs were judged. Many federal and state regulatory agencies either formally or informally adopted the SVP’s Standard Guidelines for the mitigation of construction-related adverse impacts on paleontological resources. The SVP’s guidelines outlined acceptable professional practices in the conduct of paleontological resource impact assessments and surveys, monitoring and mitigation programs, data and fossil recovery, sampling procedures, and specimen preparation, identification, analysis, and curation. The SVP’s Standard Guidelines were approved by a consensus of professional vertebrate paleontologists and most practicing professional paleontologists involved in mitigation adhered closely to the SVP’s assessment, mitigation, and monitoring recommendations.

Although the 1995 SVP Standard Guidelines were highly successful in standardizing procedures for protecting paleontological resources, in 2009 several paleontologists suggested to the SVP Executive Committee that the guidelines should be reviewed to determine their effectiveness and adequacy—a particularly timely suggestion, since legislation requiring federal agencies to rewrite resource regulations pertaining to the preservation of paleontological resources was also coming into effect. The SVP Executive Committee reconvened the Conformable Impact Mitigation Committee (which wrote the 1995 edition of the Standard Guidelines) under the new name “Ad hoc Committee on SVP Impact Mitigation Guidelines Revision” and appointed six new members to join six members of the original committee, with Bob Reynolds and Lanny Fisk as co-chairs. The co-chairs and committee members were selected for their experience with mitigation of construction-related impacts on paleontological resources. Members include paleontologists active in the private sector, paleontologists employed by federal and state public agencies, and academicians involved with mitigation on a part-time basis. Committee members engaged in lively and fruitful discussions as they strived for mutual understanding and consensus.

From the beginning, all agreed that the professional paleontological community must be proactive in establishing “best practice” guidelines for the protection of paleontological resources. Committee members agreed that the profession must step forward with standard guidelines so that individual agencies would not be tempted to establish separate and perhaps inconsistent guidelines without professional input. Likewise, the committee agreed that the SVP’s Standard Guidelines should be acceptable to the community of professional paleontologists so that they would not be tempted to develop their own individual guidelines independent of the SVP. There was universal agreement that the SVP Standard Guidelines should clearly and unequivocally state what the community of professional paleontologists would like to see as standard procedures for assessing potential impacts to fossils and mitigating these impacts. Overall, the committee’s goal was to develop revised guidelines that would gain wider acceptance, approval, and application and thus result in greater protection of paleontological resources.

The Ad Hoc Committee on SVP Mitigation Guidelines submitted its final draft of the revised guidelines, retitled Standard Procedures for the Assessment and Mitigation of Adverse Impacts to Paleontological Resources, to the SVP Executive Committee for review in March 2010. While still emphasizing vertebrate fossils, the revised guidelines provide broader application to other paleontological resources so as to be consistent with the 2009 Paleontological Resources Preservation Act (PRPA, 16 U.S.C. 470aaa) and new regulations currently being developed by the departments of Interior and Agriculture. The 2010 edition of the SVP standard guidelines also amends rock unit classification categories (1) high, (2) low, or (3) undetermined to add a fourth--(4) no potential for containing significant paleontological resources, meant to apply to high-grade metamorphic rocks (such as gneisses and schists) and plutonic igneous rocks (such as granites and diorites). Another proposed revision addresses standardization of verbs such as “will be,” “should be,” and “may be” to help clarify exactly what actions the community of professional paleontologists consider important and necessary versus those that are optional or only recommended.

KEYWORDS—Society of Vertebrate Paleontology, SVP Standard Guidelines, Paleontological Mitigation, Paleontological Resource Impact Assessment, Paleontological Protection

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POSTER SESSION

MILESTONES IN U.S. GOVERNMENT PALEONTOLOGY

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ABSTRACT—As it acquired various territories, the young and expanding United States needed to know what mineral, cultural, and natural resources existed on its western lands. A Congressional survey of the Territories was followed by detailed mapping and analysis by the US Geological Survey (USGS) and eventually evolved into the bureaucracy of federal land management agencies that we still have today. Each step of the way, the laws and policies of the ever-expanding nation were informed by exploration and scientific inquiry.

Following the "Bone Wars" of 1891 and the exclusion of fossils from the Antiquity Act of 1906, policy regarding paleontological resources has lagged behind that regulating nearly every other natural or cultural resource on America's public lands. This timeline, which traces the history of paleontological exploration and policy, illustrates the complex and often nuanced relationship between historical events, notable personalities, and legislative actions.

KEYWORDS—Policy, USGS, Antiquity Act

ORAL PRESENTATION
Article, p. 43–50

PALEONTOLOGY AND PUBLIC DIPLOMACY

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ABSTRACT—Questions of global climate change and other currently relevant social and political issues require applications of paleontological research that are far more complex than which dinosaur fossil is largest or how many new fossil species may be identified in one year. Management of public lands, both for current development and for the enjoyment of future generations, requires that people making decisions have the best information that is based on scientific principles and expertise. An inability to reach the general public with meaningful and relevant scientific results has led to a lack of appreciation for the importance of paleontological research. A lack of diplomatic skills may also have hindered paleontological managers from garnering the bureaucratic support necessary to develop paleontology into a fully functioning independent program within the United States Government.

With advances in scientific methodology, including increased collaboration between related sciences, understanding paleontology is more important than ever. The science of paleontology offers a unique "deep-time" perspective that can enrich understanding of many current scientific questions on topics ranging from nuclear proliferation to global climate change. With the recent implementation of the Paleontological Resources Preservation Act, government paleontologists have a unique opportunity to create and mold concepts of policy and diplomacy that will affect the way paleontological resources will be viewed and managed well into the future.

KEYWORDS—Paleontology, Policy, Land Management

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ORAL PRESENTATION

A HISTORY OF FEDERAL PALEONTOLOGISTS

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ABSTRACT—Starting with O. C. Marsh and continuing through the present, the United States government has continuously employed paleontologists. The earliest paleontologists were contracted to conduct surveys of the Territories. The federal government began directly funding paleontological exploration, research, and curation in 1878, when the U.S. Geological Survey was created and directed to deposit collections with the Smithsonian. The National Park Service did not establish a full-time paleontologist position until 1953, however, and the Bureau of Land Management and the U. S. Forest Service did not do so until 1980 and 1992, respectively. To date, the Bureau of Reclamation, Fish & Wildlife Service, U. S. Department of Defense, and U. S. Department of Energy—all federal agencies that manage lands containing significant paleontological resources—have never hired a paleontologist.

Today there are approximately 38 paleontologists assigned to paleontology positions in the federal government; nearly the same number of geologists, archaeologists, and museum curators have job responsibilities that require advanced knowledge of the field. While this is the largest number of paleontologists to be employed at any time in U.S. history, it is still too few to compel the U.S. Government's Office of Personnel Management to establish a career series in paleontology. Over the past 30 years there has been a shift in paleontological careers in the federal government from basic exploration and research to management and development of paleontological programs, providing infrastructure for greater participation by non-governmental paleontologists.

KEYWORDS—Paleontology, Policy, Federal Land Management

ORAL PRESENTATION

TRILOBITES FROM THE UPPER CADIZ FORMATION (MIDDLE CAMBRIAN; DELEMARAN) OF THE SOUTHERN MARBLE MOUNTAINS OF CALIFORNIA

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ABSTRACT—*Glossopleura* (*G. walcotti* and *G. boccar*?) and *"Anoria" lodensis* dominate a sample of about 200 trilobite specimens from the top of the middle Cambrian Cadiz Formation in the Marble Mountains of California. Fauna also includes indeterminate kochaspids (possibly including *Amecephalus* sp.), *Kochina vestita*, *Mexicella mexicana*, *Mexicaspis stenopyge*, and *Caborcella* sp. The sampled fauna is from the *Glossopleura* biozone (Delamaran; Series 3) and is from approximately 5–10 meters below the Bonanza King Formation. The degree of articulation at the site is extremely low; the sample is dominated by cranidia and librigenae. Corynexochida accounts for nearly 75% of the specimens collected; small specimens are less common but still present and well preserved. A revised faunal list for the site is presented along with a discussion of previous summaries, of which there are very few for the Cadiz Formation. The site exhibits taphonomic characteristics quite different from similar-age deposits in the Spence Shale and Bright Angel Shale.

KEYWORDS—Trilobites, Cambrian, Cadiz Formation

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ORAL PRESENTATION

UTAH'S PALEONTOLOGICAL LOCALITY DATABASE SYSTEM

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ABSTRACT—In 1977, a revision of the Utah State Antiquities Act added "paleontology" to the wording of the law, created the office of the Utah State Paleontologist, and provided a legal basis for the protection and management paleontological resources on state lands. Since then, the office of the State Paleontologist, now at the Utah Geological Survey (UGS), has worked to develop programs, policies, and strategies to protect and manage Utah's fossils. Efforts to preserve and protect paleontological resources on all lands in Utah have relied upon partnerships and cooperative agreements with state and federal land management agencies, private landowners, paleontological consultants, and researchers working in the state of Utah. One of the major resource management projects has been to develop and maintain the Utah Paleontological Locality Database System. The original database, begun over 30 years ago as a compilation of paleontological localities from the published literature, has developed through the years into an integrated statewide database system. It is currently maintained in a Microsoft Access Database linked to an ArcGIS map project that displays fossil locality data in relation to other data layers, including topographic, geologic, and land-ownership data. Since 2002, the UGS has had a cooperative agreement with the Utah State Office of the Bureau of Land Management for the management of paleontological locality data. Effective data management is key to the successful management of paleontological resources. Data collection standards, data security, and availability of accurate GIS data are some of the data management issues that will be discussed.

KEYWORDS—Utah State Antiquities Act, Utah Geological Survey, Paleontological Locality, Database System

ABSTRACT

UPDATE ON MINERAL WELLS FOSSIL PARK–A PROJECT BY THE CITY OF MINERAL WELLS, TEXAS WITH ASSISTANCE FROM THE DALLAS PALEONTOLOGICAL SOCIETY

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ABSTRACT—Development of Mineral Wells Fossil Park (MWFP, www.mineralwellsfossilpark.com)—a free, city-owned park located 90 minutes west of downtown Dallas and 45 minutes west of downtown Fort Worth—continues to progress. After the City of Mineral Wells' City Council and Park Board approved its establishment, the Dallas Paleontological Society (DPS, www.dallaspaleo.org) raised and donated over $7000, numerous individuals and organizations contributed toward its opening, and the City agreed to match these funds. A gate, school bus parking lot, primitive toilet, informational sign, fencing, and chain handrail were installed and MWFP officially opened on 8 May 2010 with a ribbon cutting witnessed by more than 400 visitors (see Figures).

The site is now an outdoor hands-on science museum where visitors can touch and collect common Pennsylvanian Age marine fossils in situ, creating excitement and positive feelings about paleontology.

Information about the new park is being disseminated in a variety of forms: newspapers in Dallas, Fort Worth, Denton, and Austin have published articles; Texas Highways magazine will release an article about Mineral Wells mentioning Mineral Wells Fossil Park in May; Channel 4 in Dallas will be doing a video article; printed flyers from the Mineral Wells Chamber of Commerce are making their way to local museums; and a facebook page dedicated to Mineral Wells Fossil Park already numbers 574 members. Although highway signage for the park is not yet resolved, it should be forthcoming.

KEYWORDS—Mineral Wells, Fossil Park, Pennsylvanian Age, Dallas Paleontological Society

FIGURES. Mineral Wells Fossil Park, Texas, Grand Opening, November 2010. Example of fossils found at the park (image at right).

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ORAL PRESENTATION

FUN WITH TRACKS AND BONES: COOPERATIVE MANAGEMENT OF PARK PALEONTOLOGICAL RESOURCES BY COLORADO NATIONAL MONUMENT AND THE MUSEUM OF WESTERN COLORADO

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ABSTRACT—In the decade following George Callison's paleontological survey of Colorado National Monument in western Colorado in 1977, little paleontological work was done in this National Park Service unit. After Foster (1998) listed several sauropod tracksites in the Morrison Formation of the Monument, the Museum of Western Colorado began working with the monument in 2001 to document new paleontological sites and monitor those previously found. Work by museum crews, and by Ryan King and Josh Smith, documented a number of dinosaur track sites in the canyons of the monument, both in place and in fall blocks of Wingate Sandstone. Most of these tracks consist of *Grallator* specimens 6–17 cm in length (King et al., 2004) and occur as both natural casts and impressions. At least seven of the sites occur in Ute Canyon. A second, monument-wide survey by Kelli Trujillo and others in 2004 documented more sites and relocated many of Callison's sites. Most significant among the new finds was the tooth plate of a lungfish from the lower Morrison Formation (Imhof and Trujillo, 2005). In 2005, Fruita resident Marilyn Sokolosky showed museum crews a track site in the lower Morrison Formation that contained the second known occurrence of turtle tracks from the Late Jurassic of North America (Lockley and Foster, 2006). Not far from this site, and at the same stratigraphic level, was a second locality with tracks of a theropod and an ornithopod, the latter assigned to *Dinehichnus* (Lockley and Foster, 2006). Part of the slab with turtle tracks was collected in September 2010. Around the same time, Jim Roberson, a monument maintenance employee, found a small theropod or ornithopod track in the lower Morrison near Artists Point. John Foster and ReBecca Hunt-Foster found a new type of track, possibly belonging to small reptiles, in the lower Morrison in the same area.

The partnership between Colorado National Monument and the Museum of Western Colorado strengthened in 2010 with collaboration for the first ever National Fossil Day. National Fossil Day, hosted by the National Park Service and the American Geological Institute, is a celebration organized to promote public awareness and stewardship of paleontological resources and to foster a greater appreciation of the scientific and educational value of fossils. On October 12, 2010, Colorado National Monument and the Museum of Western Colorado provided a paleontology-focused field trip for more than 230 fourth grade students. During this National Fossil Day celebration, students visited both the museum and the monument: at the museum, students learned how fossils form, about geologic time and the geology of our area, and about fossils we find locally; at the monument, students took a ranger-guided hike in relevant geologic strata. Field trip content not only highlighted local fossil discoveries but also aligned with Colorado state science standards. Junior Paleontologist activity books were distributed to the three local, participating schools prior to the field trip date; students completed educational fossil activities and were awarded their Junior Paleontologist badges during the field trip. The fourth graders were the first public to view the "unveiling" of newly recovered fossilized turtle tracks displayed at the monument (later moved to the museum). Colorado National Monument hosted a public fossil "unveiling" on October 13, 2010, highlighting the recent discoveries, new exhibits, and honoring George Callison, John Foster and Bill Hood for their contributions to paleontological and geological research in the monument.

The partnership between Colorado National Monument and the Museum of Western Colorado has grown over the years, resulting in numerous educational opportunities, cooperative exhibits, and increased scientific research. This great working relationship benefits not only the residents of western Colorado, but all visitors to both venues.

KEYWORDS— Colorado National Monument, Museum of Western Colorado, National Fossil Day, Wingate Sandstone, Morrison Formation, Fossil Tracks

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ORAL PRESENTATION

ANCIENT CHANGES, MODERN MESSAGE: UTILIZING PALEOECOSYSTEMS OF THE CENOZOIC FOSSIL PARKS TO INTERPRET PAST AND PRESENT CLIMATE CHANGE

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ABSTRACT—At a fossil park, visitors are surrounded by a modern ecosystem different from the one experienced by its ancient inhabitants, making fossil parks ideal locations for interpreting past and present climate change. Oregon State University and the National Park Service are in the process of developing a training manual for interpreters at six Cenozoic fossil parks, designed to help interpreters connect visitors to the fossil evidence of changing landscapes, climates, and life preserved in the parks as well as clues about how change will affect our future. The manual focuses on the dramatic shift that occurred over the past 65 million years as the Earth transitioned from the greenhouse world experienced by the dinosaurs to a planet so cold that ice sheets advanced and retreated during the ice ages, with each park telling a different chapter of that story. Using the horse family as an illustration, the manual discusses how animals and plants migrated to more favorable conditions, adapted to the changes, or did not survive when the ancient ecosystems changed outside of an organism's "comfort zone." As modern climate continues to change, all living things—including humans—will face those same challenges. The manual also includes background information and suggestions for interpreting paleontology while answering three common visitor questions: "How old is it?" "What is a fossil?" and "Were all of those fossils found here?!" Although designed for use at the Cenozoic fossil parks, the interpretive suggestions can be tailored to any fossil site.

KEYWORDS— Climate Change, Cenozoic Era, Interpretation, Education, Paleoecosystem

POSTER PRESENTATION
Article, p. 51–60

ESTABLISHING A PALEONTOLOGICAL MONITORING TEST SITE AT GLEN CANYON NATIONAL RECREATION AREA

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ABSTRACT—Several factors were taken into consideration while establishing a paleontological monitoring test site at Glen Canyon National Recreation Area. Strata in the Recreation Area preserve a significant fossil record that includes many world class paleontological sites (Santucci and Kirkland, 2010), most notably a wealth of Lower Jurassic dinosaur tracksites preserved in the Glen Canyon Group along the margins of Lake Powell (Lockley et al., 1992, 1998). Santucci et al. (2009a) summarized the factors affecting in situ paleontological resources and strategies for monitoring their effects. There is little documentation of the long-term effect of these factors on fossil resources, but it is generally not an extremely rapid process unless the fossil is in an area of active erosion such as the bank of a river or the coast of a large body of water, or if the fossil in located in soft sediment. Vandalism and theft by humans pose a major threat to in situ fossil resources.

It is important to consider the costs associated with developing a monitoring plan. The most sophisticated methodologies may be cost-prohibitive and require trained scientists to carry out. Once a paleontological site has been properly documented, a plan can be developed to provide a means for low-cost, long-term monitoring. If significant changes are documented during subsequent visits, a follow-up inspection may be made by specialists (Milner et al., 2006; Santucci et al., 2009a, Spears et al. 2009).

KEYWORDS—Paleontological Monitoring, Glen Canyon National Recreation Area, Dinosaur Tracksite

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ORAL PRESENTATION

PLANNING, EXCAVATING, AND RECLAIMING A DINOSAUR EXCAVATION USING MECHANIZED EQUIPMENT IN THE 21st CENTURY

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ABSTRACT—While investigating a pipeline corridor with Uinta Paleontological Consultants, Inc. in 2002, Bureau of Land Management (BLM) geologist Roland Heath discovered ornithopod dinosaur bones weathering out of the Lower Cretaceous Cedar Mountain Formation a few tens of meters east of the pipeline corridor northwest of Dinosaur National Monument (DNM). The site, now known as the Reef Ornithopod, was referred to Scott Madsen, then preparator-geologist at DNM, who secured permits from the BLM and began a test excavation on the site in 2004. Several unguals, phalangies, and caudal vertebrae were recovered and curated into the DNM collections.

Policy changes at DNM precluded further work on the site by DNM personnel, and the site was turned over to the Utah Geological Survey (UGS). Permits were secured and more extensive excavations resumed in the spring of 2007 with the Utah Museum of Natural History as the newly designated repository. These excavations resulted in the exposure of a more associated skeleton with many more phalangies, vertebrae, and ribs, portions of the forelimbs, teeth, and possible skull material in a large block of rock, with more of the skeleton extending into the ground.

The site is situated on a steep slope and the enclosing strata dip steeply into the hill, requiring an extensive high wall to be excavated in the rock to expose even a small portion on the bone-bearing layer. This phase of the excavation required about three days of back-breaking pick, shovel, and electric jack hammer work for each day of work on the bone-bearing interval (estimated at about 0.5 meter thick). Upon reaching a large natural parting surface cutting across the specimen, we made a plaster jacket over the block then flipped the jacketed block (which weighed several hundred kilograms) off the parting with railroad pry-bars without splitting any bones. Because the pipeline crew was scheduled to reach the area in a few weeks, we decided to request permission from the BLM to take advantage of the pipeline company's offer to use their equipment to lift the jacketed portion of skeleton off the site and to remove overburden upslope so that the rest of the skeleton could be excavated. The plaster jacket and quarry were buried until we could return and excavate the remainder of the skeleton.

The National Environmental Policy Act required a new evaluation of the site and the environmental consequences of utilizing mechanized equipment to excavate the remainder of the skeleton. The Utah State Paleontologist quickly put together a formal excavation plan (Fig. 1) and submitted it to the BLM, but the opportunity to have free use of mechanized equipment had passed. A permit was issued in the spring of 2009, but funds were unavailable to support field work or to hire equipment to assist in the excavation for the 2009 field season. Over the winter of 2009–2010, a connection was made with Ames Construction through the interest their engineer, Don Brummel, and his family have in dinosaur paleontology. Ames Construction was generous enough to provide equipment, transportation, and operators to assist in the excavation in May 2010.

The UGS crew arrived a few days early to uncover the jacket, ready the quarry, and become familiar with the route into the site approved by the Vernal BLM office. The plaster jacket had corroded badly over the two winters it lay buried in the field and had to be completely rejacketed. By the time Don Brummel arrived with his crew, we had harnessed the jacket up so that it was ready to be lifted out of the quarry, transported down to the road, and put on a truck for transport to the UGS preparation lab in Salt Lake City. Meanwhile, Ames Construction excavated the overburden from above and around the remainder of the skeleton, leaving the remaining dinosaur bones in a small hill within a large hole.

Over the next week the UGS crew worked to delineate, map, and jacket the remainder of the skeleton so that we would be ready when Ames Construction returned to Vernal to assist in lifting the remainder of the dinosaur out of the excavation and transporting it to the road. Had we not completely excavated the dinosaur in the area they exposed for us, any additional bones would have to be left in the ground, as it would have been impractical to dig the pit any deeper in the tough rock enclosing them. Fortunately, we were able to excavate all of the skeletal remains and encase them in a jacketed block (which also weighed hundreds of kilograms). The Vernal Field House of Natural History offered to help prepare this block. We decided if enough fossil material was available to construct a mounted skeleton, we would seek to get a mount for Vernal as well as the Utah Museum of Natural History. While there is much work to go on that block, preliminary preparation has exposed at least one jaw with teeth.

Ames Construction was completely responsible for the reclamation of the excavation, which would easily have taken more than a week if our crew had attempted it with hand tools. They filled the excavation pit, contoured the slope, and smoothed out the rough area to ensure good drainage of the site. Additionally, they raked out the access route and dropped some large rocks across the gap in the ridge that they had used to access the site from the road to discourage use by off-road vehicles. Six months after reclamation, there is barely a sign that this excavation took place.

Preparation of the fossils themselves is still in the early stages, but we have skull material so it is likely that we have collected taxonomically-significant material. Our initial guess, based on stratigraphic position, was that the dinosaur might represent the first specimen of *Tenontosaurus* to be collected in Utah, but the morphology of the jaw suggests it may be something else, perhaps something new. A publication on our geological observations of the stratigraphic section exposed crossing the site and on the implications of a new radiometric date we obtained from the overlying Dakota Formation is currently in review.

Despite the trials and tribulations involved in this excavation, it still stands out as a true success story for the kind of research and minimal environmental impacts that may result from interagency cooperation and a bit of patience on all sides.

*Presenting author

KEYWORDS—Site Steward, Volunteer, Resource Management

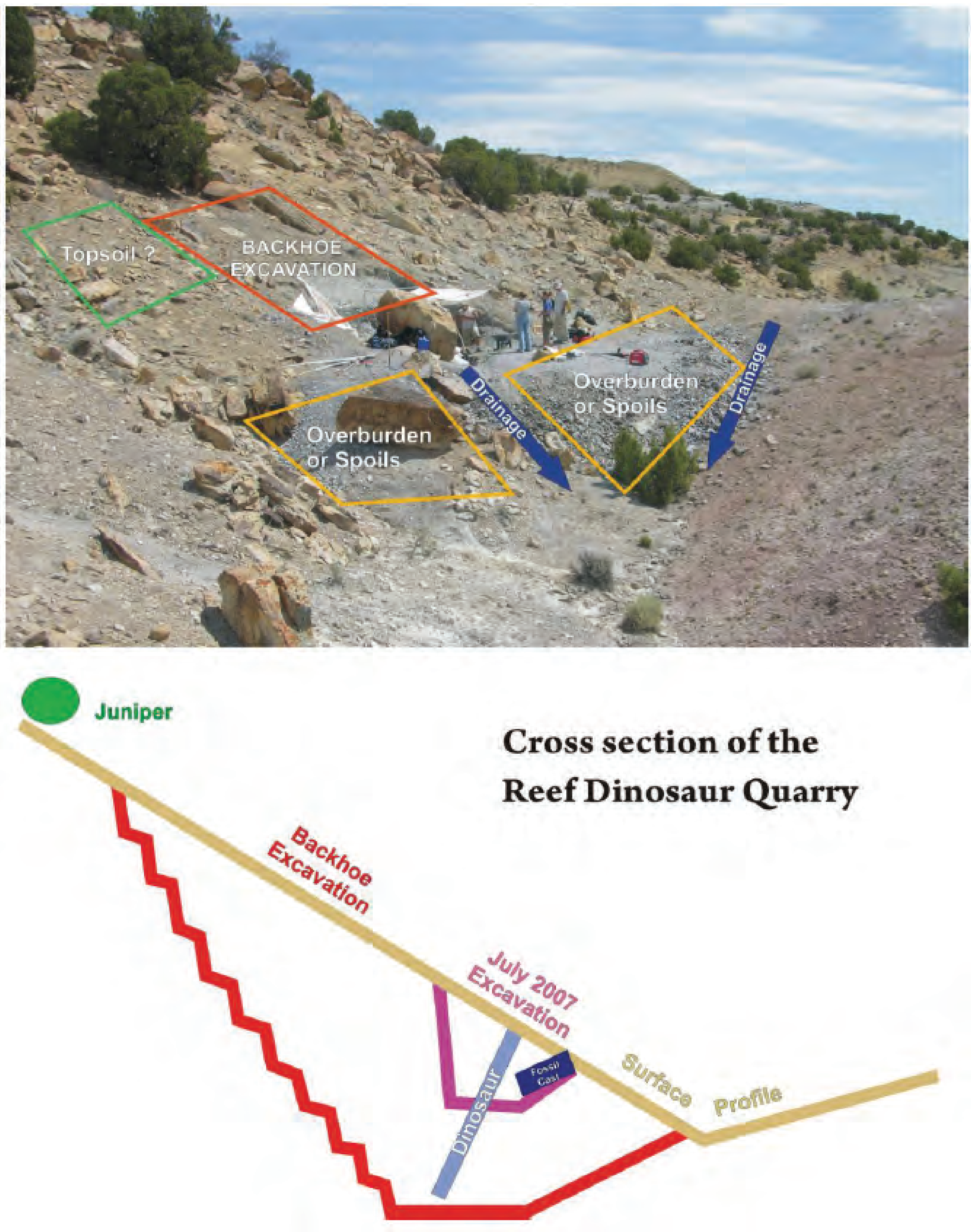

FIGURE 1. Initial excavation plan for the Reef Ornithopod.

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ORAL PRESENTATION

THE EFFECTIVENESS OF PRE-SURVEY AERIAL PHOTOGRAPHY AND GEOLOGIC MAP REVIEWS: A CASE STUDY BASED ON FOSSIL DISTRIBUTION WITHIN THE UINTA FORMATION, UINTAH COUNTY, UTAH

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ABSTRACT—Prior to conducting field surveys, mitigation paleontologists commonly examine topographic, fossil locality, and geologic maps, as well as aerial photography in order to delineate areas with the highest paleontological potential. This practice has become especially prevalent in recent years with ready access to high resolution aerial imagery via free software such as Google Earth and data sets such as the USGS Seamless Data Warehouse. These methods are especially useful to mitigation paleontologists when analyzing large geographic areas as part of the permitting process for surface disturbing projects on public lands. Many such projects have time, cost, and/or access constraints which make such analyses beneficial. Subsequent to this initial desktop review the overall sensitivity of a project area is generally considered to be adequately assessed, and the information is used to determine a field survey strategy. At this point it is typically assumed that areas with the greatest amount of exposed sedimentary bedrock have the highest paleontological sensitivity (greatest potential to yield scientifically significant surface fossils). Using a large data set comprised of approximately 5,000 fossil occurrences recorded during a block paleontological survey of the Uinta Formation in the vicinity of Leland Bench, Uintah County, Utah, we explore the effectiveness of pre-field survey desktop analyses to predict actual surface fossil distribution. Using aerial photography of six square miles within the original block survey, we calculated the amount of terrain consisting of a) well exposed bedrock; b) weathered and partially vegetated bedrock; and c) bedrock completely covered by vegetated surficial sedimentary deposits, then inferred differential paleontological sensitivity. We compared the resulting sensitivity map with the fossil occurrence data from the field survey to determine the reliability of the predictive model.

KEYWORDS—Uinta Formation, Uintan, Geologic Mapping, Paleontological Resource Management, Aerial Photography

ORAL PRESENTATION

INVENTORY AND UPDATING THE WHITE RIVER GROUP COLLECTIONS FOR THE MOVE TO THE JAMES E. MARTIN PALEONTOLOGICAL RESEARCH LABORATORY

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ABSTRACT—The collections at the Museum of Geology at South Dakota School of Mines and Technology (SDSM), started in 1885, currently numbers more than 500,000 specimens. A large number of these specimens were recovered from federally-managed lands in the extensive White River Badlands of South Dakota and Nebraska (Oligocene through Miocene); SDSM acts as a repository partner for federal land management agencies. Fossils have been used for research, teaching, and training.

When construction of the new James E. Martin Paleontological Research Laboratory began in 2009, SDSM undertook a complete review and inventory of these fossils and their associated data for the first time in many years. The extent and complexity of the White River Badlands fossil holdings and their associated data have made this a particularly important project. The principal goal of this project was to move the fossils into the best possible biostratigraphic sequence in order to facilitate future retrieval and research. Secondarily, the project will separate the White River Badlands collection into three administrative sub-collections: those associated with Badlands National Park (North Unit), those associated with Badlands National Park and the Pine Ridge Reservation (South Unit), and the remaining White River Badlands fossils from all other public and private lands. This project will be ongoing through 2011 and will result in much finer-grained and accurate data for all specimens as well as better management of fossil collections with multiple stakeholders.

KEYWORDS—South Dakota School of Mines and Technology, White River Badlands, Paleontological Research Laboratory, Museum Collections

*Presenting author

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ORAL PRESENTATION

THE IMPACT OF VOLUNTEER PALEONTOLOGICAL MONITORING AND SURVEYING IN CARIBOU-TARGHEE NATIONAL FOREST ON THE CRETACEOUS PALEONTOLOGY OF SOUTHEASTERN IDAHO

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ABSTRACT—In 2001, volunteers began monitoring and surveying paleontological resources in mid-Cretaceous strata found within the boundaries of the Caribou-Targhee National Forest near the Wyoming border of southern Idaho. Fieldwork focused in the Caribou Basin and Fall Creek areas of Bonneville County, and the Tincup Canyon area of Caribou County and was conducted on a volunteer basis by the primary author (LK), an undergraduate student at Idaho State University at the time, under the supervision of the Caribou-Targhee National Forest Regional Paleontologist at the time, the secondary author (SR), through a formal voluntary agreement. The purpose of this paleontological reconnaissance was the monitoring of known fossil localities, collection of additional specimens from these localities, and the search for new paleontological localities; it also resulted in numerous undergraduate research projects, published abstracts and a paper, a MS thesis, and ongoing research opportunities.

Findings from this work include a freshwater vertebrate fauna from the Aptian-Albian Draney Limestone of the Gannett Group, exposed in Tincup Canyon. The Draney Limestone represents a series of one or more large lakes that straddled the Idaho/Wyoming border in the mid-Cretaceous. The Draney fauna is known from two localities, Pine Bar and Cretaceous Park. The Pine Bar locality has produced the most varied fauna, consisting of rare teeth from the shark *Hybodus*, abundant crushing teeth from the fish cf. *Lepidotes*, numerous unidentified fish bones and ganoid scales, a poorly preserved large dinosaur trackway, as well as plastron and carapace fragments from the turtle cf. *Glyptops*. Invertebrates include numerous ostracods, freshwater gastropods, and unionid bivalves, while flora are represented by unidentified wood petrifactions and angiosperm leaf fragments. The Cretaceous Park locality is less varied, with plastron and carapace fragments from the turtles cf. *Glyptops* and cf. *Naomichelys* and crocodylian teeth. Invertebrates here consist of abundant ostracods and rare gastropods.

Work in the Cenomanian Wayan Formation, as exposed in Tincup Canyon, Caribou Basin, and the Fall Creek area, has facilitated understanding of what is now Idaho's best represented Mesozoic terrestrial fauna. Deposition of the Wayan Formation occurred in a narrow inland alluvial strip with the Paris and Meade Thrust highlands of the early Sevier Orogeny to the west and the Mowry Seaway to the east. This area was subject to a monsoonal climate represented by numerous well developed paleosol horizons with calcareous nodules. Discoveries include numerous partial skeletons of Idaho's first well represented dinosaur, the small fossorial ornithopod *Oryctodromeus*. Taphonomic evidence for these specimens supports fossorial behavior and social grouping as demonstrated for the holotype and paratype specimens from the Blackleaf Formation of southwestern Montana. Other specimens include associated vertebrae and pedal elements from an indeterminate small iguanodontian, a dromaeosaurid theropod tooth, abundant eggshell of the family Elongatoolithidae (possibly representing nesting sites of indeterminate large theropods), a partial large crocodylian skull that exhibits similarities to the later Cretaceous form *Deinosuchus*, crushing fish teeth and ganoid scales similar to *Lepidotes*, and unidentified turtle carapace and plastron fragments. Moderately well-represented flora is known from one locality and consists of foliage from the ferns *Gleichenia* and *Anemia*, as well as foliage and cones from conifers, partial angiosperm leaves, and wood petrifactions.

Notably, all of these discoveries result from work done by volunteers through 2008. Because supervised volunteer locality monitoring and prospecting were conducted on a relatively cost-free basis and afforded opportunities for Caribou-Targhee National Forest and other federal land management agencies with the same strata to gain a greater understanding of fragile paleontological resources, this represents an advantageous model of paleontological conservation on federal lands. Significant specimens, which have since been utilized in numerous research projects, were collected under supervision of the Regional Paleontologist and were reposited in federally accredited repositories. In addition, this opportunity of volunteerism represents an advantageous way to harness amateur and student enthusiasm, providing a springboard for student research and related projects and valuable hands-on and field experience learning opportunities.

KEYWORDS—Idaho, Cretaceous, Wayan, Draney, Caribou-Targhee

*Presenting author

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ORAL PRESENTATION

EDUCATING FUTURE PALEONTOLOGICAL RESOURCE MANAGERS AT OGLALA LAKOTA COLLEGE (OGLALA SIOUX TRIBE), PINE RIDGE RESERVATION, SOUTH DAKOTA

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ABSTRACT—Since the decision to return the South Unit of Badlands National Park to the Oglala Sioux Tribe in late 2010, there has been a growing interest within Oglala Sioux Tribe (OST) governmental agencies to employ academically trained Lakota people in the field of cultural and paleontological resource management. On the Pine Ridge Reservation, fossils, artifacts, and human remains are collectively considered to be *cultural resources*, in that they are all remains of the interconnected once-living that are recovered by excavating the earth. Oglala Lakota College (OLC) has responded to this need by obtaining external funding to support undergraduate and graduate student curricula in cultural (paleontological) resource management and by establishing data and specimen repositories to support the OST Tribal Historical Preservation Office's (THPO's) efforts. Our undergraduate curriculum, which is still being developed, consists of a Cultural Resources Emphasis in our B.S. in Natural Science. The OLC Department of Humanities contributes coursework in archeology to this degree program. Our graduate curriculum is also in progress, and consists of an M.S. in Cultural Resource Management granted by St. Cloud State University. This curriculum consists of coursework and research conducted principally at OLC, and presently accommodates a cohort of four graduate students. The OLC data and specimen repositories were originally intended to house biological collections. However, ongoing plans to repatriate fossils and artifacts from the South Dakota School of Mines & Technology, the Smithsonian Institution, Augustana College, and the South Dakota Archeological Center, along with fossils and artifacts recovered during highway salvage operations, has required that we expand the mission of our repository. The repository is under construction with completion projected for late 2011 or early 2012. In addition, discussions are underway to house the OST THPO at the OLC Department of Math, Science, & Technology. The curriculum development and repository described herein are supported by National Science Foundation Tribal Colleges and Universities Program and Academic Research Infrastructure grants to C. Jason Tinant and Hannan E. LaGarry (CoPIs).

KEYWORDS—Paleontological Resources, Tribal, Oglala, Education, Management

ORAL PRESENTATION

GIS MAPPING OF FOSSIL LOCALITIES USED AS A MANAGEMENT TOOL

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ABSTRACT—The Farmington, New Mexico Field Office (FFO) of the Bureau of Land Management manages the 44,897 acre Bisti/De-Na-Zin Wilderness. The last systematic inventory of paleontological resources in the Bisti was conducted in 1977; the FFO has used Geographic Information Systems (GIS) to generate a map using that data. We have also incorporated locality data collected over the last 20 years by the New Mexico Museum of Natural History and Science (NMMNHS) and the State Museum of Pennsylvania through reconnaissance, surface collection, and excavation. The map's spatial data will help to highlight areas where fossils were recorded or collected sorted by year, by project, by collector, or by fossil type.

A complete paleontological resources inventory of the Bisti will begin in July of 2011 through an assistance agreement with the NMMNHS. This multi-year project will review all previously-known fossil localities in the Wilderness (published and unpublished), including a re-inventory of the 1977 sites. Use of the map will help identify survey priorities by pinpointing areas where the most pressing needs for inventory exist. New localities discovered during the course of the survey will be added to the GIS data base map.

This map provides an effective visual inventory and a valuable paleontological resource management tool for the FFO. In the future, similar GIS maps can be developed for the FFO's nine paleontological Specially Designated Areas. The BLM can use these maps to protect fossil resources, coordinate volunteer efforts, prioritize field work, develop monitoring strategies, locate new research areas, and reconstruct paleoenvironments. They can also be used for partnerships, public outreach, and educational purposes.

KEYWORDS—Bisti/De-Na-Zin, Inventory, GIS, Survey, Strategy

*Presenting author

ORAL PRESENTATION

BUILDING A NEW PALEONTOLOGY SITE STEWARD PROGRAM

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ABSTRACT—Ideally, paleontological resource management would include a smorgasbord of surface reconnaissance, monitoring of recorded fossil localities, patrolling areas of heavy public use in fossil-rich areas, monitoring permitted field projects, assisting with research projects, in-house endeavors, outreach, and monitoring erosion at known sites. The BLM Farmington Field Office (FFO) manages 1.8 million acres, of which 120,299 acres fall into paleontological Specially-Designated Areas. The FFO manages 85% of the acreage in New Mexico's paleontological specially-designated areas. In addition, the remaining 1.6 million acres in the FFO are classified as 5 (Very High/highly fossiliferous and/or at risk) on the Potential Fossil Yield Classification scale. Management of this vast resource falls on one half-time paleontology specialist.

Following on the heels of a highly successful Archeology Site Steward Program, management will fill the gap with well-trained volunteer manpower. Volunteers will provide the BLM with additional "boots on the ground" to exponentially increase observation and recordation. The program offers concerned citizens opportunities to participate proactively in the stewardship of paleontological resources. The FFO will draw on its own thriving Archeology Site Steward Program and the St. George Field Office's dual-resource Site Steward Training Manual and modify them to fit local needs.

Trained volunteer manpower will help the FFO manage our vulnerable and scientifically important paleontological resources. These volunteers will also increase public awareness of the significance and value of paleontology while promoting an understanding of local geology and federal paleontology laws.

KEYWORDS—Site Steward, Volunteer, Resource Management

POSTER PRESENTATION
Article, p. 61–68

THE KEYA PAHA FAULT AND RELATED STRUCTURES: THEIR SIGNIFICANCE TO THE GEOLOGY OF SOUTH DAKOTA

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ABSTRACT—A major geological structural feature, the Keya Paha Fault, occurs in south-central South Dakota and appears to extend northwestward across South Dakota. The fault is subparallel to the well-documented White Clay Fault, occurring farther west in South Dakota, and to other lineaments occurring between the two faults. Ponca Creek and even the portion of the Missouri River subparallel the direction of the Keya Paha Fault to the east. The trends of all these structural features suggest a northwesterly directed structural fabric across western South Dakota. The Keya Paha Fault is demarked by the absolute straight trend of the Keya Paha River across Tripp and Todd counties, offset of Tertiary fossiliferous beds in the Badlands, and perhaps the trend of the Northern Black Hills Tertiary Intrusive Province. Additional subparallel lineaments occurring along the South Dakota-Nebraska border may also eventually prove to be of fault origin in South Dakota. Recent investigations along the Missouri River have indicated smaller scale faults and clastic dikes. These too are often trending northwesterly and have been found with glacial debris within the fault gauge, suggesting relatively recent movement. Overall, this northwesterly trending structural fabric has great impact upon the distribution of natural resources in South Dakota, including, among others, water, petroleum, minerals, and fossils

KEYWORDS—Keya Paha Fault, South Dakota, Lineaments, Structural Geology

*Presenting author

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ORAL PRESENTATION

TAKING MEASURE OF TECHNOLOGY: WHERE WE HAVE BEEN AND WHERE WE ARE GOING WITH 3D IMAGE CAPTURE AND CLOSE-RANGE PHOTOGRAMMETRY

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ABSTRACT—In 1997, dinosaur footprints preserved in the limestone bed of a dry wash in the Bighorn Basin of Wyoming were observed and reported to the Worland Field Office of the Bureau of Land Management (BLM). This discovery started a chain of events that has led to the Red Gulch Dinosaur Tracksite (RGDT) becoming one of the most thoroughly documented fossil footprint sites in the world. Early in the history of the RGDT project, it was decide to use the best science to capture the scientific value of the site prior to developing and interpreting it for the public. Thus began BLM's use of close-range photogrammetry for the documentation of vertebrate fossil sites.

Photogrammetry is the art, science, and technology of obtaining reliable measurements from photographs. The basic requirement for photogrammetry is an overlapping pair of photographs taken to mimic the perspective centers of human stereoscopic vision. During the early days of 3D photodocumentation at RGDT, the process was very labor intensive and could require as much as a week to get a final dataset for a single footprint. As technology advanced, stereoscopic photographs, captured at a variety of heights from a number of different platforms at the RGDT, provided a wealth of 3D data for interpretation and analyses. Not only did these efforts increase the knowledge of the unique, paleontological resources at the site, they also provided a visual and quantifiable baseline that is being used to evaluate and better understand changes that occur to the track surface.

In the years since its beginnings at RGDT, close-range photogrammetry has been used to document and interpret fossil footprints sites throughout the western United States. Following the model established at RGDT, the camera and in some cases the photographer have taken to the air, using blimps, helicopters, and ladders to obtain the needed photographic perspectives of the subject. Individual tracks, trackways, and even entire track surfaces have been documented using close-range photogrammetry on lands managed by BLM, U.S. Forest Service, National Park Service, and Bureau of Reclamation in Wyoming, Utah, Colorado, Nebraska, Oklahoma, New Mexico, Arizona, California, and Alaska.

Today, advances in digital cameras, computer architecture, and multi-view matching software make it possible to take photos and produce a final dataset in a matter of minutes. In addition, the technique is much more portable, allowing the capture of stereoscopic photos to be conducted by field personnel. This makes close-range photogrammetry (CRP) an effective method for capturing important data about a wide variety of resources. Often the use of photogrammetry can be more efficient, less labor-intensive, and more cost-effective than other types of field 3D data collection.

Recent advancements in software now provide low- and no-cost solutions for successfully processing stereoscopic photographs that have been taken with 60 to 75 % overlap. This will significantly increase the use of CRP for resource documentation by allowing the field photographer to receive almost immediate feedback on the success of image capture. With the introduction of low/no cost software the processing of close-range photogrammetric images is no longer confined to a few locations, thus reducing the limitations on generating, using, and sharing 3D date of ichnological features.

KEYWORDS—Resource Inventory, Resource Monitoring, Close-Range Photogrammetry, Ichnology, Vertebrate Paleontology

*Presenting author

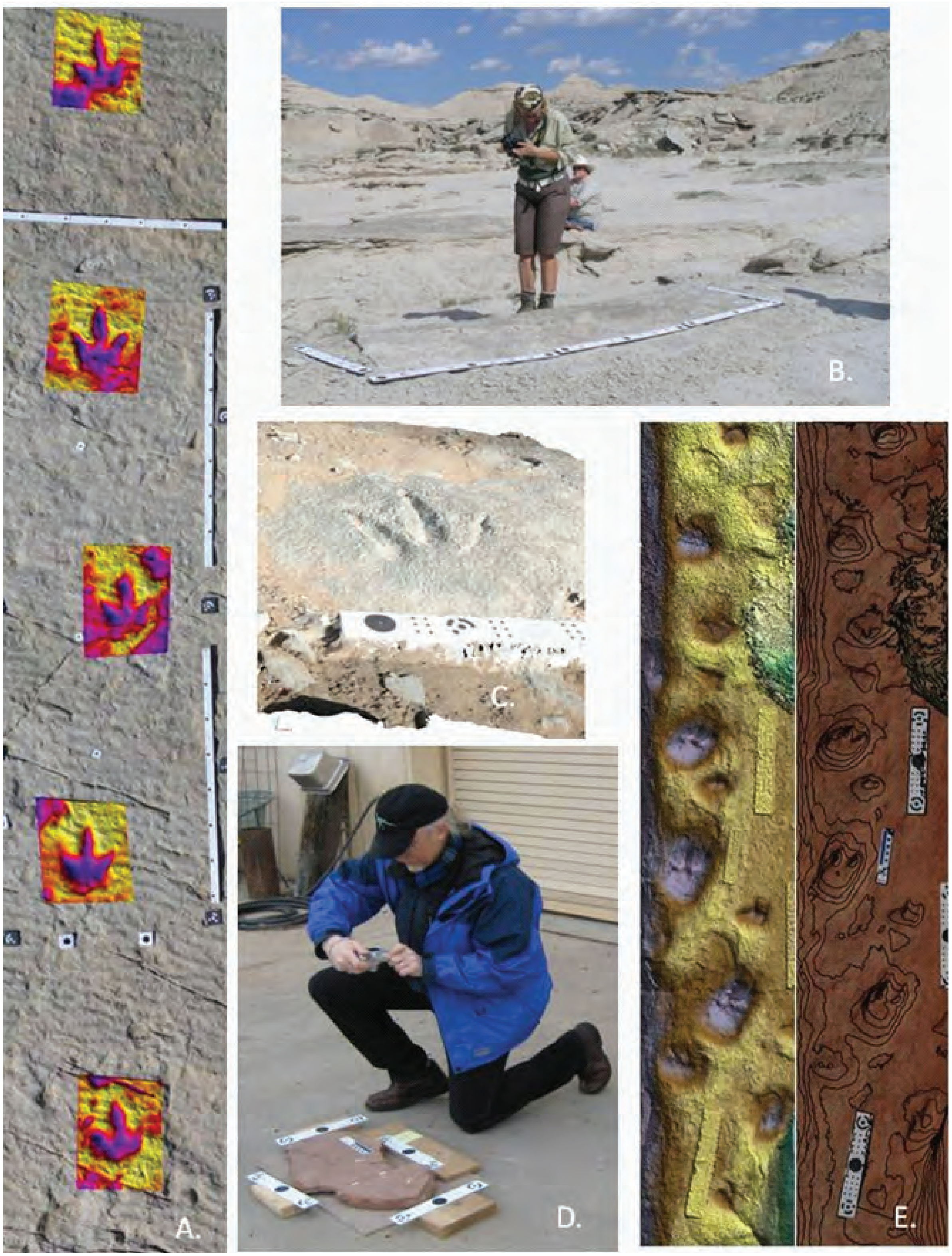

FIGURE 1. **A**, Orthoimage of the "Crosstown" theropod trackway from the Red Gulch Dinosaur Tracksite, Wyoming; tracks are depicted with color contours. **B**, Close-range photogrammetric capture of a track surface at Toadstool Geologic Park, Oglala National Grasslands, Nebraska. **C**, Mill Canyon Road, Utah, track rotated to 3D perspective, **D**, Photography of museum specimen from the Prehistoric Trackways National Monument, New Mexico. **E**, *Navahopus* trackway shown in color surface model and 2 mm contours, Paria Canyon-Vermilion Cliffs Wilderness, Utah.

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POSTER PRESENTATION

THREE-DIMENSIONAL FOSSIL FOOTPRINT TRACKING: VERTEBRATE ICHNOLOGY IN THE NATIONAL LANDSCAPE CONSERVATION SYSTEM

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ABSTRACT—The Western United States contains 27 million acres set aside as National Landscape Conservation System (NLCS) lands administered by the Bureau of Land Management (BLM). The Omnibus Public Lands Management Act established the NLCS as a formal system of BLM-administered public lands and also enacted Paleontological Resources Preservation legislation. There are more than 886 federally-recognized areas within the NLCS, including National Monuments, National Conservation Areas, Wilderness Areas, Wilderness Study Areas, and other areas of special designation. NLCS lands contain significant paleontological resources. Federal agencies now have a mandate to preserve these resources on public lands and manage them using scientific principles and expertise. Over the past decade, the BLM has adopted a more active approach in the management of paleontological resources by coordinating and promoting external research partnerships, as well as by using cutting-edge Geographic Information Systems, Global Positioning Systems, close-range photogrammetry (CRP), 3-D visualization, and other technological methods. During this time, CRP has experienced rapid technological evolution. Economic high-resolution digital SLR cameras, increasing capabilities of computers, and advancements in the analytical software have simultaneously decreased the costs and increased the usability of CRP. Both ground-based photography and low-level aerial imagery have been used in ichnological studies within the NLCS. These cutting-edge studies documented Permian through Middle Jurassic fossil footprints located in Prehistoric Trackways National Monument, New Mexico, Vermilion Cliffs National Monument and Paria Canyon-Vermilion Cliffs Wilderness, Arizona and Utah, and Grand Staircase Escalante National Monument, Utah.

KEYWORDS— Resource Inventory, Resource Monitoring, Close-Range Photogrammetry, Dinosaur Tracks

POSTER PRESENTATION

BURGESS SHALE FOSSIL MANAGEMENT THROUGH PROTECTION, PRESENTATION AND SCIENCE: YOHO NATIONAL PARK, BRITISH COLUMBIA

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ABSTRACT—As one of the most significant fossil localities in the world, designated a World Heritage Site by UNESCO in 1981, the Burgess Shale is important for understanding early animal evolution during the Middle Cambrian Period. As the steward of this internationally significant resource, Parks Canada strives to protect the fossil sites and collections, provide visitors with experiences that promote awareness and understanding of the importance of Burgess Shale, and support ongoing scientific research. In particular, Yoho National Park is undertaking a suite of initiatives directed at effectively managing and promoting the in-situ and off-site Burgess Shale resources. This poster presents the park's current management plans related to the protection of the resources within the context of the following themes: planning, area signage and fencing, site monitoring, enforcement, access and research. The poster also presents achievements related to the provision of visitor opportunities in the area of interpretation, guiding and off-site presentation through the use of wireless webcams. Parks Canada strives to enhance its management of the Burgess Shale resources by continuing to observe and adapt the strategies used by others who have similar responsibilities for the care of fossil resources elsewhere.

KEYWORDS—Burgess Shale, Resource Management, Protection

*Presenting author

ORAL PRESENTATION

CREATIVE STRATEGIES IN CONSERVATION: DOCUMENTING THE ESTABLISHMENT AND HISTORY OF FLORISSANT FOSSIL BEDS NATIONAL MONUMENT

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ABSTRACT—We are using firsthand accounts to complete a book on the controversial establishment and important history of Florissant Fossil Beds National Monument. The Monument was created from private lands in 1969. Before then, real estate subdivision threatened to destroy the fossil resources while establishing legislation was stalled in Congress. Scientists and citizen groups organized to form the Defenders of Florissant in an effort to stop the planned development. The Defenders were represented by the lawyer who founded environmental law, and the Florissant case became well-recognized for its innovative strategies applying the Public Trust Doctrine to an environmental legal issue. The effort was successful in obtaining an injunction from the federal courts, which stopped the development long enough for Congress to act. Once established, the new monument took many years to achieve its congressionally-defined priorities in paleontology. Our emphasis in the book demonstrates the influence of this significant fossil site on early stages of the environmental movement and the establishment of environmental law. We also address the accomplishments and impediments made by the National Park Service in focusing on its defined purpose for a paleontology park and providing public recognition for the lawyers and others who made history at Florissant. The book has stimulated new recognition by NPS for important players in the movement, and it provides an important contribution to the administrative history and paleontological significance of the Monument.

KEYWORDS—Florissant Fossil Beds National Monument, Environmental Law, Estella Leopold

ORAL PRESENTATION

FULL DISCLOSURE OF PALEONTOLOGICAL LOCALITY DATA: AN INTEGRAL COMPONENT OF CREDIBLE SCIENCE

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ABSTRACT—Collection and reporting of primary data are fundamental components of the scientific method. Observational data form the basis for analysis, synthesis of results, and formulation of conclusions. The process of credible peer review requires that primary data be openly accessible in publication for reviewers and readers to critically analyze the study's merits. Because geology and paleontology are inherently three-dimensional, spatial data for stratigraphic and geographic coordinates are critical for documenting and interpreting fossiliferous assemblages, geologic formations, paleoecological context, and taphonomic bias. Publication of these data typically requires presentation in tables, maps, and figures. Unlike archaeology, where spatial data occur within a limited internal framework that can be documented without revealing geographic location, fossils occur in a geologic context over large spatial areas. Withholding primary data, including precise locality data, significantly compromises the integrity of the science of paleontology; failure to report these data constitutes a breach of research integrity, including an inability to repeat the study, which is foundational to the scientific method. Furthermore, the data management plan of the National Science Foundation newly requires primary data be made available to the public; preventing open availability of locality data dooms the field of paleontology to fall behind other fields that are making great strides in understanding the influence of abiotic and biotic variables on the biogeography and evolution of organisms. By restricting access to these invaluable specimen metadata, we lose the ability to study broad-scale spatial patterns of the past and generate predictive models for the future.

KEYWORDS—Paleoecological Context, Geologic Context, Scientific Data, Fossil Locality

*Presenting author

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ORAL PRESENTATION

ROCKS, REGULATIONS AND REPOSITORIES: THE THREE "Rs" OF A SUCCESSFUL CURRICULUM FOR PALEONTOLOGISTS IN A PRPA WORLD

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ABSTRACT—With passage of the Paleontological Resources Preservation Act (PRPA), the need for resource management paleontologists is just as imperative as that for researchers and educators. The South Dakota School of Mines offers programs which emphasize "hands on" aspects of paleontology, particularly field and collections work. The challenge remains to strike a balance between training paleontologists with diverse skills desired in a PRPA world and maintaining the rigor of a curriculum which prepares students to be effective researchers.

Our undergraduate curriculum stresses "geology first" and employability. The standard suite of geology courses is complemented by extensive training in Geographic Information Systems (GIS). Geology and paleontology field camps are required. Mandatory senior thesis projects instill research skills and promote professional interaction outside the classroom. Additional courses on fossil preparation, collections and resource management enhance the baccalaureate course load.

The Master's program emphasizes a traditional, geological approach to paleontology. Comparative Osteology familiarizes students with skeletons of various groups enhancing bone identification skills. Vertebrate Paleontology is an in-depth treatment of the fossil record of vertebrates. Biostratigraphy places fossils in spatial and temporal context and develops familiarity with stratigraphic units. Advanced field training is coupled with courses in fossil preparation, curation, and resource management.

Additions to this type of curriculum may better prepare students for jobs in government or private firms. Courses such as business management, business and research ethics, and American civics may result in better functionality in a non-academic environment. Increased cooperation among academic, government, and private entities is essential for continued development of effective paleontology curricula.

KEYWORDS—Paleontology, Education, Curriculum, Resource Management

*Presenting author

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ORAL PRESENTATION

PRELIMINARY REPORT OF THE FIRST RECORDED LATE PLEISTOCENE MAMMAL TRACKS FROM SOUTHEAST IDAHO AND MANAGEMENT IMPLICATIONS

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ABSTRACT—Late Pleistocene mammal tracks were recently discovered in southeast Idaho on both US Bureau of Reclamation (BOR) and US Forest Service (USFS) administered lands. While tracks from earlier time periods have been reported in Idaho, this is the first report of Pleistocene tracks. A USFS employee (lead author) discovered these tracks during the inventory and salvage of fossils from the Palisades Reservoir area. This individual also discovered tracks at American Falls Reservoir (AFR) while working under a voluntary agreement with the BOR. Because the tracks are located in popular recreation and high erosion areas, impacts will destroy these tracks if management plans are not developed and implemented. The location of these tracks presents both concerns and opportunities for federal agencies to manage and/or protect these important non-renewable resources by developing cooperative agreements with other agencies/individuals.

Tracks are known from a few localities on USFS lands in the Palisades Reservoir area, near the Idaho-Wyoming state line. Stratigraphy of the track-containing loess deposits is complex, and correlation between track localities generally cannot be established. The tracks appear to represent the following taxa (detailed studies forthcoming): proboscidean, camelid, horse, bison/musk ox, and possibly other ungulates. Known skeletal fossil remains from these deposits include mammoth, mastodon, camel/llama, horse, bison, musk ox, big horn sheep, mountain goat, and other megafauna. As many as 10 different track horizons may be present at the most prolific track locality. Individual track-ways have not yet been recognized because of limited outcrop exposure and trampling.

Three additional track localities have been found at AFR on BOR lands near Pocatello, Idaho. Two of these localities are below the high water line and one just above it. The known late Pleistocene fauna from the American Falls Reservoir area is extensive and well-documented, but this is the first report of tracks.

A small locality that preserves numerous horse tracks in a calcareous, fine-grained sandstone was found at AFR in 2009. Little could be done at this locality in 2009 because the tracks were under water when found and were not exposed again until fall 2010. Two short trackways, with a few actual tracks and numerous under-tracks, are present. Wave action and recreational activities have contributed to the destruction of these tracks. A cooperative agreement between the BOR and the Idaho Museum of Natural History (IMNH) to document and salvage these tracks was started in October, 2010.

Probable proboscidean tracks were found in an unconsolidated silty clay layer at AFR in 2010. Repeated wind and wave erosion are removing most of the delicate surface track details and structures. The surface appears to be somewhat trampled, yet a few individual trackways appear to be recognizable. Many traces here may only be under-tracks.

The third track area at AFR, also discovered in 2010, lies just above the high water line at the base of a cliff of unconsolidated sand, silt and clay. The proboscidean tracks here were initially recognized in cross-section in the cliff face in a silty clay layer. In fall 2010, some of the overburden was removed, revealing numerous near-pristine tracks which appear to continue into the cliff. The preservation quality of these tracks was aided by burial by a fine-grained sand with little apparent erosion prior to burial. Two relatively large felid tracks—a very rare occurrence anywhere—are associated with these proboscidean tracks.

Over the past 25 years, the BOR has performed erosion control work at AFR to help prevent heavy erosion of the shoreline and surrounding cliffs. This program involves back-sloping the top of the cliff and using geotextile fabric, earthen barriers, and large boulders in a process called rip-rapping to prevent erosion and loss of land surface, reduce sediment input into the reservoir, and reduce safety hazards associated with the cliffs. This track locality is in an area scheduled for rip-rapping in July, 2011.

Due to the paleontological significance of the cliff track locality, the BOR has agreed to modify erosion control activities in the immediate area and is working with experts to develop a management plan to document and conserve these tracks. An initial on-site evaluation was made in October, 2010 to begin the preliminary discussion of possible erosion control modifications. A team of researchers is being assembled and will be brought on-site in 2011 to document and conserve the tracks and make recommendations for a management plan for this and the other track localities.

KEYWORDS— Pleistocene, Fossil Tracks, Idaho, Proboscidean, Felid

*Presenting author

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ORAL PRESENTATION

NEW FOSSILS FROM OLD FOSSIL BEDS: PALEONTOLOGICAL RESOURCE MONITORING AT JOHN DAY FOSSIL BEDS NATIONAL MONUMENT

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ABSTRACT—The John Day River Basin in east central Oregon is well known for its rich fossil resources, which have been studied since the late 19th century. Today, John Day Fossil Beds National Monument includes three separate units with fossil beds ranging from 5 to 50 million years old, which preserve vertebrate, invertebrate, and plant fossils. Cyclic prospecting by park paleontologists helps locate and preserve these paleontological resources. Despite a history of almost 150 years of research in the region, ongoing work regularly uncovers new species and occurrences. Recent finds include the earliest known record of a modern beaver in North America (at least 7 million years ago), the only known skull and jaws of an Oligocene pocket mouse, specimens of an unusual lagomorph, and the park's first postcranial bone from the large sabertooth *Pogonodon*. These finds improve our understanding of the region's history and changes in the structure of ecosystems over the past 50 million years.

KEYWORDS—John Day Fossil Beds National Monument, Oligocene, Paleontological Resource Monitoring

ORAL PRESENTATION

DOCUMENTATION OF PALEONTOLOGICAL RESOURCES THROUGHOUT THE NATIONAL PARK SYSTEM

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ABSTRACT—Baseline paleontological resource data is essential to support decision-making associated with the management, protection, preservation, and interpretation of National Park Service (NPS) fossils. This principle is supported by the Paleontological Resources Preservation Act which was signed into federal law in March 2009. Section 6302 of the legislation requires five federal land managing agencies, including the NPS, to develop plans for inventory, monitoring, and the scientific and educational use of paleontological resources. The NPS established a strategy for the compilation of baseline paleontological resource data for each of the agency's 394 administrative units. The strategy adopted the system of 32 Inventory and Monitoring Networks established under the agency's Natural Resource Challenge and set out to develop paleontological resource summaries for each network. The first network-based paleontological resource inventory was initiated for the sixteen parks of the Northern Colorado Plateau Network in 2002 and completed in early 2011. Written summaries for each network park include information on the scope, significance, distributions, research, museum collections, resource management issues and other information associated with the park's fossils, as well as a comprehensive bibliography of relevant geology and paleontology references and a series of recommendations for future work, research, management or other actions which would promote the preservation of the park's non-renewable fossils. This effort has documented fossils in situ, within the park museum collections, and/or within a cultural resource context in at least 230 units of the NPS. These network reports are not a substitute for field work, but aimed to provide a foundation for future field-based resource management and interpretation.

KEYWORDS—National Park Service, Paleontological Resources, Inventory and Monitoring Networks

*Presenting author

ORAL PRESENTATION

NATIONAL FOSSIL DAY: CELEBRATING THE SCIENTIFIC AND EDUCATIONAL VALUES OF FOSSILS

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ABSTRACT—The inaugural National Fossil Day was celebrated on October 13, 2010 as a means to recognize and promote the scientific and educational values of fossils. More than 130 institutions, organizations, government agencies and other groups joined together to form the National Fossil Day partnership. Hundreds of fossil related events, activities and educational programs were hosted throughout the country. Some of the impetus behind the establishment of National Fossil Day is derived from the Omnibus Public Lands Act of 2009, specifically from within the Paleontological Resources Preservation Act. Section 6303 of the legislation mandates five federal land managing agencies, including the National Park Service (NPS), to establish a program to increase public awareness about the significance of paleontological resources.

The date for National Fossil Day was selected to coincide with Earth Science Week. Thousands of classrooms, representing millions of school children, participate in Earth Science Week activities. In order to build upon the successful educational outreach achieved by the American Geological Institute during Earth Science Week, a cooperative agreement was established between this organization and the NPS. As the word spread about the plans for a national celebration for fossils, the dimensions of National Fossil Day expanded and took shape. Scientists, educators and park rangers found a common cause to contribute to and work toward. A logo, song, video and website helped to give birth to the identity of this new national event.

On the morning of National Fossil Day, a special letter addressed from the White House and signed by President Barack Obama was delivered to those participating in the opening ceremony on the National Mall in Washington, D.C. Throughout the day, large numbers of children from across the country were sworn in as Junior Paleontologists, the winners of the National Fossil Day art contest were announced, the Trail of Time exhibit at Grand Canyon National Park was dedicated, and a new generation of young people was inspired by fossils and paleontology.

KEYWORDS—National Fossil Day, National Park Service

ORAL PRESENTATION

PALEONTOLOGICAL RESOURCE MONITORING OF IN SITU VERTEBRATE TRACKSITES AT GLEN CANYON NATIONAL RECREATION AREA, UTAH

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ABSTRACT—The stability of in situ paleontological resources is a function of the natural processes, environmental conditions, and anthropogenic factors present at the fossil locality. Once destructive forces begin to act upon fossils in situ, the scientific and educational values of these non-renewable resources are usually diminished. In 2009, a paleontological resource monitoring strategy was developed to outline five methodologies, referred to as vital signs, for evaluating the condition and stability of fossils maintained in a geologic context. Glen Canyon National Recreation Area was established as a prototype paleontological resource monitoring park to field test the monitoring strategy. A team of paleontologists from the National Park Service, Utah Geological Survey and the St. George Dinosaur Tracksite collaborated to identify paleontological localities which would be suitable for long-term monitoring. Two vertebrate track localities, including the “Slick George Dinosaur Tracksite” and the “Megatrack Block Locality,” both within the Early Jurassic Navajo Sandstone, were initially identified, assessed, mapped, and photodocumented. Both localities contain an important vertebrate ichnofauna and exhibit varying degrees of deterioration related to natural and human related factors. Monitoring recommendations were developed for each locality to promote tracksite conversation.

KEYWORDS—Paleontological Resource Monitoring, Glen Canyon, Vertebrate Tracksite

*Presenting author

ORAL PRESENTATION

AN EVALUATION OF SIXTEEN YEARS OF PALEONTOLOGICAL VISITOR SITE REPORTS IN BADLANDS NATIONAL PARK, SOUTH DAKOTA

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ABSTRACT—Badlands National Park contains some of the best paleontological exposures of the Eocene–Oligocene White River Group. In 1994, park staff developed a noninvasive method for park visitors to report fossil exposures. A one-page (front and back) Paleontological Visitor Site Report (VSR) includes guides for indicating physical appearance of the fossil, a description of the surrounding bedrock and terrain, and a general location of the exposure, all of which are subsequently reinvestigated in the field by a trained paleontologist. After reinvestigation of each VSR, park staff enter data on the biological, taphonomic, and geologic condition of the fossil exposure into a spreadsheet database. While VSRs have regularly been filled and investigated since 1994, no cumulative evaluation of the database had occurred prior to 2010. In the summer of 2010, we studied sixteen years of VSRs in the database (n=900, 1995–2010) for patterns among the 17 data categories (i.e. taxa represented, host formation). The cumulative VSRs account for 443 fossils representing 46 different taxa. The most commonly reported fossils and host rocks represent the most common taxa and formations in the park, and taphonomic condition of the fossils (fragmentation or modern weathering) did not bias whether an exposure was reported. This suggests that this process of reporting can provide an approximate census of the fossil fauna in areas of high visitation.

KEYWORDS—Badlands National Park, Paleontological Resource Monitoring, Visitor Site Report

ORAL PRESENTATION

PALEOECOLOGICAL AND PALEOENVIRONMENTAL IMPLICATIONS OF MICROFOSSIL SPECIMENS UTILIZING GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

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ABSTRACT—Since 1979, the Pioneer Trails Regional Museum in Bowman, North Dakota has been collecting and protecting fossils through the effort of a volunteer work force. They have accurately collected and re-collected annually from a number of sites including 46 microfaunal sites from the Late Cretaceous Hell Creek Formation of southwestern North Dakota. When these collections were made, the details of the ongoing collection of macrofauna, pollens and other plant material, microfauna, sedimentary specimens and associated information was only recorded in hard copy—not digitized or converted to any database. This limited the museum's ability to correlate the information in any way other than manually. Now, the ability to link information tables to points on a map using Geographical Information Systems (GIS) has introduced a new future for paper-based data collections. GIS, with its ability to generate detailed maps with links to associated data, allows for more complex and in-depth scientific analyses, such as reconstruction of paleoenvironmental and paleoecological conditions in this critical transition zone. This study analyzes the implications for data available to date, but there is still much room for growth, as more data can be added to the maps using the GIS ability to add layers of data. Layers can include anything from pollen to sedimentary information and can accommodate information from many more microsites.

KEYWORDS—Microfauna, Late Cretaceous, Geographical Information Systems, Paleoecology

*Presenting author

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ORAL PRESENTATION

THE SDSMT MUSEUM OF GEOLOGY'S JAMES E. MARTIN PALEONTOLOGY RESEARCH LABORATORY: A REGIONAL REPOSITORY FOR FEDERAL, TRIBAL, AND STATE COLLECTIONS

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ABSTRACT—The exhibit, collection, and preparation capacity of the Museum of Geology at South Dakota School of Mines and Technology has been an important part of the school's geology and paleontology programs since 1885. In 2010, the collections and laboratories moved to a new building—the James E. Martin Paleontology Research Laboratory (PRL),—thanks to funding provided by the South Dakota Board of Regents and private donors. This facility will enable a comprehensive program of preparation, research and education under one roof, uniting all the collections, Federal, tribal and state repository holdings, and associated data. The building will also showcase the Museum's extensive field, laboratory and classroom work, including visible preparation areas. The monumental task of moving over 500,000 fossils, minerals, and associated holdings has resulted in greater accessibility and organization, creating opportunities to build stronger research and programmatic relationships between the Museum and its stakeholders as well as regional students, educational programs, and communities. The PRL was designed to meet all requirements for environmental conditions and monitoring, security, and access specified in the Federal curation checklists and standards. The result is a major regional repository that will ensure the best use of paleontological resources for research, education, professional training, and public programs, benefiting all stakeholders.

KEYWORDS—South Dakota School of Mines and Technology, Resource Repository, Paleontological Research

POSTER PRESENTATION

PALEONTOLOGIC SITE STEWARDSHIP ON FEDERAL LAND IN NEVADA: A MODEL FOR PROMOTING CITIZEN SCIENCE

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ABSTRACT—In 2008, the Bureau of Land Management awarded the San Bernardino County Museum (SBCM) a Federal Assistance Agreement entitled "Upper Las Vegas Wash Conservation Transfer Area (CTA)—Treatment, Protection, and Interpretation of Heritage Paleontologic Resources through Public Involvement." The CTA comprises about 5,000 acres, including sediments that indicate changing levels of ground water discharge through the last two glacial maxima, and protects about 500 fossil sites, including one of the most significant late Pleistocene vertebrate assemblages in the American southwest. The grant directs the collection and curation of late Pleistocene (Rancholabrean) taxa from the Las Vegas Formation, geologic mapping, and research.

Objectives of the agreement include creation of a site stewardship program to engage the local community in the management of fossil resources within the CTA, allowing for hands-on involvement whereby stewards actively participate in citizen science. Training includes a three-day classroom/field workshop to orient future stewards on the geology and paleontology of the region, an introduction to GPS and maps, and a primer on Federal laws protecting fossil resources, including the 2009 Paleontologic Resources Preservation Act. Stewards conduct an initial walk-through of assigned parcels, then excavate fossils under direct supervision in a previously-disturbed quarry, doubly illustrating the need to protect the resources. Stewards are expected to return to prospect their parcel on a quarterly basis. Additionally, the SBCM produced exhibit content and fossils for interpretive kiosks.

KEYWORDS—Las Vegas, Vertebrate Fossils, Pleistocene, Site Stewardship, Citizen Science

*Presenting author

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POSTER PRESENTATION

THE TULE SPRINGS LOCAL FAUNA: LATE PLEISTOCENE VERTEBRATES FROM THE UPPER LAS VEGAS WASH, CLARK COUNTY, NEVADA

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ABSTRACT—The Tule Springs site in the upper Las Vegas Wash north of Las Vegas, Nevada was the focus of archaeological scrutiny from the 1930s through the early 1960s. Forty years later, the San Bernardino County Museum has discovered hundreds of new fossils throughout the upper Las Vegas Wash, greatly extending the geographic and temporal footprint of earlier investigations. The upper Las Vegas Wash encompasses the largest open-site Rancholabrean vertebrate fossil assemblage in the Mojave Desert / southern Great Basin, warranting designation as a local fauna named for the original Tule Springs site.

Mammuthus columbi and *Camelops hesternus* dominate the large mammal assemblage, with three distinct species of *Equus* and two species of *Bison* also present. Newly-recognized faunal components include *Rana* sp., *Anniella* sp., *Masticophis* sp., cf. *Arizona* sp., *Marmota flaviventris*, *Neotoma* sp. cf., *N. lepida*, *Reithrodontomys* sp., cf. *Onychomys* sp., *Lynx rufus*, an indeterminate large bovid, and the first definitive fossils of *Bison antiquus*. The latter fossils constitute the youngest reliably-dated *Bison* remains known from the Mojave Desert.

The depositional setting is a series of fine-grained ground water discharge deposits of the informally designated Las Vegas Formation. Seven stratigraphically-ascending units (A through G) are recognized. Units B, D, and E were known to be fossiliferous from earlier studies; recent efforts confirm unit C is also sparsely fossiliferous. The deposits span as much as the last 200 ka, encompassing a sedimentary and faunal record of multiple glacial-interglacial climatic shifts including the end-Pleistocene transition.

KEYWORDS—Las Vegas, Pleistocene, Rancholabrean, Mojave Desert, Great Basin

POSTER PRESENTATION

NEW FOSSIL RECORDS FROM BLANCAN (PLIO–PLEISTOCENE) DEPOSITS, GRAHAM COUNTY, ARIZONA

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ABSTRACT—The Safford Field Office of the Bureau of Land Management (BLM) manages vertebrate fossil sites of Blancan (Plio–Pleistocene) age, from near the beginning of the Ice Age. These contain mammals such as glyptodonts and capybaras that record the beginning of the Great American Faunal Interchange. Numerous other mammals have been found, as have birds and reptiles, especially tortoises. Over 50 species have been recorded, representing one of the best Blancan-aged mammal assemblages in North America.

The Safford Field Office works in partnership with the Arizona Museum of Natural History in Mesa, their affiliate the Southwest Paleontological Society (SPS), the International Wildlife Museum in Tucson, Western Arizona College in Yuma, and the University of Arizona in Tucson to inventory, collect, and curate the fossils. Particularly productive areas are periodically monitored by the BLM and SPS.

More than 1,000 fossils have been collected since the project started in 1998. Previously unreported taxa collected from these beds include beaver, tapir, deer, duck, swan, goose, box turtle, and a mud turtle. Some material collected may be the basis for new taxa. We have also come across several trackways in the Safford Valley, including those of camel, llama, mastodont, and the three-toed horse *Nannippus*. Fossils from this inventory are on display at the Arizona Museum of Natural History and the Graham County Historical Society in Thatcher, Arizona. Others have been sent to specialists around the country for study.

KEYWORDS—Plio–Pleistocene, Mammal Fossils, Bureau of Land Management, Southwest Paleontological Society

*Presenting author

ORAL PRESENTATION
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MANAGEMENT OF PALEONTOLOGY RESOURCES IN LANCE CREEK FOSSIL AREA

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ABSTRACT—Huge numbers of fossils were collected and excavated from the Lance Creek Fossil Area beginning in the 1880s and are now scattered to museums and other institutions all over the globe. The National Park Service recognized the significance of these fossil discoveries by designating the area a National Natural Landmark (NNL) in 1973. The area designated was approximately 16 sections and consisted of a mixture of public lands, split estate, and private lands and minerals. The Bureau of Land Management (BLM) Newcastle Field Office Resource Management Plan (RMP) developed in the 1990s initially proposed designating the BLM lands within the NNL as an Area of Critical Environmental Concern (ACEC). During RMP scoping many private landowners became aware for the first time that their ranches were inside an NNL. Public outcry led to de-designating the NNL in 2006. An ACEC designation was also dropped from the BLM RMP signed in 2000, partly due to lack of survey data identifying exactly where fossils were located. The large amount of split estate and private lands and the scattered locations of BLM lands make it difficult to manage paleontology resources on the public lands. Large numbers of fossils are still collected from the Lance Creek Fossil Area reputedly from private lands. However, following a widely publicized fossil theft trial in 1995, fossils documented as removed from Federal lands were returned to the BLM.

KEYWORDS—Lance Creek Fossil Area, National Natural Landmark

ORAL PRESENTATION

HIGHWAY CONSTRUCTION AND FOSSIL RESOURCES: ROAD TO DESTRUCTION OR PATH TO PRESERVATION? NEBRASKA'S HIGHWAY PALEONTOLOGY PROGRAM

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ABSTRACT—In Nebraska, there is a possibility that fossils will be uncovered whenever highway construction disrupts the land surface. The Nebraska Department of Roads (NDOR) and University of Nebraska State Museum (UNSM) work together to prevent the destruction of these irreplaceable scientific resources. In 1960, Nebraska created the nation's first full-time program devoted to fossil recovery on road construction projects. Backed by state and federal legislation, the Highway Paleontology Program has collected approximately 200,000 fossil vertebrate specimens, including 20 holotypes, from more than 150 localities in the past five decades.

UNSM works closely with contractors and NDOR personnel in all phases of construction to preserve the state's rich prehistoric past without causing delays. Early notification of pending projects allows for field surveys and test excavations prior to construction. Pre-construction meetings and on-site training inform the contractor and NDOR staff of potentially fossiliferous areas and what to look for while excavating. If fossil remains are discovered during construction, contractors continue working but shift their grading operations to avoid paleontologically sensitive areas. After construction is completed, NDOR will provide equipment to re-open localities for additional study. This successful inter-agency partnership enhances our scientific knowledge by preserving specimens which otherwise would be destroyed during construction.

KEYWORDS—Fossil Mitigation, Paleontology, Highway Construction, Nebraska Highway Paleontology Program, Fossils

*Presenting author

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ORAL PRESENTATION
Article, p. 75–82

ANCHISAURUS FROM SPRINGFIELD ARMORY

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ABSTRACT—The term “dinosaur” was only 13 years old in 1855 when blasting operations at the Water Shops of Springfield Armory in Massachusetts uncovered the partial fossil skeleton of an extinct reptile. Paleontological discoveries were not new to the area; the Connecticut River Valley, which includes the Armory, was an early hotbed of vertebrate paleontology thanks to the combination of Late Triassic–Early Jurassic-age footprints and interested naturalists. The Armory specimen, now the holotype of *Anchisaurus polyzelus*, has passed through several generic names and been classified with theropods, prosauropods, and sauropods. Views on its paleobiology have changed from an active carnivore, to an herbivore, to an omnivore. Along the way, it has been discussed in print by numerous well-known figures in paleontology.

The holotype of *A. polyzelus* is one of a handful of tetrapod body fossils from the Hartford Basin. As part of the history of Springfield Armory National Historic Site, it is also one of many historically and scientifically significant fossil specimens associated with National Park Service areas.

KEYWORDS—*Anchisaurus*, Springfield Armory National Historic Site, Portland Formation, Hartford Basin, History of Paleontology

ORAL PRESENTATION

INTERPRETING PLEISTOCENE ENVIRONMENTS AT THE FLORISSANT FOSSIL BEDS NATIONAL MONUMENT, COLORADO

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ABSTRACT—The Florissant fossil beds are one of the most taxonomically diverse fossil sites in the world. The lacustrine shales of the Eocene Florissant Formation have yielded at least 1,700 described species of plants, insects, and spiders. The fossil beds also preserve a fossil record in Quaternary sediments. Fragmentary material of a mandible and molar of a Columbian mammoth has been recovered near the Visitor Center in Pleistocene gravels. The tooth has been radiocarbon dated at 49,830 ± 3290, a date that exceeds the reliable range for radiocarbon dating. Associated in these sediments are pollen and spores that enable reconstruction of Pleistocene terrestrial plant communities contemporaneous with the mammoth.

Interpretation of Florissant’s Quaternary fossil record has been designed with hands-on activities. These include activities to reconstruct the dimensions of the mammoth, to demonstrate how mammoth species are determined by making simple dental measurements, and to use actual fossil pollen and spores for reconstructing the Pleistocene environment. These activities emphasize how to conduct a paleontological excavation, how environments and climates change over time, how pollen and spores are collected and processed, and how Florissant’s Pleistocene environment is reconstructed using proxy data such as pollen and spores.

Florissant’s Pleistocene fossil record engages visitors in the process of `scientific discovery. Visitors are connected to the process of science and learn observational skills, learn about the scientific method, and experience discovery as they use pollen to reconstruct ancient environments. These interpretive activities also clearly demonstrate the importance of interdisciplinary studies in reconstructing paleoenvironments.

KEYWORDS—Florissant Fossil Beds, Columbian Mammoth, Pleistocene, Pollen, Spores

*Presenting author

POSTER PRESENTATION

THE REDESCRIPTION AND EXCAVATION OF WILBUR KNIGHT'S 1895 *MEGALNEUSAURUS REX* SITE: MAPPING AN INCOMPLETE HISTORY

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ABSTRACT—Rediscovery of the collection site of the large Jurassic pliosaur *Megalneusaurus rex* on Federal land was made possible by the use of Wilbur Knight's letters and geological description of the area. Rediscovery of the site is significant in that little is known about this largest member of the Sundance marine reptile fauna. This information was used to verify that *Megalneusaurus rex* was collected from the upper Redwater Shale Member of the Sundance Formation and that the original excavation was incomplete.

Examination and mapping revealed new fossil material as well as artifacts from the 1895 excavation. Newly-collected fossil material included another articulated flipper, portions of vertebrae, pectoral and/or pelvic material, epipodials, ribs and large amounts of gut contents. Mapping of the site, based on known limb dimensions and the proportions of the vertebrae, ribs and gut material as well as potential skull material, has allowed for some speculation of the taphonomy of the pliosaur and an outline and parameters of the original excavation.

Scattered piles of bone and spoil mounds indicate past disturbance. Artifacts such as a broken knife blade, a button and a nail were recovered from the site. The nail is significant as it was recovered above the uncollected flipper bones, suggesting the site was marked for potential return to the excavation in 1895. Remains of a metal 'Hercules Blasting Powder' canister and an intact whiskey bottle were also collected from near the site; both artifacts were comfortably dated to the late 1890s and early 1900s.

Portions of ichthyosaur material including vertebrae and ribs found in the pit suggest that some of the material Wilbur Knight collected may have included bulk collection from the general area. However, a second site collected in the Southern Bighorn Basin revealed ichthyosaur material mixed with large pliosaur bones.

Uranium pits were noted in the locality, and whereas the history of theses pits are not known, they were most likely excavated post 1900. The surface disturbance of these pits may have camouflaged the excavation site allowing for its rediscovery. Likewise, an intact central spoil pile may have existed, but could have been reworked by transport with heavy equipment in the course of the industrial uranium excavation.

KEYWORDS—Wilbur Knight, Pliosaur, Paleontological Excavation

POSTER PRESENTATION

PALEONTOLOGICAL INVENTORY OF BIG BEND NATIONAL PARK

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ABSTRACT—Big Bend National Park (BIBE) encompasses more than 800,000 acres in southwestern Texas on the border with Mexico. We have recently completed an inventory of the park's fossil resources.

BIBE contains a very diverse, largely uninterrupted, Late Mesozoic–Tertiary geologic interval (spanning 135 million years) containing a wide variety of fossil plants, invertebrates, and vertebrates. BIBE ranks as one of the most paleontologically diverse parks in the National Park Service (NPS) system, with over 1100 reported fossil taxa.

Numerous sites in BIBE have important scientific value. These include type localities for unique specimens (holotypes) known only from the park and fossil sites which have produced spectacular and important specimens. Furthermore, several particularly charismatic specimens from the park have become famous world-wide (e.g., the giant pterosaur *Quetzalcoatlus*, the giant crocodile *Deinosuchus*, and the dinosaur *Alamosaurus*).

BIBE harbors deposits from a unique, southern paleobiogeographic province separated from other more intensely-studied paleontological localities to the north. The park's location, ensemble of formations, and associated fossils are crucial to the understanding of Cretaceous floral and faunal relationships on a continental scale. Many current and hotly debated theories involving paleofaunal endemism, biostratigraphy, paleoclimate, and taxonomy relating to Cretaceous North America would be incomplete (or impossible) without including the strata and fossils of BIBE. The park also preserves deposits from the extinction episode at the end of the Cretaceous Period, making it one of very few public lands and perhaps the only NPS unit where K–P boundary strata can be studied.

KEYWORDS—Paleontological Inventory, Big Bend National Park, Cretaceous Period

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ORAL PRESENTATION

THE HANKSVILLE-BURPEE QUARRY: COOPERATIVE MANAGEMENT OF AN IMPORTANT PALEONTOLOGICAL BONEBED

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ABSTRACT—One of the largest new dinosaur bonebeds found in the last decade, the Hanksville-Burpee Quarry (Fig. 1) is a sauropod-dominated, latest Jurassic quarry on lands administered by the Bureau of Land Management (BLM) in Southern Utah. The quarry is stratigraphically placed within the Brushy Basin Member of the Morrison Formation and was previously known to local fossil collectors for producing petrified wood and bone "scrap." In 2007, BLM geologist Francis "Buzz" Rakow showed this prolific locality to field crews from the Burpee Museum of Natural History. Burpee initially identified more than six well-preserved, partially articulated dinosaurs (Fig. 2) at the locality. Since excavations began under BLM permit in 2008, several thousand pounds of dinosaur material have been collected, including the following taxa: *Camarasaurus, Diplodocus, Barosaurus,* and a partial undetermined theropod. The extent of the locality has been explored and as excavations continue the quarry is being mapped. It appears the site is massive, with the bone-bearing layer extending approximately half a kilometer.

During this excavation process, Burpee Museum has partnered closely with other institutions including the BLM and Western Illinois University (WIU). The size and scope of the quarry provides the resources to conduct introductory college field courses in geology and paleontology. WIU has conducted annual field courses at the Hanksville-Burpee Quarry since 2008, allowing in-the-field, hands-on opportunities for undergraduate and graduate students. WIU will continue to bring students to the quarry for future field work. Additionally, Western Illinois University is working closely with Burpee to research the locality in an effort to reconstruct the paleoenvironment, compare this quarry to other large bonebeds, and to identify research grants.

Aside from formal excavation and research, Burpee has utilized the quarry for ongoing public education (Fig. 3). During select weeks over the last two summers, education staff from Burpee Museum have conducted programmatic tours for the general public. These tours have introduced more than 1100 people to general principles of geology, paleontology and the importance of fossil resources. Burpee Museum staff and the BLM have worked closely with the town of Hanksville to help protect and preserve this locality. Local businesses post information regarding quarry tours and contact information for the BLM, and the BLM provides educational information about the quarry to a broader audience through its web pages that are updated as the quarry continues to develop.

These many opportunities for research, public education, and collaboration are not without challenges. The infusion of large quantities of vertebrate fossil material to Burpee's permanent collection has created challenges for timely fossil preparation. To address some of these issues, Burpee Museum has recently finished a capital campaign which allowed the construction of a larger and more modern fossil viewing lab that, when properly staffed, will be a living exhibit and educational program. To meet the demands accompanied by new fossil material, additional space within the permanent collections was created. Finally, a full-time Chief Preparator has been hired to train and supervise grant-funded fossil preparators and volunteers. However, in order to maintain a steady rate of fossil preparation and to provide the "living exhibit" part of the process, additional funds will be sought and stronger volunteer programs developed. As these challenges are addressed, the Hanksville-Burpee Quarry will continue to be utilized as an active quarry where students learn the principles of geology and paleontology; where field paleontologists collect quality specimens for eventual preparation, research and exhibition; and the public can see "in progress" field paleontology in order to foster a better understanding of paleontological resources on their public lands.

KEYWORDS—Burpee, Hanksville, Jurassic, Morrison, Sauropod

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FIGURE 1. Hanksville Burpee Quarry 2007

FIGURE 2. Articulated diplodocid caudal vertebra

FIGURE 3. Scott Williams talking to students from Hanksville Elementary School

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POSTER PRESENTATION

GEOLOGY OF THE WASATCH AND GREEN RIVER FORMATIONS (EARLY EOCENE) AND MAMMALIAN PALEONTOLOGY OF THE WASATCH FORMATION, NORTHWESTERN GREATER GREEN RIVER BASIN: FIELD WORK UPDATE

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ABSTRACT—Erathem-Vanir Geological Consultants (EVG) have conducted geological and paleontological studies on Early Eocene strata in the Pinedale, Wyoming area since 1995. This work includes pre-field searches, field surveys, and Bureau of Land Management (BLM)-driven mitigation and monitoring. In 2011, EVG will continue this work with detailed geologic and paleontologic-sensitivity mapping west of the Jonah Field. Our revised west to east geologic cross section of Early Eocene rocks along Wyoming 351 includes from oldest to youngest (Tw= Wasatch Formation, Tg = Green River Formation): (1) LaBarge Member (Tw); (2) Scheggs Bed of the Tipton Shale (Tg); (3) Farson Sandstone (Tg); (4) Alkali Creek Member (Tw); (5) Wilkins Peak Member (Tg); (5) an as yet unnamed member of the Tw; and (6) Laney Member (Tg). Stratigraphic relations are complicated by a plethora of named units and the presence of an unconformity at the base of the Laney Member, attributed to desiccation of Lake Gosiute, subsequent erosion during and following deposition of the Wilkins Peak Member, and re-expansion of the lake during deposition of the Laney Member.

The Green River and Wasatch formations produce fossils of scientific importance and are ranked as having a Probable Fossil Yield Class of 3 and above. Fossil vertebrate material is common in all the members of the Wasatch Formation. Based on our definition of paleontological significance, the Wasatch Formation includes approximately 100 fossil localities yielding about 40 mammalian taxa.

KEYWORDS—Wasatch Formation, Green River Formation, Fossil Vertebrate, LaBarge Member, Alkali Creek Member

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ARTICLE

PALEONTOLOGICAL RESOURCE MANAGEMENT AND THE OGLALA SIOUX TRIBE'S TRIBAL HISTORIC PRESERVATION OFFICE

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ABSTRACT—The Oglala Sioux Tribe has historically delegated responsibility for cultural/historic preservation and paleontological resource management to various Tribal agencies through Tribal Council Resolutions and Ordinances based on the need of each specific situation. In April 2008, a Tribal Council Ordinance established a Tribal Historic Preservation Office (THPO). This office was directed to: 1) develop a Tribal Historic Preservation Plan and Program, 2) obtain National Park Service (NPS) Historic Preservation Program approval for official status as a nationally recognized THPO, as provided by the National Historic Preservation Act, 3) negotiate a Memorandum of Agreement (MOA) with the NPS to acquire funding necessary to implement the Program, 4) assist in developing a paleontological resource management plan, and 5) create an Advisory Council to serve as an elder advisory group for all cultural and historical management. Since its inception, the Advisory Council has been called upon to address paleontological resource management issues on the Pine Ridge Reservation. Based on traditional teachings, it is believed that everything is connected. This connection means that anytime the earth is disturbed, a human-related and/or fossil item may be uncovered, so there is no real distinction between archaeological and paleontological resources. Currently, the Oglala Sioux Tribe has a nationally recognized THPO, program funding and personnel, consultants, a Tribal Historic Preservation Plan, and a MOA with the NPS assuming certain functions previously conducted by the State Historic Preservation Office. The THPO is working collaboratively with several other Tribal and Federal entities as well as educational institutions to address ongoing needs for protecting and preserving cultural/historic properties and paleontological resources. There are plans in place to make Oglala Lakota College, through its Department of Math, Science & Technology, the official repository and archival warehouse for Oglala Sioux Tribal paleontological resources.

KEYWORDS—Tribal, Oglala, Resource Management

INTRODUCTION

The Pine Ridge Reservation of southwestern South Dakota is the home of the Oglala Lakota people (Oglala Sioux Tribe) and the second largest reservation in the United States with over 3.4 million acres and approximately 28,000 residents. The greater Reservation boundary includes all of Shannon and Bennett counties and the southern half of Jackson County, encompassing an area about the size of the state of Connecticut. The reservation includes various fossiliferous rock formations of late Mesozoic and Cenozoic age, including the Cretaceous Pierre Shale, the Paleogene White River Group, the Paleogene–Neogene Arikaree Group, the Neogene Ogallala Group, and many unconsolidated Quaternary units. In addition to an abundant fossil record, the region's Pleistocene and Holocene sediments record at least 14,600 years of human history. On the Pine Ridge Reservation, people consider both fossils and artifacts to be *cultural resources*, in that both are records of past life and part of an unbroken cycle of existence. Also, both are recovered by excavating in the Earth, and have been the subject of a long history of dispossession of relics from Native lands (Bradley 2010). The cultural resources of the Pine Ridge Reservation are managed by the Oglala Sioux Tribe's Tribal Historical Preservation Office. This paper will briefly describe the role and function of this office so that the paleontological and archeological scientific and resource management communities can be effective partners in research and management in the years ahead.

OGLALA SIOUX TRIBE TRIBAL HISTORICAL PRESERVATION OFFICE—ORDINANCES

The Oglala Sioux Tribe (OST) has historically held responsibilities related to historic preservation and cultural resource management through various Resolutions under the Tribal Fifth Member's Office. Because this Office is politically appointed, it often changes with the changing Tribal Administrations every two years. To provide more consistency and continuity, in April 2008 the Tribal Council created a Tribal Historic Preservation Office (THPO) through Tribal Council Ordinance No. 08-09, making this office a Tribal program under the existing P.L. 93-638 contract for Natural Resources Regulatory Agency.

The THPO was successful in obtaining acceptance for the "*Oglala Sioux Tribe—Tribal Historic Preservation Plan*" (the Plan) from the National Park Service (NPS) Historic Preservation Program on May 27, 2009. As approved by the Tribal Council and National Park Service (NPS), this Plan addresses responsibilities of protecting and preserving cultural/historic properties and any environmental impacts within the Treaty, ancestral, and aboriginal territories.

Later in 2009, the Tribal Council passed Ordinance No. 09-29, approving the "*Memorandum of Agreement with the National Park Service*" for the Tribe to assume and administer certain functions previously conducted by the State Historic Preservation Office in accordance with the National Historic Preservation Act (NHPA) based on the language provided in the Plan.

In May 2010, the Tribal Council enacted Ordinance No. 10-13, approving the "…*Tribal Preservation of Paleontological, Archaeological, Cultural and Historic Resources Code, to be codified at Law and Order Code Chapter 49*." It was of utmost importance to create this Ordinance; the Oglala Sioux Tribal Council deemed it necessary to effectively manage, regulate, and protect its paleontological, archaeological, cultural and historic resources. The Code was written to incorporate a Lakota philosophy expressing the special relationship between the people and the land, which includes paleontological resources. The Code also provides a process to maintain the balance of this relationship while preserving and protecting the resources that provide our people and future generations with portions of our history and our past.

FUNDING

With the authorization to establish the Oglala Sioux Tribal Historic Preservation Office (THPO) through Ordinances No. 08-09 and No. 09-29 and the Memorandum of Agreement (MOA) with the NPS, the OST entered into an Annual Funding Agreement through the NPS Historic Preservation Fund to fulfill its duties as a THPO. The THPO still seeks additional funding to supplement the National Park Service funding received to sustain its minimal staff, though. Former Tribal President Theresa Two Bulls was successful in obtaining additional funding in 2010 through her Aid to Tribal Government funding from the Bureau of Indian Affairs—Pine Ridge Agency (BIA PRA). Currently we are asking that returning Tribal President John Yellowbird-Steele continue with a similar funding level and even assist the THPO with a request for additional funding from other federal agencies such as the BIA PRA. The THPO also collaborates with other Tribal entities such as Oglala Lakota College (OLC), which is working to further enhance a repository for archaeological and paleontological collections from projects on the Pine Ridge Reservation.

Ordinance No. 10-13 provides a mechanism for the THPO to create a budget to administer its duties through permit revenues collected and/or through civil forfeiture/penalties.

STAFFING AND OFFICES

By Tribal Presidential re-appointment on December 14, 2010, Mr. Wilmer Mesteth was named the new Tribal Historic Preservation Officer (THP Officer) following the previous appointment of Mr. Michael Catches Enemy in 2009. This appointment was understood as being strictly on a volunteer basis, as Mr. Mesteth was and currently still is an instructor for OLC. Prior to the appointment, Mr. Mesteth was nominated to serve on the THPO Advisory Council, as provided in the Plan and Ordinance 08-09.

At the request of the current THP Officer Mr. Mesteth, administrative and historical assistance was required of Mr. Catches Enemy as the returning Natural Resources Director. Project Review Officer Ms. Roberta Joyce Whiting is the only full-time position at this time. Mr. Mesteth also requested technical assistance and repository guidance from the Co-Chair of the Math & Science Department at Oglala Lakota College, Dr. Hannan LaGarry. The THPO anticipates Tribal Administration financial support in order to fulfill duties listed in the Plan and agreed upon in the MOA with the NPS.

TRIBAL HISTORIC PRESERVATION ADVISORY COUNCIL

Through Ordinance 08-09, the Oglala Sioux Tribal Council authorized a three (3) member Tribal Historic Preservation Advisory Council (THPAC) to be appointed with legal authority to act and perform as the lead preservation program that will advise and make scheduled reports to the Oglala Sioux Tribal President and the Tribal Council. A THPAC consisting of Mr. Tom Bad Heart Bull from Oglala District, Mr. Francis "Chubbs" Thunder Hawk from Porcupine District, and Mr. Garvard Good Plume, Jr. from Wakpamni District is currently in place.

Training

The THPO will provide relevant training and certification to other Tribal programs, following receipt of this same training by THPO staff, on topics such as the National Environmental Policy Act (NEPA), the Native American Graves Protection and Repatriation Act (NAGPRA), the National Historic Preservation Act (NHPA), and the Archaeological Resources Protection Act (ARPA) in order to remain in compliance with both Tribal and federal regulations and laws regarding ground-disturbing activities that are considered a federal undertaking. Federal undertakings have a tie to federal funding and are subject to the National Historic Preservation Act.

CONFIDENTIALITY

All THPO staff, consultants, monitors, contractual agents, and other associated individuals will adhere to strict confidentiality and will be expected to encourage other entities to help protect the integrity of cultural resources.

EDUCATION AND OUTREACH

Because education outreach can help residents of the Pine Ridge Reservation understand on-going issues concerning cultural resource protection and preservation, it will be an essential component of the THPO. The THPO continues to disseminate information on cultural resource protection and preservation, codes compliance, and historic sites through brochures, news-letters, posters, calendars, presentations, at career fairs, District/Community meetings, schools, OST Programs, businesses, and other entities as requested.

REPOSITORY NEEDS

The Math and Science Department at Oglala Lakota College has secured funding to establish and maintain a specimen repository. The funding enables the purchase of cabinets and supplies; labor required for maintenance of the repository will be provided by OLC researchers and interns as part of their regular grant-funded duties. Additional funding will likely be required in four years' time. Dr. Hannan LaGarry is Curator, and Alessandra Higa is Collections Manager. Fulfilling the function of a THPO repository to maintain document archives, LaVera Rose, OLC Archivist, has agreed to work with the Math and Science Department to establish and maintain a records repository.

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ARTICLE

PALEONTOLOGY AND PUBLIC DIPLOMACY

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ABSTRACT—Questions of global climate change and other currently relevant social and political issues require applications of paleontological research that are far more complex than which dinosaur fossil is largest or how many new fossil species may be identified in one year. Management of public lands, both for current development and for the enjoyment of future generations, requires that people making decisions have the best information that is based on scientific principles and expertise. An inability to reach the general public with meaningful and relevant scientific results has led to a lack of appreciation for the importance of paleontological research. A lack of diplomatic skills may also have hindered paleontological managers from garnering the bureaucratic support necessary to develop paleontology into a fully functioning independent program within the United States Government.

With advances in scientific methodology, including increased collaboration between related sciences, understanding paleontology is more important than ever. The science of paleontology offers a unique "deep-time" perspective that can enrich understanding of many current scientific questions on topics ranging from nuclear proliferation to global climate change. With the recent implementation of the Paleontological Resources Preservation Act, government paleontologists have a unique opportunity to create and mold concepts of policy and diplomacy that will affect the way paleontological resources will be viewed and managed well into the future.

KEYWORDS—Paleontology, Policy, Land Management

INTRODUCTION

Questions of global climate change and other currently relevant social and political issues require applications of paleontological research that are far more complex than which dinosaur fossil is largest or how many new fossil species may be identified in one year. Management of public lands, both for current development and for the enjoyment of future generations, requires that people making decisions have the best information that is based on scientific principles and expertise. An inability to reach the general public with meaningful and relevant scientific results has led to a lack of appreciation for the importance of paleontological research. A lack of diplomatic skills may also have hindered paleontological managers from garnering the bureaucratic support necessary to develop paleontology into a fully functioning independent program within the United States Government.

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THE ANTIQUITIES ACT OF 1906

The Antiquities Act of 1906 was one of the most influential pieces of public land management legislation in the history of the United States. In addition to calling for the preservation and protection of antiquities, it served as the authority for permitting the excavation of paleontological resources. The act also grants the President of the United States executive authority to assign particular parcels of public land national monument status and direct how they be managed.

Many areas of special paleontological significance have been designated National Monuments through the Antiquities Act. These monuments are administered by four separate land management agencies: the National Park Service (NPS), the Bureau of Land Management (BLM), the US Fish and Wildlife Service (USFW), and the US Forest Service (USFS). While administration of national monuments by four agencies may cause some confusion, it actually makes a great deal of sense. It is analogous to the administration of wilderness areas by the same agencies, as designated by the Wilderness Act of 1964. The BLM manages National Monuments as part of the National Landscape Conservation System, which has a mandate to "conserve and protect nationally significant landscapes that have outstanding cultural, ecological, and scientific values for the benefit of current and future generations" (P.L. 110-011, Title II, Subtitle A, Sec. 2002). This mandate is similar to that of the NPS, which is "to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS Organic Act, 1916) (Fig. 1).

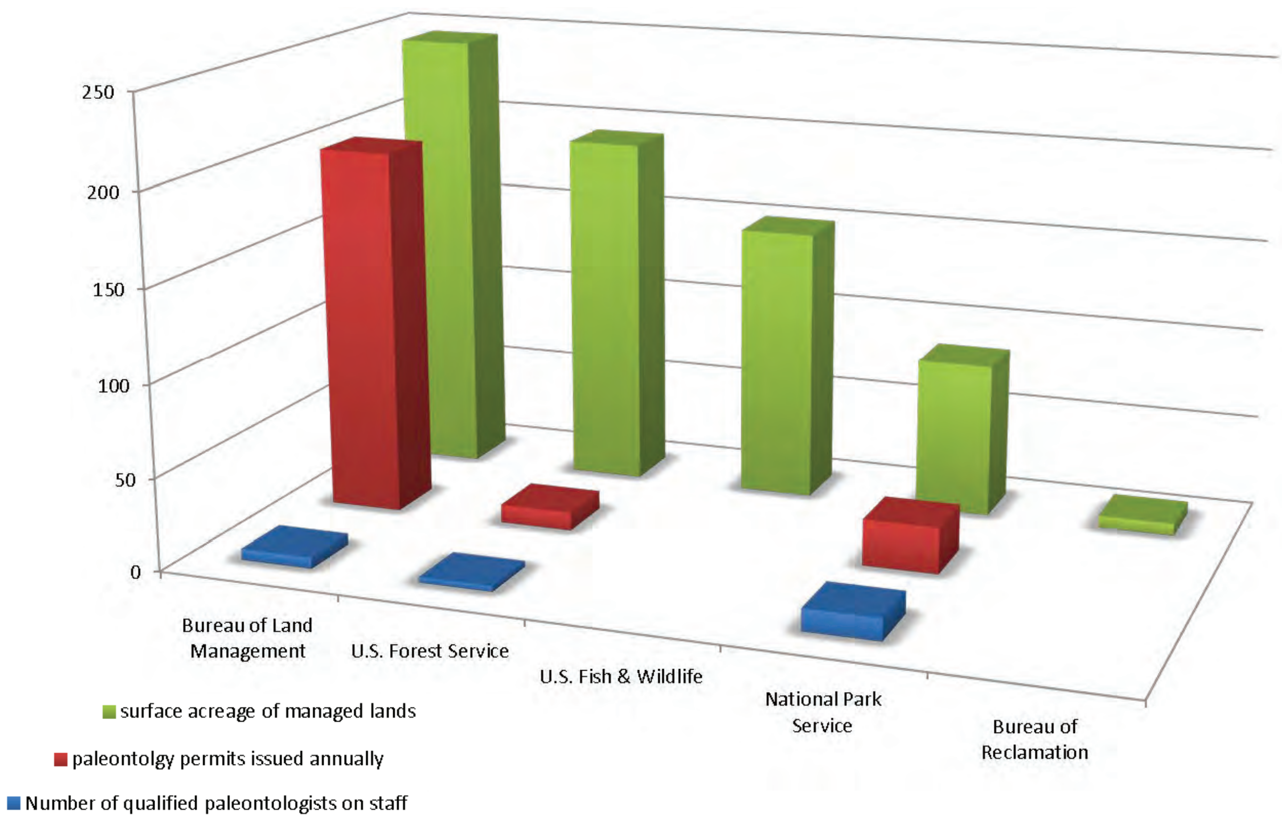


FIGURE 1. Where are we managing paleontological resources?

The most important point, better appreciated by researchers than by public land managers or politicians, is that wildlife, both extinct and extant, doesn't appreciate boundary fences, plat lines, or section markers. The great Western Interior Seaway of the Cretaceous Period, full of marine lizards and shelled ammonites and bordered by horned dinosaurs and cycad plants, engulfed what is now public, private, and Tribal lands. In many ways, the variable styles of management of public lands is less important for what the land was and more important for what land will be many generations from now.

SURVEYS OF THE TERRITORIES

The legacy of managing paleontological resources on America's public lands started well before the Antiquities Act of 1906. The mid-1800s saw settlers moving West in enormous numbers, which drove the U.S. Government to take inventory of the western lands at an accelerated rate. Wildlife, minerals, water, and the ethnology of native peoples needed to be cataloged and, in the case of natural resources, claimed and exploited at an incredible rate. One small facet of these early surveys included locating, recording, and collecting fossils.

The first description of a fossil from the west was published in 1847 by an amateur paleontologist, Dr. Hiram Prout from St. Louis. Most fossils were sent East for description. Joseph Leidy at the Philadelphia Academy of Sciences received one of the earliest of these shipments. He recognized new species of fossil mammals from the White River Badlands of what is now South Dakota and, in 1853, published the earliest monograph with descriptions of new species of extinct animals from the new American West (Owen, 1853). This was the beginning of paleontological resource management on America's public lands.

THE COPE - MARSH FEUD

"What practical use has the Government for Paleontology?"
—Representative Herbert, 1892

What is probably the most important chapter in the history of managing paleontological resources on America's public lands dates to 1890, when a professional rivalry reached national headlines. First Edward Drinker Cope then Othniel C. Marsh launched a series of accusations, threats, and insults at one another from the headlines of the New York Harold, one of the nation's largest newspapers at the time. Neither paleontologist gained an advantage through these repeated volleys; eventually both found their careers mortally damaged. The feud did, though, invite a critical view into the workings of paleontological resource management and congressional scrutiny into the administrative leadership of John Wesley Powell, who was the head of the U.S. Geological Survey and the only funding source for a fledgling federal paleontology program. Both the public and Congress were made aware of shortfalls in institutional paleontological management, specifically the lack of both professional and public access to federally owned museum collections in the care of O.C. Marsh. People started to ask why Marsh, Cope, and other paleontologists did not allow public access to publicly-owned paleontological collections. Collateral damage to their friends and peers was severe; many former collaborators chose to distance themselves not only from Cope and Marsh, but from the science of paleontology in general.

Paleontology became the pariah of federal science at a time when Congress was looking to significantly reduce the federal budget. Two years later, a member of the House of Representatives noted, "[w]e are expending today on science twenty times more than any government in the world." He went on to state, "[i]f there is on this earth an abstract science, it is paleontology. What practical use has the Government for Paleontology?" (Op. Cit. Jaffe, 2000, p.338). In 1892, the politically-weakened USGS suffered a massive budget reduction. The first cut was made to Marsh's paleontology program. Powell wired to Marsh: "Appropriation cut-off. Please send your resignation at once."

It was left to the peers of Cope and Marsh to regain what credibility the science of paleontology could muster. Henry Fairfield Osborne, then curator of mammals at the American Museum of Natural History and professor of paleontology at Columbia University, was able to lobby for the inclusion of invertebrate paleontology in subsequent USGS surveys because of its importance to correlating geologic strata, but was forced to concede that vertebrate paleontology was less important (Jaffe, 2000). After Powell left the Geological Survey in 1894, Charles Doolittle Walcott took over. Walcott, an invertebrate paleontologist himself, continued to include invertebrate paleontology in subsequent surveys (including important Cambrian localities in western Utah), but vertebrate paleontology was all but extinct in the parlance of public land management. Walcott became the secretary of the Smithsonian in 1907 and went on to discover important Cambrian localities in the Burgess Shale in British Columbia (Yochelson, 1998).

Marsh had run the first and only federally-funded paleontology program and, through Powell, had directed federal paleontological policy. He was the first paleocrat. In spite of the introduction of the Antiquities Act in 1906, after Congress pulled the plug in 1892, paleontology as a program and a science would not receive a clear federal mandate for another 117 years.

THE PALEONTOLOGICAL RESOURCES PRESERVATION ACT

On March 30, 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law by President Barack Obama. The PRPA, which directs land management agencies to "manage and protect paleontological resources on Federal land using scientific principles and expertise," is the most important paleontological legislation ever enacted in the United States. The act (formally 16 U.S.C. 470aaa) provides the unified authority that agencies need to in order to manage paleontological resources, issue permits, promote recreational collecting, develop educational programs, and, when necessary, issue citations and prosecute criminal theft (Foss, 2009). It is the primary permitting authority for the collection and study of paleontological resources on public lands. The permitting process must be comprehensive enough to incorporate various types of authorized use, including research, survey, collecting, excavation, and consulting. Streamlined procedures must also be met with a common ethical standard that applies to all permittees.

PERMITTING

Permittees—Paleontological resource use permittees are responsible for all of the paleontological research that occurs on public lands. With mandates such as the Presidential Memorandum of March 9, 2009—Scientific Integrity; Presidential Memorandum of April 16, 2010—America's Great Outdoors; DOI Secretary's Order 3289—Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources; and DOI Secretary's Order 3305—Scientific Integrity Policy, it is critical that land management agencies generate relevant scientific insights into both the land management and the social issues of the day. Paleontological research on public lands has not only resulted in a record number of new dinosaur species over the past year, but has also brought us important revelations about the history of ecosystem diversity and climate change on Earth over the past 500 million years.

Collecting paleontological resources—Significant paleontological resources belong to the American people. All collecting must be on behalf of and for the benefit of the American people. Therefore, in order to collect significant paleontological resources, permittees need a permit that guarantees the following conditions:

1. The collection will benefit the American people and the act of collecting will not hinder the preservation of other equally important resources.
2. Paleontological resources (fossils and associated data) will be preserved for the public in an approved repository where they will be available for study.
3. The permittee will work with the public land manager to ensure that all rules are followed and that the terms and conditions of the partnership are met.

Public lands are not a private research laboratory. In return for access to this public laboratory, the permittee owes something back to the American people. This is explained in the obligations of a permit holder, discussed below.

OBTAINING A PERMIT

All permits require a partnership with the issuing agency. Obstacles to obtaining a permit are normally due to difficulty in forming a partnership. The scope of work for a research or salvage project should take the form of a partnership. In other words, "what's in it for the agency?," "what's in it for the resource?," and "what's in it for the American people?" Why should a land management agency take the time to consider a proposed project that does not offer a return on the investment of time and money by the American people? Scientific results are a valuable asset that should be shared with the Agency.

Consider the responsibilities, mandates, authorities, and priorities of the agency. Are they compatible with those of the permittee? Often they are, and the permit will be processed. If they help perform the function of the agency for the agency, there may even be funding available to promote the project.

The land management agency, the researcher, and the museum need each other. If university researchers cannot justify the relevance of their research, they receive fewer grants and overall less support for their research. Similarly, if museums cannot justify the relevance of their collections, they will find less funding available to support the construction of storage space or even for the continued maintenance of expensive collections. It is the same in the federal government. If land management agencies cannot justify the expensive of paleontology, the program will be cut and it will be harder for researchers and museums to find partners in government to sponsor their research.

OBLIGATIONS OF PERMIT HOLDERS

Development of scientific knowledge is what drives the permitting process. Federal land management agencies are mandated to use scientific principles and expertise when making management decisions that affect paleontological resources. However, agencies as a whole do not have enough technical experts or resources to do all of the basic research that is required in order to answer all of the research questions that arise on public lands. Furthermore, most research questions require an interdisciplinary approach, time-intensive protocols, and, often, expensive equipment. Thus, although America's public lands serve as one of the world's greatest laboratories, scientific investigation, which is central to the management of these areas, must be carried out by professional researchers. Individual government scientists usually serve as only a small part of a larger collaborative scientific effort.

A permit is not a ticket to ride, rather it is a contract. Paleontological resource use permittees should be viewed as collaborators who partner with government agencies to conduct research in order to develop the scientific expertise that is required to make informed land management decisions. In return, permittees are given access to resources that may be limited to a small locality or that may extend to many land units administered by multiple agencies across many states. The breadth of access to public lands for scientific research is dependent on the permittee's scope of work or the nature of the scientific question they wish to pursue.

As a partner, the permittee has responsibilities. In return for access to America's greatest research laboratory, the permittee is responsible for being a good steward of the resource, reporting research results, allowing others to access resources, placing all collected specimens and associated data into a publicly-accessible and approved repository, and acknowledging all of their partners. "Being a good steward" means following all rules and regulations that apply to everyone else who uses and enjoys public lands; it also means agreeing to and following all terms and conditions of the permit. "Reporting research results" means providing the agency with follow-up summaries of what has been learned or synthesized, including providing copies of published papers; failing to share results denies the agency the ability to access important research results when making management decisions. "Allowing others to access resources" means recognizing that a permittee should have a reasonable amount of time to prepare, catalog, and report on their discoveries, and also that scientific research requires the ability for subsequent researchers to examine the same resources in order to test for reproducible results. "Placing all collected specimens and associated data into a publicly-accessible and approved repository" means ensuring that all discoveries are available for future research and educational outreach. "Acknowledgement of partners" means acknowledging the land management agency or owner of the land in any published report that discusses specimens or information that was collected from those lands. Agencies expend a lot of professional and logistic support to researchers and the American public owns the specimens and land from which they were collected; both deserve adequate recognition.

There is no bounty or finder's fee for discovering an important fossil. Land management agencies do not keep a store of cash on hand to reward people for spotting an elk, a bear, or even a rare bird. The same is true for fossils. Amateur paleontologists make an enormous contribution toward the science of paleontology by discovering rare or unusual fossils, but just like spotting a rare bird, the contribution is not fully appreciated until it is evaluated in context. The publicly-owned resource includes both the land and any collections made on it. Whether a fossil or an idea, individuals occasionally develop a personal connection to a discovery, but it should be recognized that the real value of a discovery is in its contribution toward scientific knowledge and the real reward is in presenting it back to the people who actually own it—the American public.

Will the Government fund this work? The permittee's proposed scope of work is important because it allows public land managers to assess the magnitude of work that will be done and the potential benefits in terms of scientific information that may be revealed. If the scope of work is either vague or inconsistent with an agency's mission, the permit request may be denied. On the other hand, if the scope of work promises to further the agency's mission greatly, the government may be able to help fund the work in the form of a grant or other logistical support.

Scientific research is not recreation. Recreational use, including collecting, is an important component of using public lands; casual collection of some paleontological resources is allowed without a permit. A permit, on the other hand, is a partnership between the agency and the researcher and therefore does not apply to recreational collecting. Scientific research performed under the guise of casual collecting or recreation denies the land management agency access to research results and other information that would otherwise be very important to its science-based decision making. It also denies the American public legitimate access to specimens and research that belong to them.

HOW SHOULD RESEARCH RESULTS BE PUBLICIZE TO THE GENERAL PUBLIC?

Imagine this scenario: You give your neighbor permission to collect some pretty rocks in the garden behind your house. On a Saturday morning two years later you wake up to a couple dozen people sifting through your garden looking for more pretty rocks. An hour after that you receive a phone call from the local newspaper asking how you feel about the new type of rock that was discovered on your property. I am betting that you are just a little bit annoyed.

Most peer reviewed journals have editorial procedures that follow established ethical guidelines for reporting on scientific discoveries and insights. It remains the responsibility of the researcher to ensure that all of the information has been collected legally, all images and artwork are legally owned, all citations are accurate, and that all contributors (including the land management agency and land owners) are properly acknowledged. Furthermore, any press release that highlights research (including new fossil species) from specific areas of land must be done in conjunction with the appropriate land owner or land management agency. The primary reason for this is that press releases and public announcements heighten public interest in an area and the land owner or land management agency needs to be prepared for this increase in interest. In addition, the publication of research from public lands will enhance a land manager's ability to promote resources in their care and potentially fund more work in the future. Finally, land management agencies have dedicated pubic affairs offices that are able to coordinate press releases and promote research results in ways that most researchers and smaller institutions are unable to match. Remember, permittees and land owners are partners.

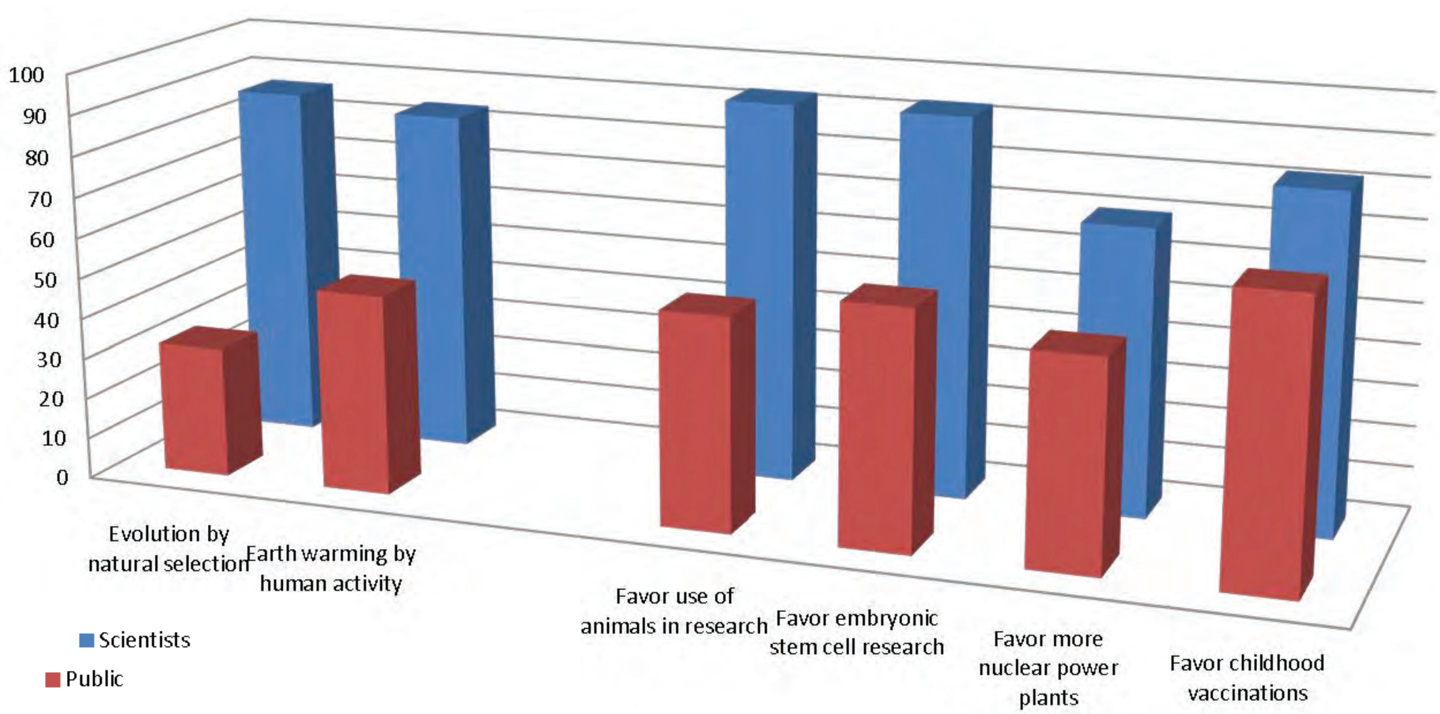
HOW DOES THE PUBLIC VIEW SCIENCE?

There is a positive correlation between the qualifications of a teacher and the subject retention of the students. However, in 1995 a full one third of all K–12 students in the United States were taught science and mathematics by teachers that had not majored or minored in the subject they were teaching. The numbers improved by 2000, but the problem persisted (Klemballa, 2005).

It has also been reported that 85% of scientists believe that one of the greatest difficulties in conducting and reporting their research is directly related to the public's ignorance of science (Pew, 2009). Despite scientists' perceptions, nearly the same percentage of the public (84%) believe that science has a positive effect on society (Pew, 2009). In fact, next to members of the military and teachers, scientists are regarded as the greatest contributors to society's well-being (Pew 2009). The fact is that scientists perceive issues in the world slightly different than the public as a whole.

When it comes to scientific or medical issues, scientists are more than twice as likely as the public to accept scientific explanations for evolution and climate change. Scientists are also nearly twice as likely to favor research on animals, embryonic stem cell research, nuclear power, and childhood vaccinations (Pew, 2009) (Fig. 2). Although most scientists claim to be non-political, as a group they tend toward similar political ideolo-

FIGURE 2. Does the public connect with science? Current issues in science. Information from Pew, 2009



gies and vote similarly (Pew, 2009). In a poll asking why they chose to go into science, 87% of scientists answered that it was to “solve intellectually challenging problems,” whereas only 3% answered that is was for “financial reward” (Pew, 2009).

Paleontology is a science that continues to capture the intellect of all ages and may be one of the best vehicles to make science accessible to the public. Whether it involves getting Americans outdoors or into a library, paleontology offers rewards that at first glance may not be apparent in other sciences. Paleontology, as a profession, must use this opportunity to show that the science goes far beyond the novelty of describing dead organisms and, in fact, elucidates important ideas that are relevant in many levels of social and political discussion.

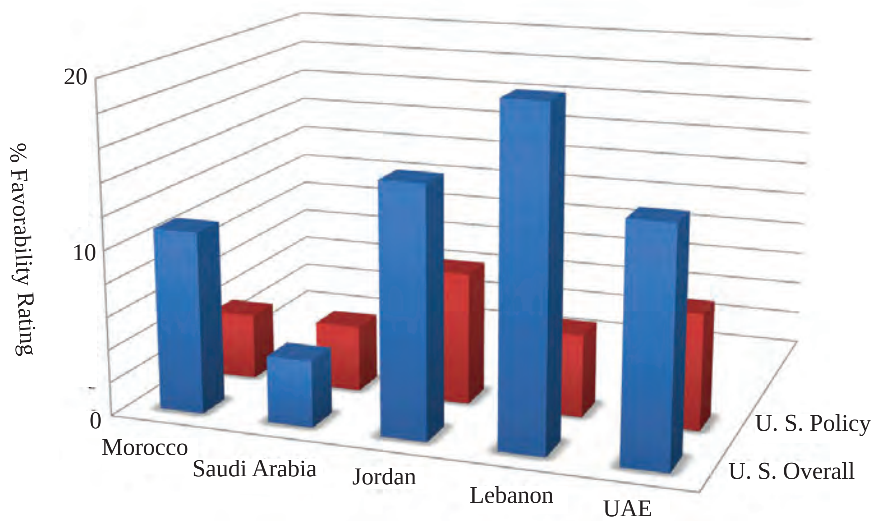


FIGURE 3. Arab attitudes toward the U.S.: They don’t like U.S. foreign policy. Information from Zogby, 2004

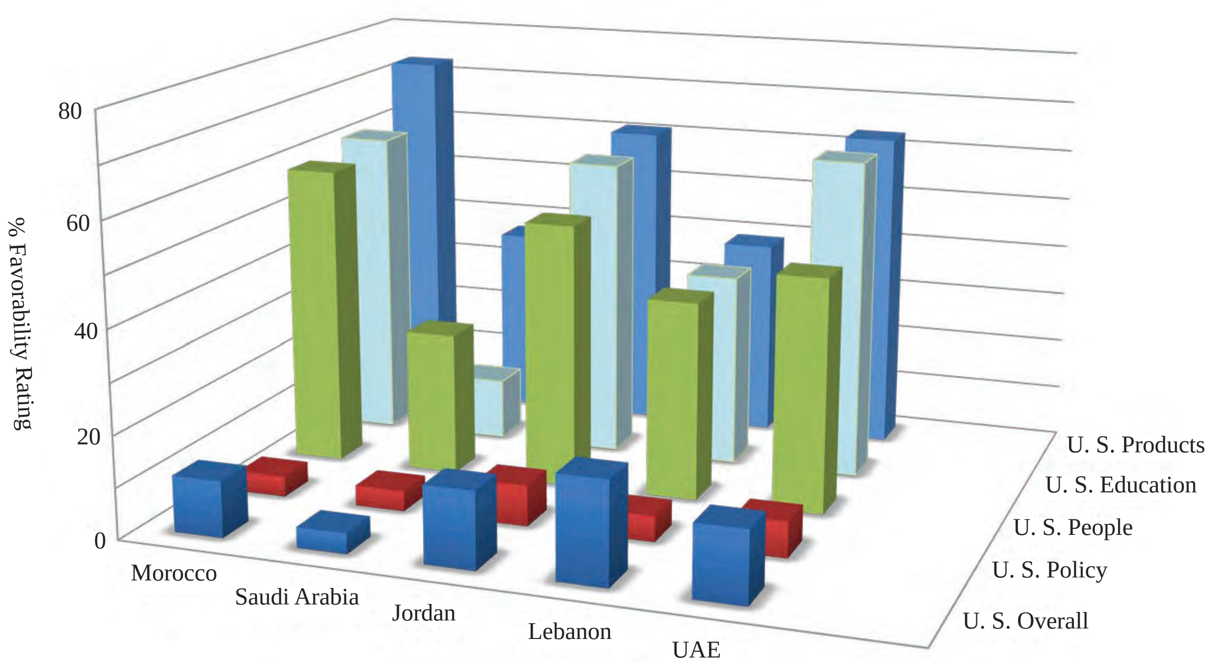


FIGURE 4. Arab attitudes toward the U.S.: They do like U.S. people, education, and products. Information from Zogby, 2004

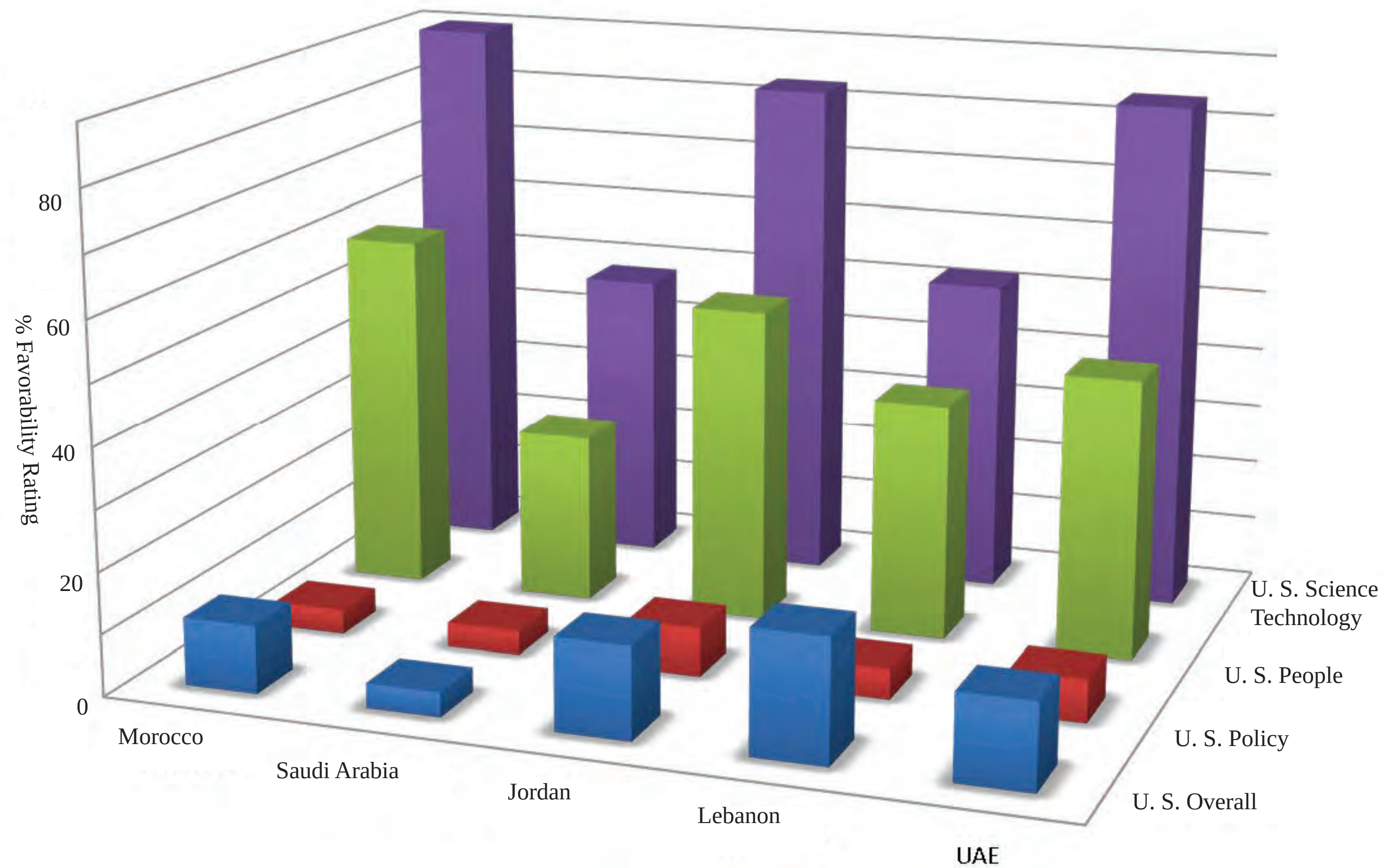


FIGURE 4. Arab attitudes toward the U.S.: They are most positive about U.S. science and technology. Information from Zogby, 2004

PUBLIC DIPLOMACY

It is no secret that the United States has an image problem around the world. The U.S. image is at its worst in the Arab world where overall favorability ratings are normally below 20% and in some cases are as low as 4% (Zogby, 2004). Such low ratings can be attributed to U.S. foreign policy toward these nations; U.S. policies have single digit favorability ratings (Fig. 3). However, these same Arab countries that have such a poor overall view of U.S. foreign policy have a substantially higher view of American people and products; these ratings tend to hover between 50% and 60% (Fig. 4).

What is startling is that the favorability rating toward U.S. science and technology is as high as 80% in many Arab nations (Zogby, 2004) (Fig. 5). This is a number that approaches the level of appreciation that American people foster toward their own science (Rand, 2009). In order to deal with such a severe image problem in foreign countries, the U.S. should promote its strongest asset, which is science.

The Arab example is the most dramatic, but the concept applies to diplomatic relations with all countries. Selling science to the public is a form of diplomacy. The U.S. State Department defines public diplomacy as "government-sponsored programs intended to inform or influence public opinion in other countries" (Rand, 2010). A simpler definition of diplomacy, applied to selling science, would be: programs intended to inform or influence opinion using known facts.

As with poor science and poor science education, there is a danger of mixing falsehoods (intentionally or not) with facts, which changes diplomacy to propaganda—a combination of falsehoods and untruths mixed with facts (Rand, 2010). The Rand (2010) report calls for the U.S. Government to engage in less "public diplomacy" in favor of the marketing model that works so well for U.S. corporations in other countries. The caution toward applying a marketing model to diplomacy is that it is too easy, whether by intention, laziness, or ignorance, to lapse into propaganda, as we observe so often in advertising.

SUBSTANCE VS. STYLE

Science education has substance, but often lacks style. Propaganda, on the other hand, normally has style (mixing of falsehoods and facts), but lacks credibility. The most important asset of good science is its credibility—its ability to maintain integrity even in the face of falsification. Good science allows even its most cherished hypotheses to be falsified; if the process that brought about those hypotheses was followed with integrity, then the process survives even in the face of falsification. That is science! As scientists we must safeguard the integrity of the scientific process while reaching for the style necessary to inform and influence public opinion.

Marketing tactics may be used to sell the science of paleontology, but scientists are bound to the sacred practice of safeguarding the integrity of the scientific process. We may use style to sell the substance, but we must not, through oversimplification or omission of facts, allow falsehoods to enter the message. This will be the most difficult part of integrating the importance of paleontology into a public message.

There is also no reason to apologize for the complexity of natural systems. The challenge is to embrace complexity while translating it into meaningful and relevant messages to our politicians, policymakers, and the general public. If the message is both relevant and delivered with sufficient style, people will listen.

THE PALEOCRAT

The profession of paleontology currently engages highest-caliber researchers, far sighted and progressive museum curators, and fantastically talented fossil preparators who all employ rigorous methodology and the latest techniques. However, paleontologists are currently ill-prepared as program managers or administrators. Until now, few people have chosen to enter the field of paleontology with the specific goal of becoming a manager or bureaucrat. As a group, paleontologists are teachers, researchers, and diggers (Foss, 2009).

The paleocrat is a breed of paleontologist who is versed in business management, public law, and diplomacy, and also maintains the skills of a researcher and teacher. These skills will become increasingly important as the profession of paleontology grows from researching novelties to addressing current social questions in our society.

THE MISSION

Science is our strongest card in the game of diplomacy. The public maintains a favorable view of science in nearly every country in the world and is willing to allow public funds to be spent on scientific inquiry. Failures in direct diplomacy around the world may be mended by playing to the strongest asset we have to offer, which is science. This fact makes it even more important that the scientific method be taught to all students and that it be employed with integrity.

Insights gained from studying paleontology have contributed to public discussions of everything from evolutionary theory to nuclear proliferation. In order to remain relevant, the science of paleontology must continue to provoke public discussion in areas of research that are germane to current issues. In a social and political environment where climate change has become a worldwide issue, the deep time perspective that is offered by the science of paleontology should continue to form a critical component of the discussion.

Every work place has a reason for existing that should be articulated in the form of a mission statement. The relevance of any given task should be measured against that statement. As public servants, the way we spend money should also be appropriate to the mission statement. Adherence to the mission will not only allow us to be more productive and effective as paleontologists, but will also help to guide us away from the political disasters that have befallen the profession of paleontology in the past. As scientists and public servants, this is our mission:

1. Promote science-based decision making in public policy and encourage scientific consideration in all levels of diplomacy.
2. Inform and educate policymakers and the public about important contributions of the science of paleontology toward relevant issues in public discourse.
3. Incorporate the science of paleontology into public outreach and education whenever possible.

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ARTICLE

ESTABLISHING A PALEONTOLOGICAL MONITORING TEST SITE AT GLEN CANYON NATIONAL RECREATION AREA

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ABSTRACT—Several factors were taken into consideration while establishing a paleontological monitoring test site at Glen Canyon National Recreation Area. Strata in the Recreation Area preserve a significant fossil record that includes many world class paleontological sites (Santucci and Kirkland, 2010), most notably a wealth of Lower Jurassic dinosaur tracksites preserved in the Glen Canyon Group along the margins of Lake Powell (Lockley et al., 1992, 1998). Santucci et al. (2009a) summarized the factors affecting in situ paleontological resources and strategies for monitoring their effects. There is little documentation of the long-term effect of these factors on fossil resources, but it is generally not an extremely rapid process unless the fossil is in an area of active erosion such as the bank of a river or the coast of a large body of water, or if the fossil in located in soft sediment. Vandalism and theft by humans pose a major threat to in situ fossil resources.

It is important to consider the costs associated with developing a monitoring plan. The most sophisticated methodologies may be cost-prohibitive and require trained scientists to carry out. Once a paleontological site has been properly documented, a plan can be developed to provide a means for low-cost, long-term monitoring. If significant changes are documented during subsequent visits, a follow-up inspection may be made by specialists (Milner et al., 2006; Santucci et al., 2009a, Spears et al. 2009).

KEYWORDS—Paleontological Monitoring, Glen Canyon National Recreation Area, Dinosaur Tracksite

INTRODUCTION

The National Park Service (NPS) has been developing monitoring programs for the natural resources within our national parks and monuments. The Utah Geological Survey (UGS) was contracted by the NPS to develop a paleontological monitoring test site at Glen Canyon National Recreation Area (GLCA).

Santucci et al. (2009) have summarized the natural and human factors affecting in situ paleontological resources and strategies for monitoring their effects. There is little documentation of the long-term effect of natural processes on fossil resources in the field, but it is generally assumed that fossils do not degrade rapidly under normal conditions unless the fossil is in an area of active erosion (such as the bank of a river or the coast of a large body of water) or if the fossil is located in soft sediment. A major threat to in situ fossil resources is vandalism and theft by humans.

It is important to consider the costs associated with developing a monitoring plan so that they may be carried out within the budget constraints of the NPS unit. The most sophisticated monitoring methodologies may be cost prohibitive and require trained scientists to carry out, thus the most effective monitoring plans are those that NPS staff can undertake with a minimum of specialized training. Once a paleontological site has been properly documented, an efficient plan can be developed that provides a means for low-cost, long-term monitoring. If significant changes are documented during subsequent visits, a follow-up inspection may be made by specialists (Milner et al., 2006; Santucci et al., 2009; Spears et al., 2009).

Strata in GLCA preserve a significant fossil record that includes many world-class paleontological sites (Santucci and Kirkland, 2010). Most notably, the Recreation Area contains a wealth of dinosaur tracksites preserved in the Lower Jurassic Glen Canyon Group along the margins of Lake Powell (Lockley et al., 1992, 1998). This paper summarizes our establishment of a paleontological monitoring test site, such that GLCA staff may appraise the potential costs inherent in developing a park-wide paleontological monitoring plan.

LOCKLEY'S COVE—A SIGNIFICANT PALEONTOLOGICAL SITE COMPLEX

Even in the most famous fossil-bearing strata, such as the Upper Jurassic Morrison Formation, significant vertebrate fossils are not distributed evenly through the outcrop. A Paleontological Site Complex (PSC) is an area of restricted geographic and temporal extent that preserves an abundance of important fossil localities (Kirkland and Foster, 2009). PSCs make up the core of some of America's most famous national parks and monuments, as exemplified by Petrified Forest National Park, Fossil Butte National Monument, Badlands National Park, John Day Fossil Beds National Monument, and Agate Fossil Beds National Monument. As with these PSCs, GLCA's first identified PSC—Lockley's Cove in the Slick Rock area—warrants special attention (Fig. 1).

In seeking a site for which we could develop a model for paleontological monitoring at GLCA, we visited an area preserv-

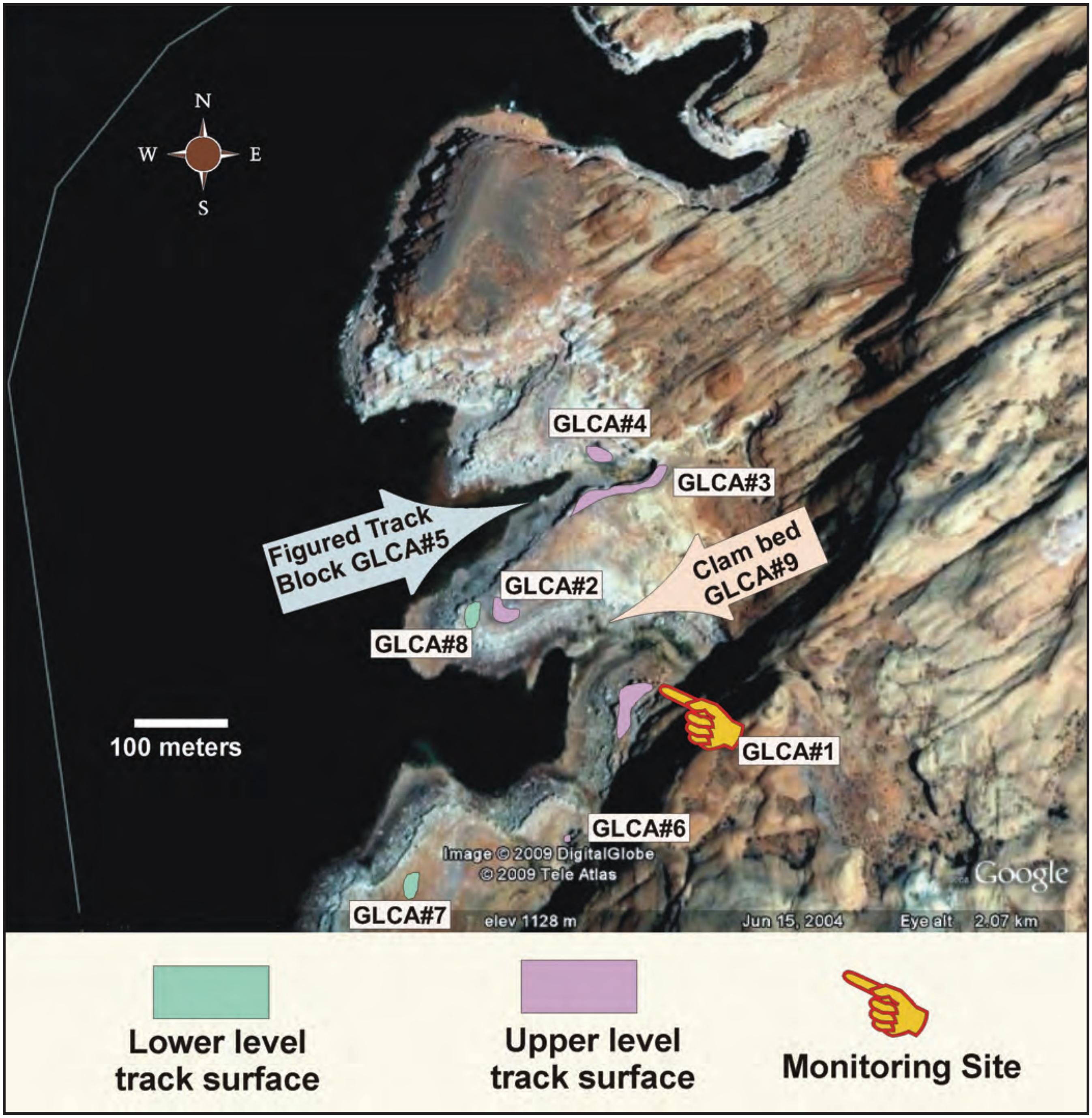

FIGURE 1. Google Earth view of the Lockley's Cove PSC with the distribution of paleontological sites and the primary monitoring site.

ing several dinosaur tracksites at multiple stratigraphic levels, initially researched by a team led by Martin Lockley in 2005 and revisited during a spring 2008 trip. Informally, we have designated this area Lockley's Cove (Fig. 1). The nine recorded fossil sites are preserved in a thick sequence of alternating mudstone, limestone, and sandstone more than 30 m (100 ft) thick, as measured from lake level to the base of the main cliff of cross-bedded Navajo Sandstone (Fig. 2 B). In addition, the area preserves a unique unionid clam bed containing molds of hundreds (potentially thousands) of individual fresh-water bivalves (Phoebes' Clam Bed); this bed was submerged during our visit (Fig. 3). Because there is an obligate parasitic relation between these bivalves and fish—all unionid larvae spend part of their life living in the gill filaments of fish (Good, 1998),—their presence indicates that fish were also present at this location during the Early Jurassic. The site had been originally identified as being in the Kayenta Formation because of the extent of fine-grained rocks and the presence of unionid clams. Using a new

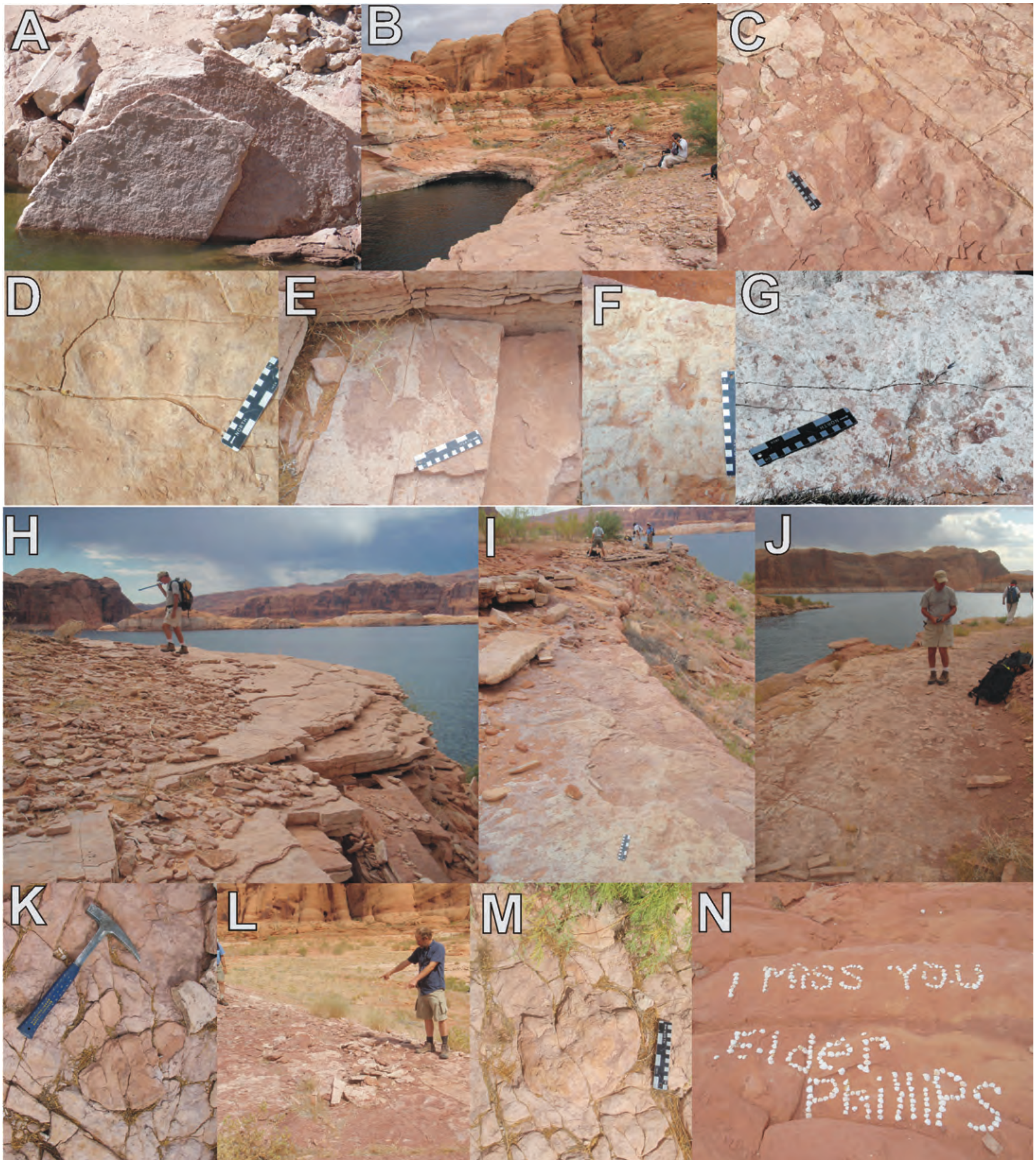

FIGURE 2. Fossil sites and features at Lockley's Cove. **A**, Large fallen track slab GLCA#5 "upper level" identified for salvage in 2008, but completely under water in 2009, figured in Santucci et al. (2009); **B**, Inundated cove northwest of GLCA#3. There would have been no water in this view a year earlier. Note cliff of Navajo Sandstone; **C**, *Eubrontes* track at GLCA#2 "upper level"; **D**, *Anomoepus* tracks at GLCA# 3 "upper level"; **E**, *Anchisauripus* tracks at GLCA#3 "upper level"; **F**, **G**, *Grallator* tracks at GLCA #3; **H**, **I**, Views of GLCA#3 "upper level"; **J**, GLCA#4 "upper level"; **K**, **M**, *Eubrontes* tracks at GLCA#8 " lower level"; **L**, GLCA#8 "lower level"; **N**, Ecologically benign graffiti made by laying out modern *Corbicula* shells.

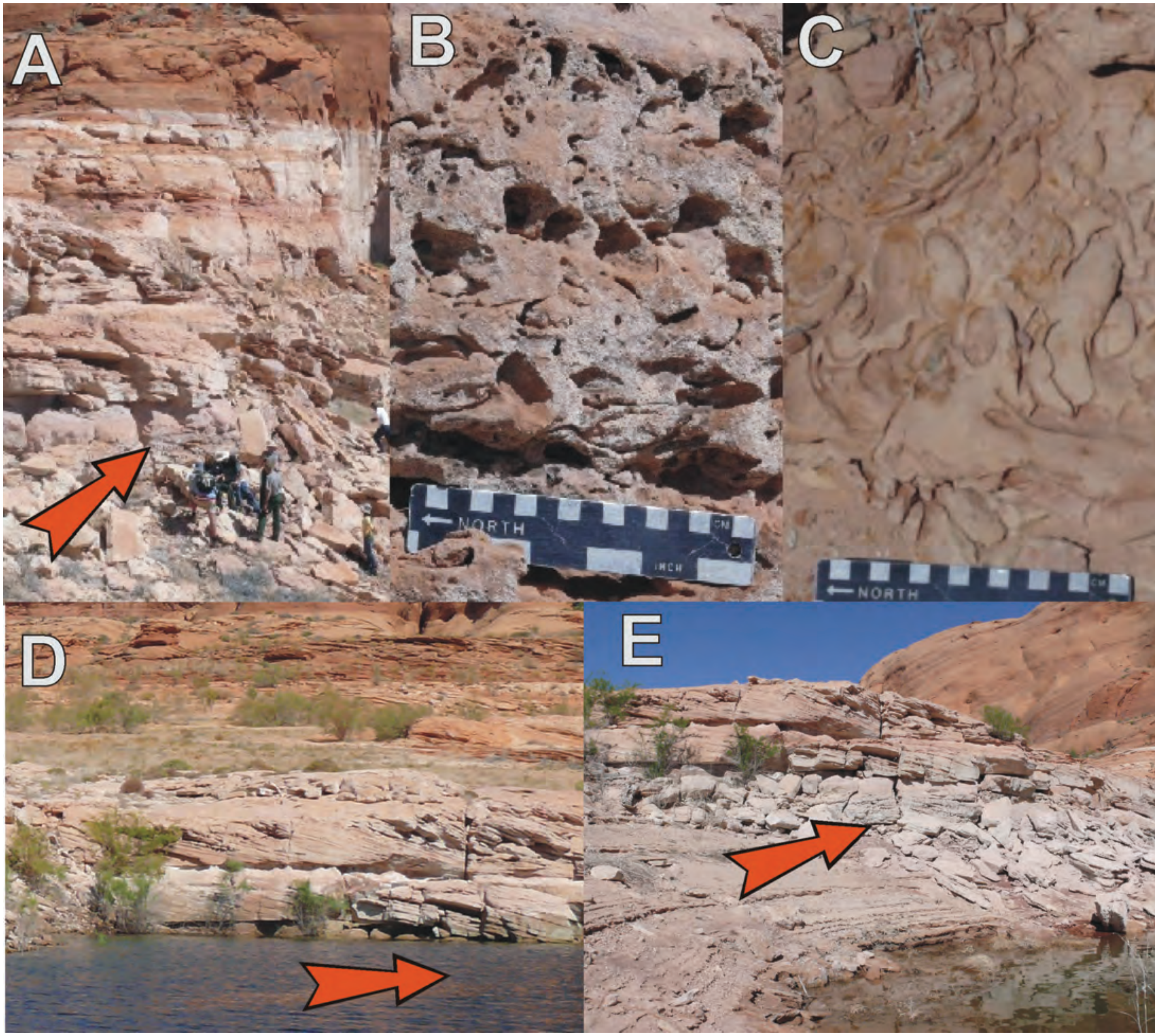

FIGURE 3. Pheobe's Unionid Clam Bed at Lockley's Cove in spring 2008. **A**, GLCA staff inspecting site, upper track level in notch ~ 5 m above, arrow points to in situ clam bed; **B**, unionid molds in cross section; **C**, unionid molds as exposed along bedding plane.

geological map (Doelling and Willis, 2008), we were able to determine that these sites were at least 400 feet above the base of the Navajo Sandstone. Previously, unionid bivalves were unknown in the Navajo of southern Utah, although they had been recognized in the Moab area (Wilkens, 2008). Therefore, unlike the other playa environments preserved within this eolian rock unit at GLCA, which represent times when the Early Jurassic water table impinged on the surface of interdune areas, this site is unique in that it records an environment connected to more permanent water sources near the center of the largest sand sea in Earth's history.

PRIMARY MONITORING SITE

In 2005, George Muller discovered an outstanding tracksite about one kilometer (0.6 mi) up river from Mile Buoy #81 in the Colorado River Arm of Lake Powell. This locality, referred to as the "Dance Floor" by Muller and "Slick George's Dinosaur Tracksite" by Martin Lockley, is down lake from Slick Rock Canyon in an alcove on the east side of the lake. The fossil-producing bed is about 8 meters (26 ft) below the high waterline at an elevation of approximately 3700 ft (Fig. 4).

As documented by Lockley, fossils consist of well-preserved *Anchisauripus*, *Anomoepus*, and *Grallator* tracks, a few of

FIGURE 4. Slick George Dinosaur Tracksite GLCA#1 in the fall of 2009 versus the spring of 2008 during lower lake levels. Position of upper track level indicated by red track symbol and arrow, and approximate position of lower track level indicated by white track symbol and arrow.

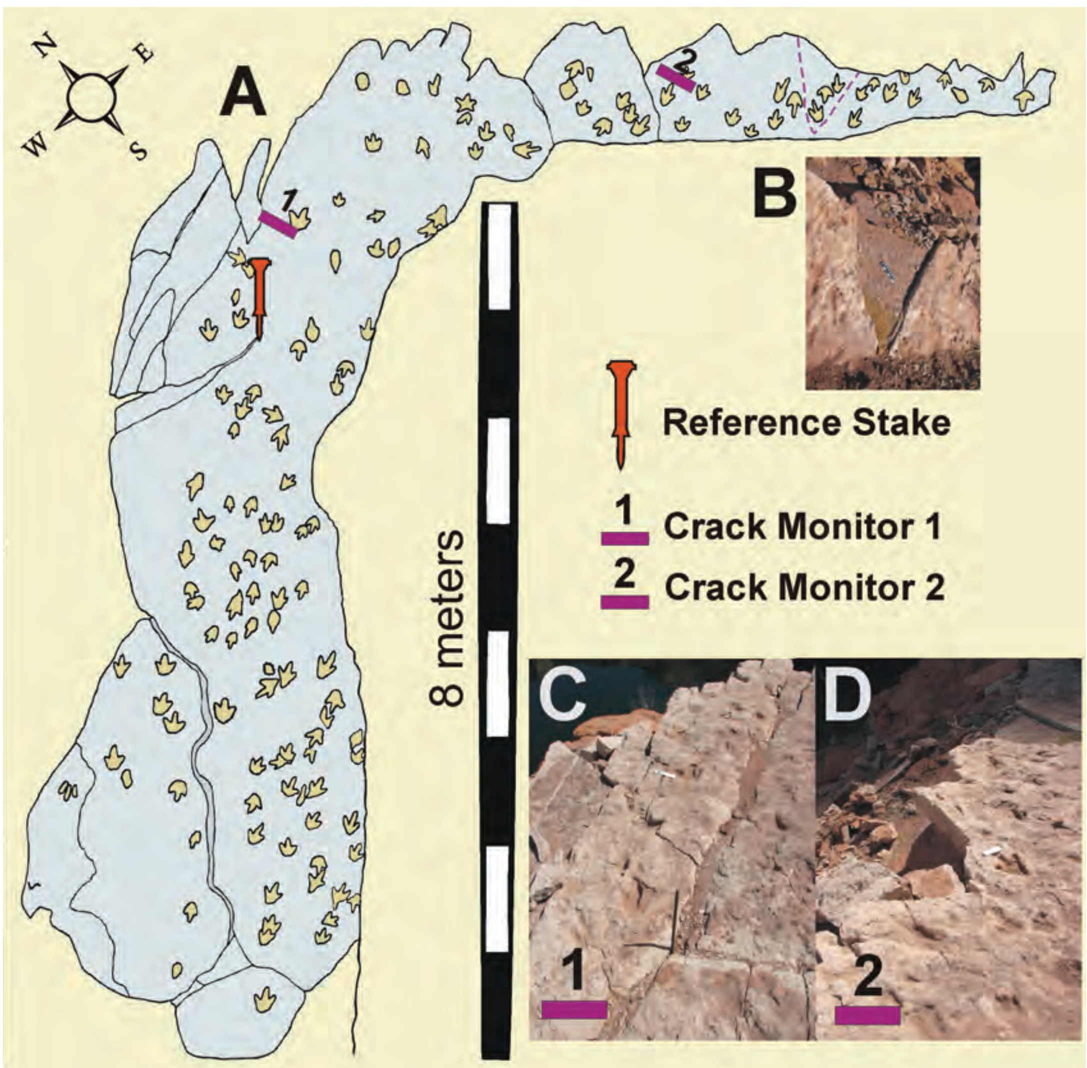

FIGURE 5. Slick George Dinosaur Tracksite, GLCA#1. A) Distribution of tracks at GLCA#1 mapped by Martin Lockley in 2005, showing the position of reference stake and crack monitors, and position of missing track section indicated by dashed line at top of figure; B) 2009 photo showing detail of site of missing track section; C) Surface of site showing position of rebar reference stake and crack monitor 1 looking north; D) Overview of crack monitor 2 looking east.

which appear to be associated trackways made by individuals walking across the surface (Fig. 5). The track-bearing unit, composed of fine-grained quartz sandstone, with rounded grains and carbonate cement, is exposed in several localities around the cove; tracks appear to be fairly abundant in the adjacent areas visited. A specimen of the track layer was sampled for petrographic analysis (Fig. 6). Initial interpretation is that this layer may represent an interdunal playa “oasis” deposit in the Navajo Sandstone, although the associated unionids suggest it may be part of a larger aquatic system. The absence of porosity in these samples is a result of extensive carbonate cementation.

This locality was established as the first Paleontological Resource Monitoring locality for GLCA because its location and wide variety of features make it a good place to implement the methodology of Santucci et al. (2009) for monitoring in situ paleontological resources. The site has the following attributes:

1. It contains significant paleontological resources (Fig. 5).
2. It is accessible from the lake shore (Fig. 1).
3. It is threatened by both natural and human-related factors (Figs. 2, 3).
4. Erosional processes at the site have resulted in a “conveyor belt” retreat of the track-bearing slabs (we documented one track slab that was down dropped from the section). Processes include undercutting of sub-adjacent beds, splitting along joints of track-bearing unit (Figs. 5, 7), and down-drop of boulders from super-adjacent units (documented rock-fall damage from Navajo blocks dropping from above the site).
5. Although the site is located above the current water level for Lake Powell, it is below the high water mark (Fig. 4). Changes to the site can be photo documented using an embedded stake as a reference point, measured directly, or calculated from recorded lake level.
6. There is evidence of human visitors to the site (Fig. 2). One section of rock from the track-bearing unit appears to have been removed intentionally following the initial mapping of the site in 2005 (Fig. 6). (Martin Lockley is not sure if he collected it.)

A reference point for the site was established by the placement of a centrally-located rebar marker (Figs. 5, 7). This marker is the geo-reference point for the site and the photo-point for repeat photo documentation of the site. The location provides views along the two main axes of the track-bearing exposures. The long axis for photo-monitoring is S. 15○ W.; the short axis for photo-monitoring is due east from the stake. GPS coordinate data for the site were obtained by several repeat measurements using a hand-held instrument.

The locality was photo-documented by Scott Madsen at 1:00 p.m. MDT on September 20, 2009. No paleontological resource collections were made from the site, and only the one rock specimen was collected from the track-bearing layer for petrographic analysis (Fig. 6). One slab had previously been removed from the locality (not natural breakage) following the initial mapping in 2005. Martin Lockley is checking his documentation to determine whether he collected any specimens; if he was not responsible, the missing slab may represent an incidence of theft.

A strong joint set is present in the fossil track-bearing unit (Figs. 5, 7). The joints are essentially vertical and strike N. 50○ E., and spaced from 0.25 to 0.5 meter (0.8–1.6 ft) apart. On April 26, 2010, James Kirkland and Scott Madsen met GLCA Aquatic Ecologist Mark Anderson at the Bullfrog Marina and proceeded

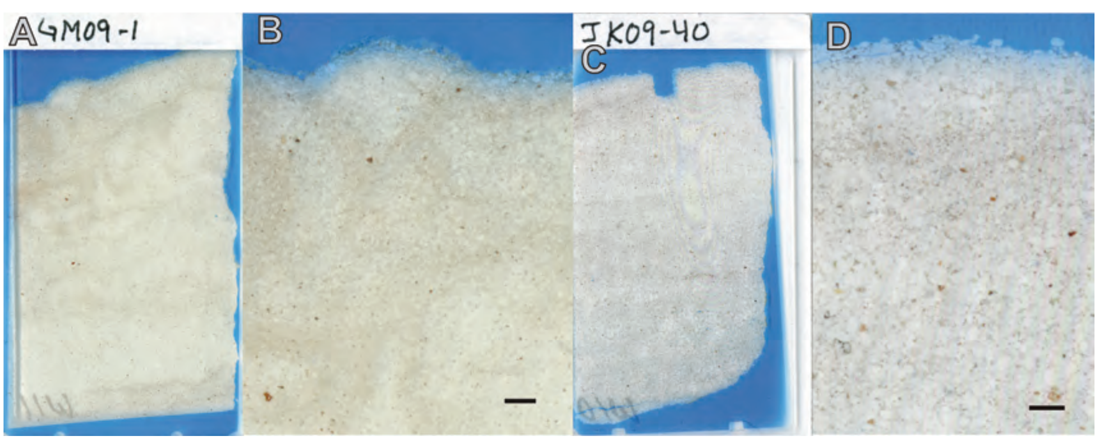

FIGURE 6. Thin sections made from upper track horizon at Lockley’s Cove. A) Thin section from Slick George Dinosaur Tracksite GLCA#1; B) Detail of upper surface of track layer GLCA#1, scale bar equals 1 mm, porosity is 0.000%; C) Thin section from Anomoepus Bench GLCA#3; D) Detail of upper surface of track layer GLCA#3, scale equals 1 mm, porosity is 0.028%. All slides are 2.7 cm wide.

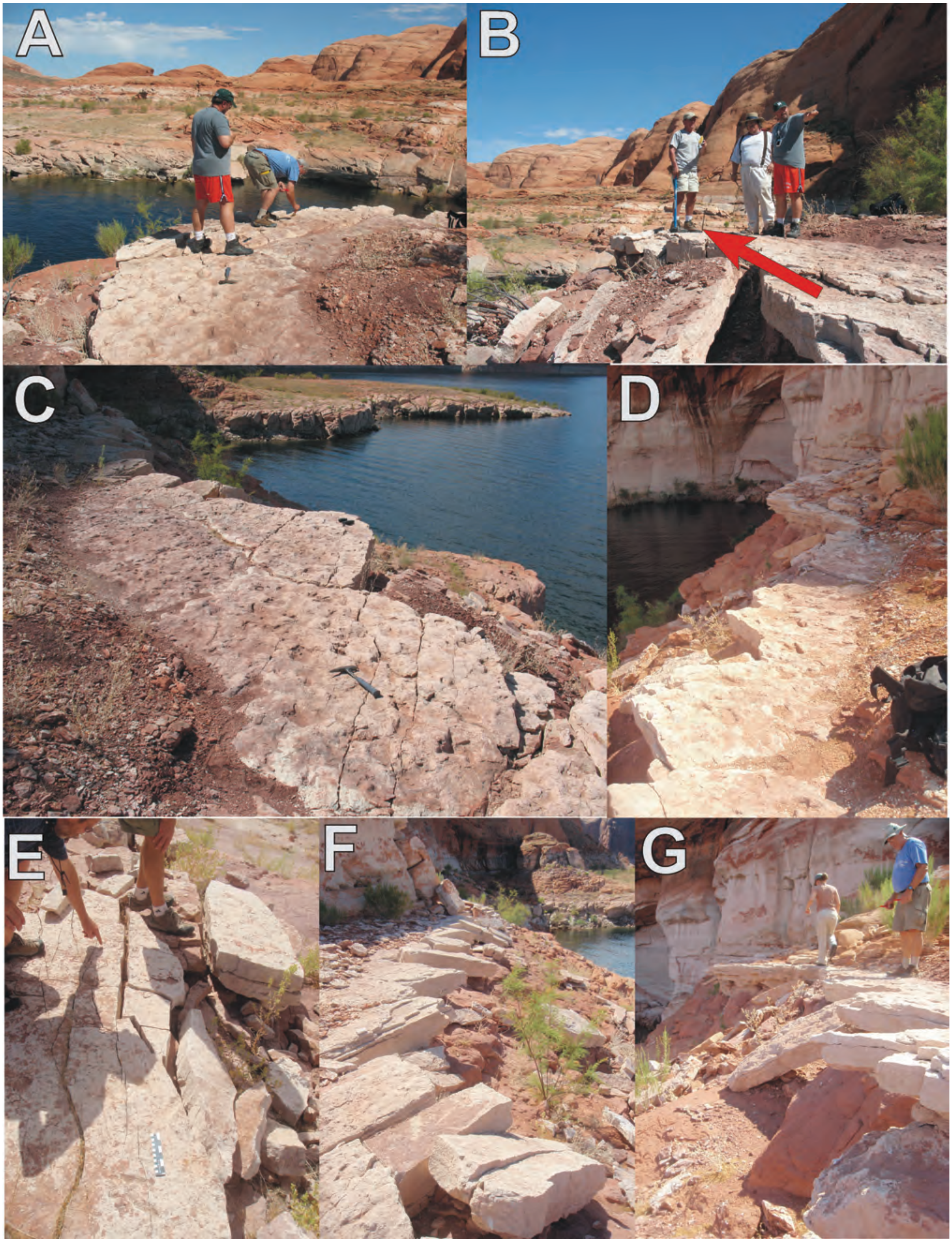

FIGURE 7. Establishing monitoring station at Slick George Dinosaur Tracksite, GLCA#1. **A**, **B**, Establishing rebar reference point, arrow indicates rebar stake; **C**, View from stake looking southwest; **D**, View from stake looking northeast; **E–G**, Sides of site being undercut, splitting along joints, and spalling down slope.

down lake to Lockley's Cove and Monitoring Site GLCA#1 to install crack monitors to measure the expansion of the joints. The team used adhesives to install two crack monitors at both GLCA#3 and GLCA#1 (Figs. 5, 8).

While there, they also took more photographs in order to evaluate any short-term changes that may have occurred in the seven months following the initial establishment of the monitoring site. No appreciable changes were observed (Fig. 9).

In order to put all the fossil sites in the Lockley's Cove area into a temporal context for future researchers, Kirkland measured a stratigraphic section from the water line up through the highest recorded fossil occurrence at GLCA #1. All three fos-

FIGURE 8. Installing crack monitors. **A–E**, Installing crack monitors at GLCA#3. **A**, Mixing epoxy; **B**, Installing crack monitor by *Anomoepus* tracks; **C**, Crack monitor by *Anchisauripus* tracks; **D**, Crack monitor by *Anomoepus* track; **E**, Close-up of crack monitor by *Anomoepus* track showing initial setting of 0,0; **F–H**, Crack monitor 1 at GLCA#1. **F**, Overview looking north; **G**, Another view looking west; **H**, Close-up of crack monitor 1; **I–K**, Crack monitor 2 at GLCA#1 by *Grallator* track. **I**, Overview looking east; **J**, Another view looking northwest; **K**, Close-up of crack monitor 2.

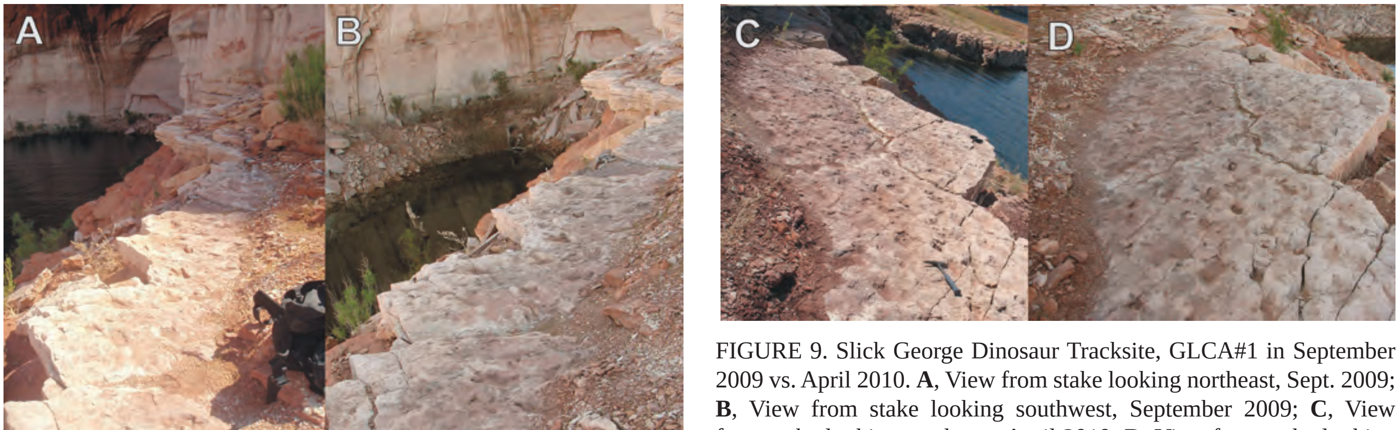

FIGURE 9. Slick George Dinosaur Tracksite, GLCA#1 in September 2009 vs. April 2010. **A**, View from stake looking northeast, Sept. 2009; **B**, View from stake looking southwest, September 2009; **C**, View from stake looking northeast, April 2010; **D**, View from stake looking southwest, April 2010.

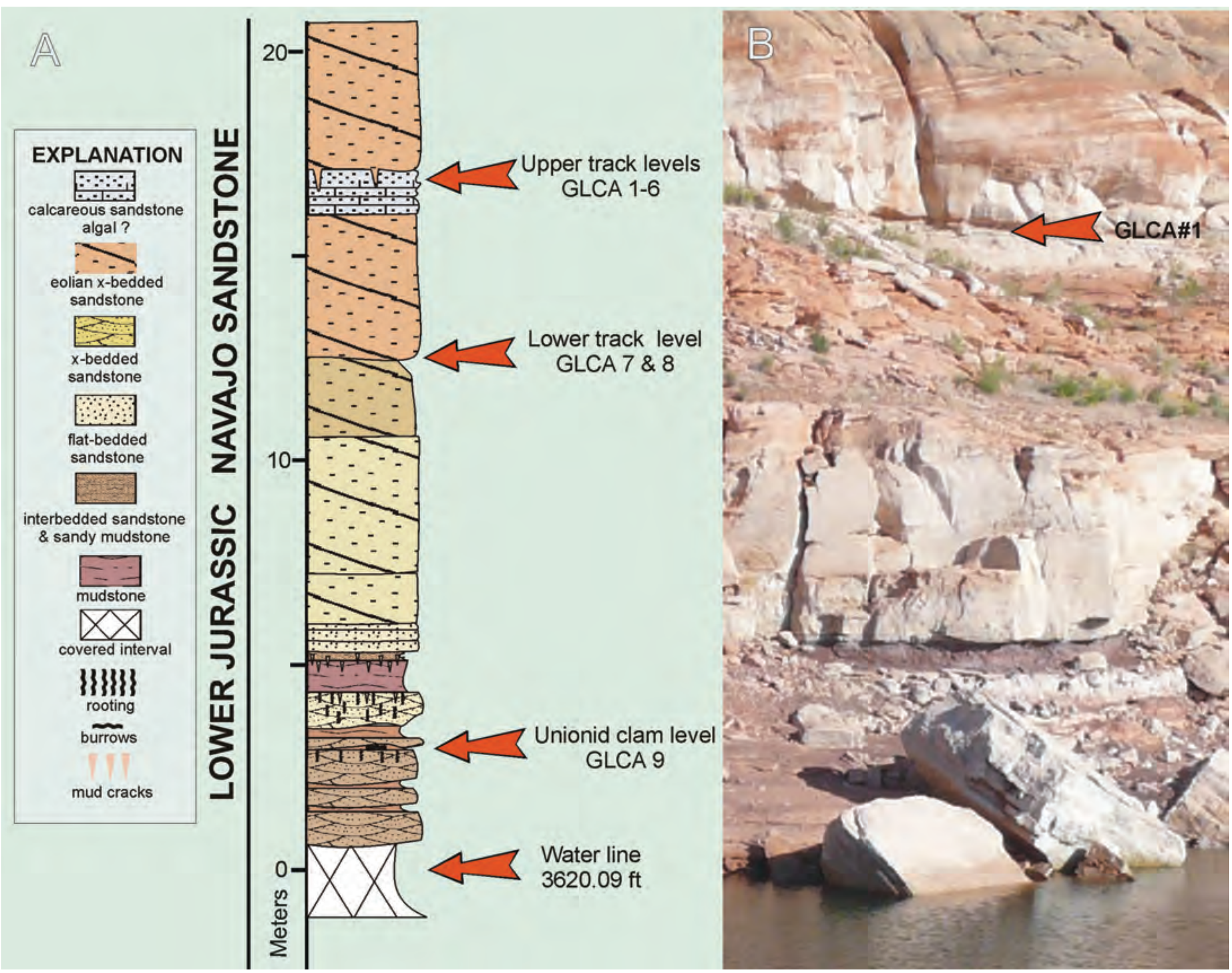

FIGURE 10. Measured section. **A**, Measured stratigraphic section on the south end of Slick George Dinosaur Tracksite GLCA#1 with stratigraphic positions of main sites in the Lockley's Cove PSC (Fig. 1); **B**, Outcrop on the south end of Slick George Dinosaur Tracksite GLCA#1, stratigraphic section was measured April 26, 2010, at a lake level of 3620.09 ft.

siliferous intervals and their relationships with these rocks were documented (Fig. 10).

NPS personnel at GLCA will continue to make regular visits to Lockley's Cove to document long-term natural and visitor-induced changes at the site.

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ARTICLE

THE KEYA PAHA FAULT AND RELATED STRUCTURES; THEIR SIGNIFICANCE TO THE GEOLOGY OF SOUTH DAKOTA

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ABSTRACT—A major geological structural feature, the Keya Paha Fault, occurs in south-central South Dakota and appears to extend northwestward across South Dakota. The fault is subparallel to the well-documented White Clay Fault, occurring farther west in South Dakota, and to other lineaments occurring between the two faults. To the east of the Keya Paha Fault, Ponca Creek and even a portion of the Missouri River lie subparallel. The trends of all these structural features suggest a northwesterly directed structural fabric across western South Dakota that is probably the result of basement offsets. The Keya Paha Fault is demarked by the absolutely straight trend of the Keya Paha River across Tripp and Todd counties, offset of Oligocene fossiliferous beds in the Badlands, and perhaps the trend of the Northern Black Hills Tertiary Intrusive Province. Additional subparallel lineaments occurring along the South Dakota-Nebraska border may also eventually prove to be of fault origin in South Dakota. Recent investigations along the Missouri River have indicated smaller scale faults and clastic dikes. These too are typically trending northwesterly and some have been found with glacial debris within the fault gauge, suggesting relatively recent movement. Overall, this northwesterly trending structural fabric has great impact upon the distribution of natural resources in South Dakota, including, among others, water, petroleum, minerals, and fossils.

KEYWORDS—Keya Paha Fault, South Dakota, Lineaments, Structural Geology

INTRODUCTION

During the compilation of the geological map of the state of South Dakota (Martin et al., 2004), one of the overall most striking features noted was the paucity of documented structures. Anticlines and synclines were more commonly mapped than faults, but neither had been extensively mapped. In the western portion of the state, with the exception of the Black Hills, only the White Clay Fault in Shannon and Fall River counties, small-scale faults in Badlands National Park in eastern Pennington and western Jackson counties, and the swarm of small-scale faults in the Slim Buttes area of Harding County in northwestern South Dakota were well-documented. During map production, the Keya Paha River was noted to be distinctly linear, trending directly northwesterly at North 65–70^{o} West (Fig. 1). This trend continues to the northwest, leading to the faults in the Badlands and, farther north, Tertiary intrusives of the northern Black Hills that extend from the Vanocker Intrusive in Meade County across the cutting stock of the Lead-Deadwood area to the Missouri Buttes/Devil's Tower intrusives in Crook County, Wyoming. The Keya Paha structure parallels the White Clay Fault in Shannon and Fall River counties to the west (Fig. 1). Moreover, a number of other smaller lineaments appear to subparallel the Keya Paha and White Clay structures along the South Dakota-Nebraska border. Although the late Cenozoic Sand Hills obscure these structures, they are discernible based on subparallel stream directions.

In 2006, I investigated the area during continued research for the South Dakota Geological Survey and noted significant displacement along the Keya Paha River. At that time, I stated,

> "The Keya Paha River exhibits one of the most unusual morphologies of any river within the state of South Dakota. The Keya Paha River has its source in north-central Todd County near the town of Mission, but trends directly southeast to the Nebraska border in southeastern Tripp County. Therefore, the River trends in a nearly straight line for over 75 miles in South Dakota in a northwest-southeast direction. Most of the major structural fabric of South Dakota, for example, the White Clay Fault in southern Shannon County, trends in this direction. A fault seems to be the most likely explanation for the straightness of the River coupled with the northwesterly direction. …" Martin (2006:27).

The Keya Paha trend may extend northwesterly into southwestern Mellette County, beyond the limit of the Keya Paha River. This area lies between the straight Keya Paha valley and the small offsets in Badlands National Park. McCormick (2010) of the SD Geological Survey dashed the structure on her map concerning the Precambrian basement terrane, but she did not formally describe the structure; she also illustrated another fault by a solid line, the Reservation Fault which trends along Ponca Creek. McCormick did not address these faults specifically in her text, but their presence on her map suggests that they represent basement structures.

During the past twenty years, I have also noted stratigraphical relationships and geological structures while directing paleonto-

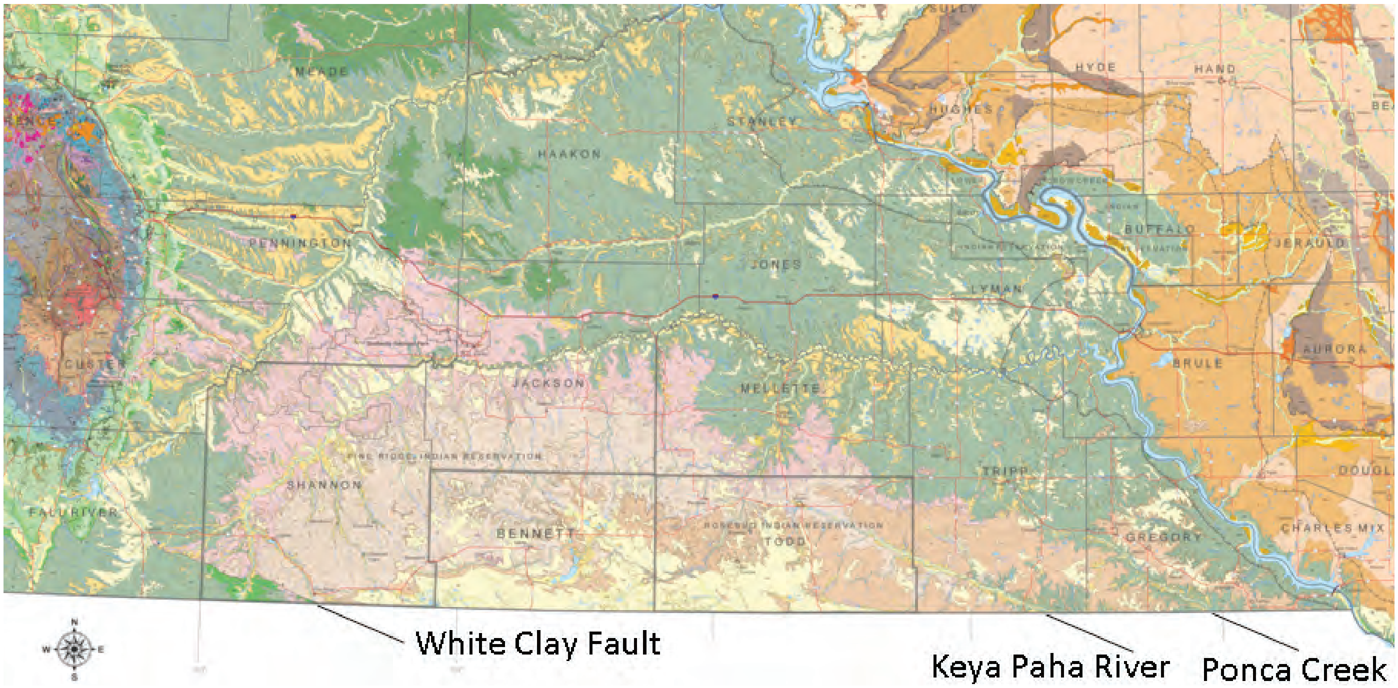
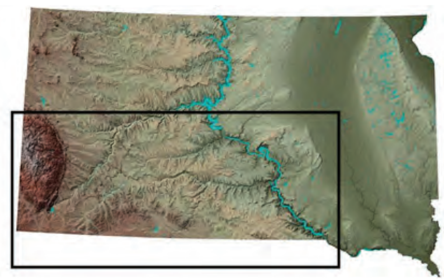


FIGURE 1. Location of Keya Paha River, Ponca Creek, and the White Clay Fault, shown on the Geological Map of the State of South Dakota (Martin et al., 2004). See Martin et al. (2004) for geological legend.



logical surveys along the Missouri River from Pierre in Hughes County south to Pickstown in Charles Mix County. Along with significant vertebrate and invertebrate fossils, I noted numerous small-scale faults, many of which exhibit a northwesterly trend. Although the tops of most faults were covered, making it difficult to assign a date more precise than post-deposition of the Late Cretaceous Pierre Shale Group (Martin et al., 2007), a fault south of Chamberlain in Brule County (Sawyer and Martin, 2004) and a clastic dike across the Missouri River in Lyman County exhibit glacial debris within the fault gouge.

Overall, this contribution represents a model concerning the structural fabric of the Northern Great Plains that requires extensive testing, particularly geophysical investigations, prior to substantiation. If this model is eventually proven, the ramifications are widespread for nearly all aspects of geologically related activities from petroleum to paleontological resources.

STRUCTURES ALONG THE SOUTH DAKOTA-NEBRASKA BORDER: THE KEYA PAHA FAULT

The Keya Paha River exhibits one of the most unusual morphologies of any river within the state of South Dakota (Fig. 1). The river has its source in north-central Todd County near the town of Mission, but trends directly southeast to the Nebraska border in southeastern Tripp County and continues along the same trend across the northern portions of Keya Paha and Boyd counties, Nebraska. In northern Boyd County, the Keya Paha River flows into the Niobrara River. At this point, the Niobrara River turns southeasterly and follows the same trend as that of the Keya Paha River. This southeasterly trend continues into Knox County, south of the town of Niobrara. Therefore, the Keya Paha River trends in a nearly straight line (North 65–70^{o} West) for over 120 km in South Dakota and continues into Nebraska along the Keya Paha and Niobrara rivers in a northwest-southeast direction for another 160 km. This northwest-southeast trend (Fig. 1) parallels other structures in South Dakota, for example, the White Clay Fault in southern Shannon County (See Martin et al., 2004).

Faulting is the most likely explanation for the straight, northwesterly direction of the Keya Paha River (Fig. 2). Stratigraphic evidence is found in T95N, R76W, Tripp County, South Dakota. Turtle Butte, composed of the Pierre Shale, possibly White River, the Arikaree, and the Ogallala Group sediments, lies in secs. 9, 10, and 11 (See Fig. 3, for regional stratigraphic relationships). Skinner (1968) mentioned Chadron-like deposits of the White River Group above the Pierre Shale and below the Rosebud Formation of the Arikaree Group, but these White River sediments are not obvious. Arikaree Group sediments consist of the pink Rosebud Formation lying subjacent to the greenish Turtle Butte Formation, and also occur in high-elevation road cuts about nine km to the south of Turtle Butte in secs. 31 and 32. The Pierre-Arikaree contact occurs at about the 670-m (2200-

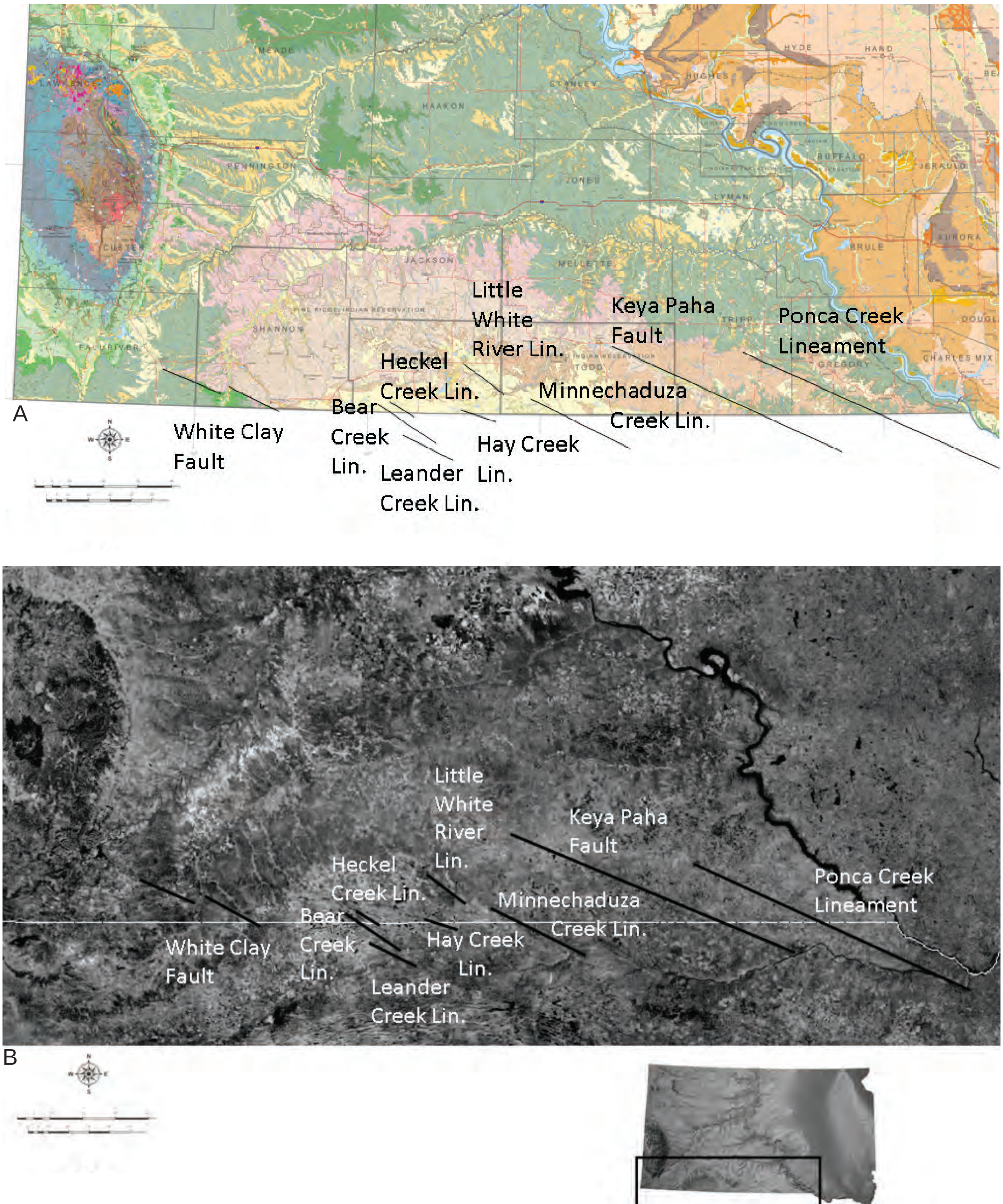


FIGURE 2. Placement of faults and structural lineaments along the South Dakota-Nebraska border on **A**, the Geological Map of the State of South Dakota (See Martin et al., 2004, for geological legend) and on **B**, satellite base.

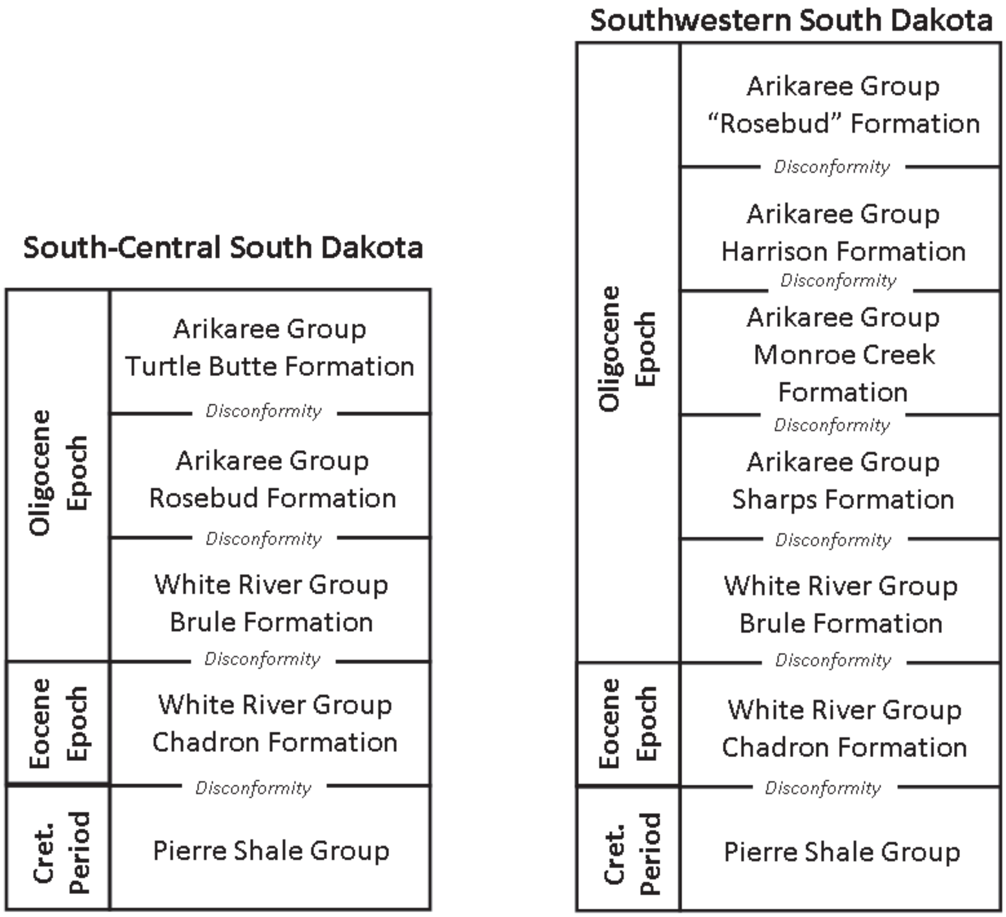


FIGURE 3. Stratigraphic nomenclature of southern South Dakota west of the Missouri River (adapted from Martin, 1983).

foot) elevation on the southern side of the Keya Paha River in sec. 20, but on the northern side in sec. 11, the contact occurs at 710 m (2330 feet). As the contact is lower on the western side of Turtle Butte, this differential may be the result of paleotopography on the Pierre Shale. The Rosebud-Turtle Butte contact lies approximately at 713 m (2340 feet) on Turtle Butte, whereas the contact lies at the 722-m (2370-foot) elevation in secs. 31 and 32. The Ash Hollow Formation of the Ogallala Group occurs at the 740-m (2430-foot) level on Turtle Butte, but at 729 m (2390 feet) in secs. 31 and 32. Although differential cut and fill at the base of the various formations, along with estimation error, account for some of the elevational differences, consistently higher-elevation formational contacts on the southern side of the Keya Paha River indicate a fault with at least 9 meters displacement in the Wewela area. The north-side down throw mirrors the displacement direction of the White Clay Fault farther west.

The Keya Paha structure may extend farther northwesterly into the southwestern portion of Mellette County, north of the town of Norris. Here, the Oligocene deposits appear to be offset, and the trace of the structure may be represented by Berry Springs in the NE1/4, sec. 26, T39N, R32W. The type area of the upper Oligocene Rosebud Formation occurs to the south in west-central Todd County, whereas the Sharps Formation and the subjacent Brule Formation occur to the west, principally in western Bennett and Shannon counties, although exposures also occur in Jackson and Mellette counties. The upper Oligocene Rosebud Formation can be traced from its type area to north of the town of Norris. The lower Oligocene Scenic Member of the Brule Formation occurs 3.2 km north of Norris near St. Paul Church, and the Brule Formation and the suprajacent Sharps Formation are superposed 7.2 km farther north, near the town of Corn Creek. More exposures of the Sharps Formation occur to the west of Corn Creek at a point 6.9 km east of the intersection with Highways 44 and 73. Berry Spring, an area of wetlands, lies between exposures of the Rosebud Formation and the Scenic Member of the Brule Formation. If this area represents the continuation of the Keya Paha structure, the south side is down. If the North 65–70^{o} West trend is followed northerly into Badlands National Park, the trend intersects the small-scale faults observable along the Badlands Loop Road (Martin et al., 2004). Clark et al. (1967) illustrated a series of five linear faults in the Badlands trending North 70^{o} West that typically exhibit south-side down displacement, although the opposite throw may be noted. Clark et al. termed one as the Sage Fault, which he considered the northern bounding fault of a trough bounded on the south by the White Clay Fault (his Pine Ridge Structure). Nearly all later workers have abandoned this interpretation and illustrate only the series of short displacements illustrated on the compilation of Martin et al. (2004). Clark et al. (1967) also felt the linear faults controlled the drainage pattern of streams flowing easterly from the Black Hills; he extended the Sage Fault west along Boxelder Creek. Lisenbee (2007) also believed that multiple basement-cored blocks occur along the eastern margin of the Black Hills. Additional geophysical investigations are required to determine if one or more of these structures do represent northern extensions of the Keya Paha structure.

STRUCTURES ALONG THE SOUTH DAKOTA-NEBRASKA BORDER: PONCA CREEK LINEAMENT

Ponca Creek, which parallels the direction of the Keya Paha Fault from South Dakota into northern Nebraska, lies just to the east of the Keya Paha River in Gregory County in south-central South Dakota (Fig. 1). In her study of the basement geology of South Dakota, McCormick (2010) illustrated the Reservation Fault in this area but did not include formal description or explanation. Having informally used the Ponca Creek lineament for this structure, I herein formalize the structure as the Ponca Creek Lineament until actual offset is documented.

The structure nearly parallels the Keya Paha Fault and extends at least 130 km from eastern Todd County in South Dakota to the area south of the town of Niobrara in Boyd County, Nebraska (Fig. 2). McCormick (2010) illustrated a North 60° West trend for the fault, whereas the creek ranges from North 60–75° West, with most areas in South Dakota averaging North 70° West. Moreover, if the overall direction of the creek is projected northwesterly, it parallels the trend of the postulated fault in the Big Badlands north of the Sage Fault, which nearly defines the northern margin of the White River Badlands in Clark et al. (1967). If this projection is substantiated, the throw of this fault would also be south-side down suggesting en echelon structures forming the northern margin of the graben in which the White River Badlands are preserved. Moreover, the trend of this structure along with that of the Keya Paha Fault can be extended across the northern Black Hills and might have provided the zones of weakness that result in a line of laccolithic structures from the Vanocker and Bear Butte laccoliths on the eastern margin of the Black Hills to the Missouri Buttes area to the west of the Black Hills. Again, extensive geophysical and stratigraphic analyses should be performed to substantiate these projections.

ADDITIONAL LINEAMENTS ALONG THE SOUTH DAKOTA-NEBRASKA BORDER

Another North 60–70° West-trending lineament extends along Minnechaduza Creek for 29 km from Valentine in Cherry County, Nebraska, to the South Dakota-Nebraska border (Fig. 2). From the border, it continues another 19 km northwesterly to the Little White River in southwestern Todd County. Eight kilometers to the west, the Little White River trends North 60° West for at least 24 km. These are collectively named the Little White River-Minnechaduza Creek Lineament (Fig. 2). Much of this trend is through the Nebraska Sand Hills, which may have somewhat altered its linear expression and obscured stratigraphical relationships on either side of the lineament.

Additional lineaments occur in Cherry County, Nebraska, farther west than the Little White River-Minnechaduza Creek Lineament along northwesterly-trending Hay, Heckel, and Bear-Leander creeks (Fig. 2). Like the Little White River-Minnechaduza Creek Lineament, these are covered by the relatively recent Sand Hills, which obscure their extent and possible displacement. The Hay Creek Lineament is defined here to extend 12 km and trends North 75° West; the Heckel Creek Lineament extends 13 km and is oriented at North 60° West, and the Bear-Leander Creek Lineament is similar to the Little White River-Minnechaduza Creek Lineament in being slightly offset. Both segments trend northwesterly and together extend over 45 km; the Leander Creek portion trends North 70–75° West and extends 26 km, whereas the Bear Creek portion trends North 60–65.5° West and extends for 29 km.

Occurrence of these shorter, northwesterly-trending lineaments between the Keya Paha Fault and the White Clay Fault suggests relationship to these larger structures. Geophysical and other geological investigations may indicate that these lineaments are the result of an overall northwesterly-trending structural fabric along the South Dakota-Nebraska border.

DISCUSSION AND HYPOTHESES

Bearing out the geological adage that small structures mirror larger structures, two major lineaments (Fig. 4) are observed to follow the same trend as the White Clay, Keya Paha, and Ponca Creek structures. First, the North Platte River trends North 70–75° West from the town of Ogallala in Keith County, Nebraska, at least to the town of Guernsey in Platte County, Wyoming; nearly east-west from Ogallala east to North Platte in Lincoln County, Nebraska; and resumes the northwest-southeast trend (N70°W) to near Lexington in Dawson County, Nebraska—a total distance of 435 km. The 290 km extent maintaining the North 70° West trend across the panhandle of Nebraska and into eastern Wyoming is herein termed the North Platte Lineament. In central Nebraska, the South Loup, Middle Loup, North Loup, and Elkhorn rivers also follow this general trend. The lineaments are named: South Loup River Lineament trending North 70° West and extending over 100 km from Pleasanton in Buffalo County to past Arnold in Custer County, Middle Loup River Lineament trending North 80° West and extending nearly 200 km from Sargent in Custer County to its source in southern Cherry County, North Loup River Lineament trending North 75–80° West and extending at least 150 km from Taylor in Loup County to near its source in central Cherry County, and Elkhorn River Lineament trending North 65–75° West and extending over 150 km from near Stanton in Stanton County to Stuart in Holt County, Nebraska.

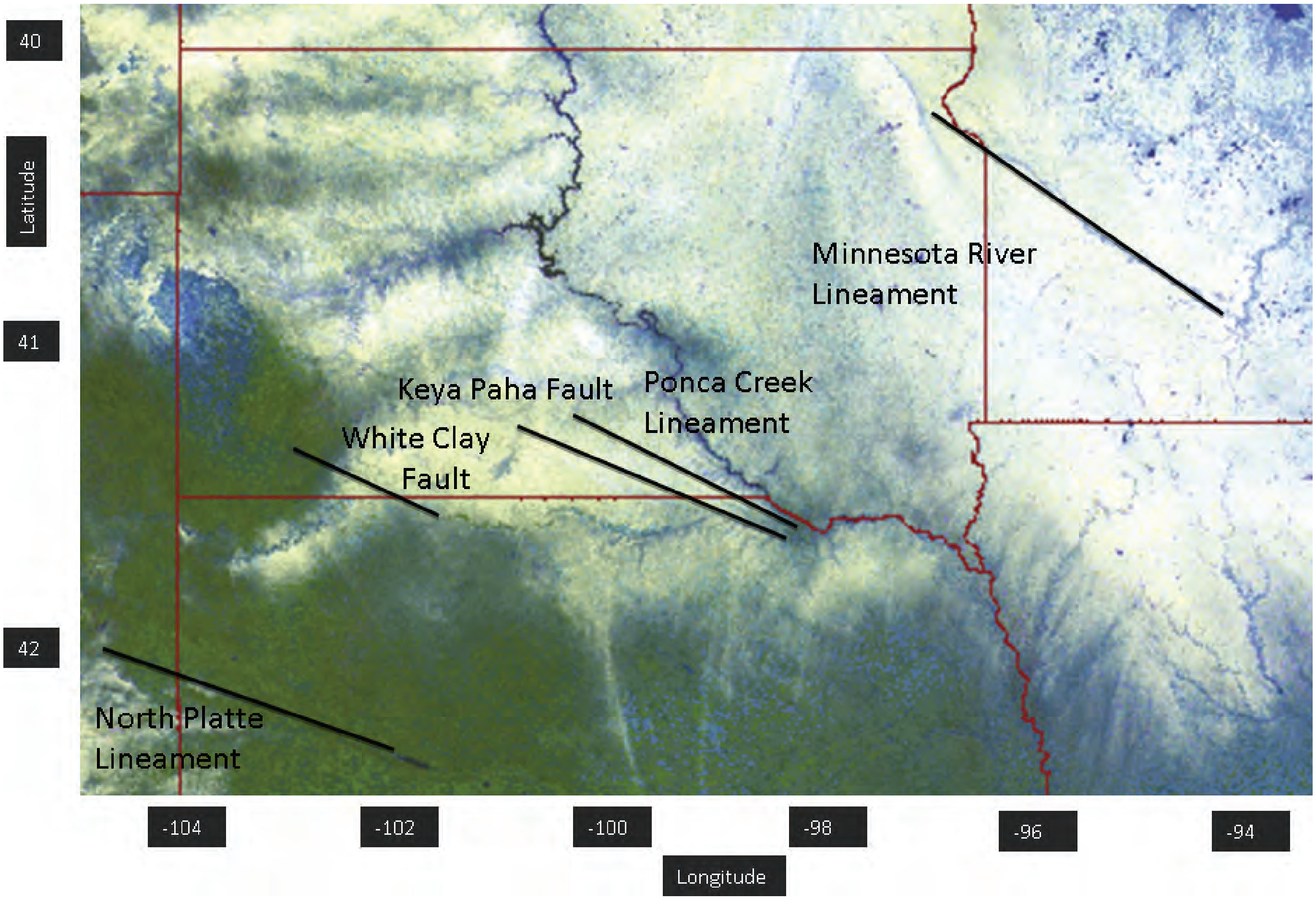


FIGURE 4. Regional distribution of the major lineaments in the Northern Great Plains on satellite base.

Second, the Minnesota River subparallels the same trend from Mankato in south-central Minnesota northwest from North 60–75° West to the eastern South Dakota border for an extent of at least 240 km. This trend is considered the Minnesota River Lineament (Fig. 4). Shorter creeks, such as the Heart, Cannonball, and Cedar rivers, subparallel this trend in the unglaciated southwestern portion of North Dakota and are designated the Heart River Lineament (extending nearly 100 km from the Heart Butte Dam in Grant County to near its source north of Dickinson, Cannonball River, trending North 65–75° West), the Cannonball Lineament (extending over 120 km from its intersection with Highway 31 in southern Grant County to near its source in Slope County trending North 70° West), and the Cedar River Lineament (extending nearly 100 km from near the eastern border of Adams County to its source in Slope County, trending North 65–70° West). Similar trends occur along rivers in northwestern South Dakota, including: Sulphur, Rabbit, and the North Fork of the Grand rivers. These are considered the Sulphur Creek Lineament (extending 100 km from the eastern edge of Meade County to its source in Butte County, trending North 70–75° West), the Rabbit River Lineament (extending nearly 100 km from near Iron Lightning in Ziebach County to its source in easternmost Harding County, trending North 65–70° West), and the Grand North Fork Lineament (extending approximately 140 km from western Corson County to Bowman Haley Lake in southwestern North Dakota, trending North 65–70° West). Together, these structures indicate a structural fabric composed of faults and joints trending northwesterly through the Northern Great Plains and probably mirror basement structures that have been periodically regenerated.

SMALL FAULTS ALONG THE MISSOURI RIVER

Since 1989, parties from the Museum of Geology have conducted geological and paleontological surveys along the Missouri River in central South Dakota, during which I documented numerous smaller faults with offsets in the tens of meters. Many of these structures trend northwesterly, with two providing some evidence of timing. One occurs south of the town of Chamberlain in Brule County, near the Burning Brule area where the petroliferous Boyer Bay Member of the Sharon Springs Formation previously caught fire (hence the name). The fault trends North 25° West and is well exposed along the shore of the Missouri River where the Sharon Springs Formation is faulted against the Niobrara Formation, which was originally deposited below. The northeastern side is down, with the Burning Brule and Boyer Bay members of the Sharon Springs faulted against the upper Niobrara chalk; maximum displacement appears to be over 12 meters and the fault plane dips 45° NE. As with other small faults along the Missouri River, this offset, which I term the Burning Brule Fault, has poor exposure, making determination of lateral extent difficult. When I first encountered the fault, Missouri River erosion had exposed the fault plane, and in the fault gouge were blocks of black shale at random orientations along with cobble to small boulder-sized glacial erratics. Granites, quartzites, and other resistant lithologies derived from glacial deposits suggest this fault might have occurred relatively late or been reactivated in the Pleistocene, as reported in an abstract in 2004 (Sawyer and Martin, 2004).

We were reluctant to emphasize this timing based upon one occurrence, but last summer, a clastic dike with similar characteristics was discovered. The dike is termed the Pontoon Bay Dike where it occurs near the town of Oacoma on the western side of the Missouri River in Lyman County. Once again, the high water of the Missouri River had scoured the area, resulting in excellent exposure of the dike. Pontoon Bay Dike occurs in the Niobrara Formation, trends North 42° West, and could be traced 10 meters laterally before being lost in vegetative cover. The dike is 10 cm wide and filled with small angular blocks of black Pierre shale and gray Niobrara chalk, so the dike is of the same hardness as the country rock. Therefore, the dike neither weathers in relief nor recess. In addition to randomly oriented angular blocks, rounded cobbles and pebbles of granite, quartzite, quartz pebbles, and other resistant erratics appear derived from glacial deposits and suggest a post-glacial opening and fill of the dike. The Burning Brule Fault and Pontoon Bay Dike indicate late movement of these two structures, maximally from the time of the Pleistocene glaciations possibly to the Holocene. Whether these offsets are the result of the northwesterly structural fabric or are the result of isostatic readjustment following ice removal cannot yet be determined. The trends suggest the latter, although their conjugal nature cannot be dismissed.

CONCLUSIONS

The Keya Paha Fault is identified along the South Dakota-Nebraska border extending 280 km from near the town of Niobrara in Knox County, NE, northwesterly to the source of the Keya Paha River in north-central Todd County, SD. The fault follows the trace of the Keya Paha River in a straight trend of North 65–70° West. This trend may be projected into Mellette County, SD, and possibly into Badlands National Park in Pennington and Jackson counties, extending the structure another 150 km. All lithostratigraphic formational contacts on the southern side of the Keya Paha River are higher than their counterparts on the northern side of the river. This suggests a fault with the northern side down and a displacement of at least 80 meters in the Wewela area of Tripp County, SD. The fact that Arikareean (North American Land Mammal Age) formations are displaced indicates that the faulting occurred after the Oligocene Period.

A parallel structure, the Ponca Creek Lineament occurs 25 km to the northeast of the Keya Paha Fault along Ponca Creek, and like the Keya Paha Fault, extends from near the town of Niobrara well into South Dakota. McCormick (2010) illustrated a structure in this area, but showed a different trend than the North 60–75° West direction of the creek. McCormick termed her structure the Reservation Fault but did not formally describe the fault and provided no evidence for offset. When the Keya Paha Fault and Ponca Creek Lineament are extended northwesterly, they appear in the position of the postulated Sage Fault and others of Clark et al. (1967), which form the northern wall of the White River Badlands exposure between Wall, Pennington County, and Cedar Pass in Jackson County. If these lineaments are found to be continuous, the Sage Fault in conjunction with the Keya Paha Fault may form important structures that control much of the geology of western South Dakota, perhaps including the Northern Black Hills Tertiary Intrusive Province and perhaps even later uplift of the Northern Black Hills and Bear Lodge blocks (Lisenbee, 1978). This hypothesis would require post-Oligocene movement, which matches with the relative occurrences of high-elevation Brule Formation deposits throughout the Black Hills (the highest occurring deposits of the Scenic Member of the Brule Formation occur in the Bear Lodge Mountains and successively lower deposits occur southerly to the Wind Cave area). Certainly, the possibility of these extensive structures should be considered when assessing fluid migration, be it water or petroleum, geological hazards, prospecting, or others.

A number of shorter lineations with the same approximate trends occur between the Keya Paha Fault and the White Clay Fault, which following additional investigations, may represent similar faults. These include from east to west the Little White River-Minnechaduza Creek Lineament, the Hay Creek Lineament, the Heckel Creek Lineament, the Bear Creek Lineament, and the Leander Creek Lineament. The latter two may be of similar geometry as the Little White River-Minnechaduza Creek Lineament.

On a larger scale, many creeks and rivers in the Northern Great Plains appear to have similar northwesterly trends. The North Platte Lineament in western Nebraska and the Minnesota River Lineament in western Minnesota are examples. On the other end of the scale, portions of many smaller creeks in the Northern Great Plains subparallel the northwesterly trend of these major lineaments. With additional investigation, these lineaments may be found to control faulting. The North 65–70° West trend of the Keya Paha Fault appears to be the dominant structural trend, although the trends deviate from North 60–80° West. Overall, a structural fabric appears to underlie the Northern Great Plains that represents a series of faults and joints that may reflect basement structures. The faults may have been active at different periods through geological time, and the Keya Paha Fault and other major faults were active after the Oligocene. Smaller faults and dikes indicate structural activity even at relatively recent geological times. The Burning Brule Fault and the Pontoon Bay Dike both contain glacial debris, indicating post-glacial movement during the Quaternary. The relatively recent dates of these movements are of great concern during land-use planning.

Overall, the northwesterly-southeasterly structural fabric of the Northern Great Plains may explain the distribution of geological phenomena that impact the search for natural resources and serve as the basis for land-use decisions. Many geological disciplines may be affected by this structural fabric. The occurrence of fossiliferous deposits in Badlands National Park and the Harris Ranch badlands in southwestern South Dakota may be the result of preservation in downthrown blocks, the result of major fault activity. The occurrences of ground and surface water are also affected by the structural trend. Petroleum plays may be guided by understanding the extensive faulting, particularly in South Dakota and Nebraska where relatively little petroleum production has occurred. Concentrations of uranium and rare earths may be controlled by these structures. Mining activities may also be dictated by this structural trend if the Northern Black Hills Tertiary Intrusive Province can be tied to basement lineations. Overall, many pertinent geologic phenomena are impacted by these dominant northwesterly directed structures.

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ARTICLE

MANAGEMENT OF PALEONTOLOGY RESOURCES IN LANCE CREEK FOSSIL AREA

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ABSTRACT—Huge numbers of fossils were collected and excavated from the Lance Creek Fossil Area beginning in the 1880s and are now scattered to museums and other institutions all over the globe. The National Park Service recognized the significance of these fossil discoveries by designating the area a National Natural Landmark (NNL) in 1973. The area designated was approximately 16 sections and consisted of a mixture of public lands, split estate, and private lands and minerals. The Bureau of Land Management (BLM) Newcastle Field Office Resource Management Plan (RMP) developed in the 1990s initially proposed designating the BLM lands within the NNL as an Area of Critical Concern (ACEC). During RMP scoping many private landowners became aware for the first time that their ranches were inside an NNL. Public outcry led to de-designating the NNL in 2006. An ACEC designation was also dropped from the BLM RMP signed in 2000, partly due to lack of survey data identifying exactly where fossils were located. The large amount of split estate and private lands and the scattered locations of BLM lands make it difficult to manage paleontology resources on the public lands. Large numbers of fossils are still collected from the Lance Creek Fossil Area reputedly from private lands. However, following a widely publicized fossil theft trial in 1995, fossils documented as removed from Federal lands were returned to the BLM.

KEYWORDS—National Natural Landmark, Bureau of Land Management, History of Paleontology

LANCE FORMATION PALEONTOLOGICAL RESEARCH

The most prolific unit for Late Cretaceous vertebrate fossils in Wyoming is the Lance Formation (Breithaupt, 1997). This rock unit is found statewide and reaches thicknesses of more than 750 meters. The formation encompasses approximately 1.5 million years at the end of the Maastrichtian and has been assigned to the Lancian "age" (Russell, 1975; Lillegraven and McKenna, 1986) because of its mammalian fauna. The Formation is dominated by nonmarine, coastal floodplain sandstones, mudstones, and marls, with marginal marine sandstones and shales in its lower parts. During the latest Cretaceous, Wyoming was a warm temperate to subtropical, seasonal floodplain on the west coast of an eastward-regressing inland seaway. The physical environment and biotic diversity of the Late Cretaceous of Wyoming was comparable to the subtropical Gulf Coast of the United States today. The lush lowland vegetation, meandering streams with coastal connections, and areas of occasional ponding with seasonal water restrictions are the best modern correlative to the floodplain environments associated with the western epicontinental sea during latest Cretaceous time (Breithaupt, 1982).

The Lance Formation is named for a small drainage—Lance Creek—in the eastern part of Wyoming and is best known for the exposures found in that region of the Powder River Basin. The discovery that first indicated the paleontological importance of this rock unit, however, was made in the western part of the state, where crews working for Ferdinand Vandeveer Hayden's Geological Survey of the Territories found the partial skeleton of a dinosaur in 1872 (Breithaupt, 1982; 1994). Edward Drinker Cope (1872) collected and described this partial skeleton, naming a new species of dinosaur, *Agathaumas sylvestris* (currently thought to be a form of *Triceratops*). The genus *Triceratops* (the most common horned dinosaur found in Wyoming and Wyoming's State Dinosaur) was defined by Othniel Charles Marsh (1889) on material he had originally called *Ceratops horridus* from the "Ceratops Beds" of Niobrara County, Wyoming. Abundant remains of vertebrate fossils were collected for Marsh by John Bell Hatcher during the years 1889–1894 (Hatcher, 1893; Hatcher et al., 1907), including large numbers of *Triceratops*. These "Ceratops Beds" represent the type area for the Lance Formation and have produced hundreds of *Triceratops* fossils, including at least 100 skulls (Derstler 1994). Derstler (1994) calculates that *Triceratops* represents 85% of the dinosaurs found in the Lance Formation, with the hadrosaur *Edmontosaurus* making up another 12%.

Since the discovery of *Agathaumas*, literally tens of thousands of Late Cretaceous vertebrate remains have been recovered from the Lance Formation. Fossil vertebrates have ranged from important microvertebrate elements to extensive bonebeds which contain nearly complete, sometimes articulated dinosaur skeletons. Some of these monospecific bonebeds have densities of more than 10 bones per square meter (Derstler, 1994). Spectacular specimens like the dinosaur "mummies" (hadrosaur skeletons surrounded by skin impressions) have also been found in the Lance Formation (Lull and Wright, 1942). Carpenter (1982) reported baby dinosaur fossils in this unit from various microvertebrate sites. In addition, diverse trackways have been discovered in the Lance Formation (Lockley et al., 2003). Further, some of the first discoveries of *Tyrannosaurus rex* can be traced to the Lance Formation of eastern Wyoming. In 1900 famed dinosaur hunter Barnum Brown discovered a partial skeleton that Henry Fairfield Osborn (1905) named *Dynamosaurus imperio-*

sus ("powerful imperial lizard") in the same paper in which he named *Tyrannosaurus rex* ("king of the tyrant lizards"). Eventually, *Dynamosaurus* was synonomized with T*yrannosaurus rex* (Breithaupt, et al., 2006; 2008). Clemens (1963) provides an excellent summary of historical investigations done in the Lance Formation of eastern Wyoming.

Because the Formation contains one of the best-known Late Cretaceous vertebrate faunas, including various cartilaginous and bony fishes, frogs, salamanders, champsosaurs, turtles, lizards, snakes, crocodiles, pterosaurs, mammals, birds, and some of the best known Cretaceous dinosaurs (e.g., *Triceratops, Torosaurus, Tyrannosaurus, Edmontosaurus, Pachycephalosaurus, Ankylosaurus, Edmontonia, Thescelosaurus, Troodon, Dromaeosaurus*, and *Ornithomimus*) (Archibald, 1996; Estes, 1964; Clemens, 1960, 1963, 1966, 1973; Derstler, 1994; Breithaupt, 1982, 1985; Whitmore, 1985; Whitmore and Martin, 1986; Webb, 1998, 2001), it has been assigned a Potential Fossil Yield Classification (PFYC) rating of 5 (very high fossil potential).

LANCE CREEK FOSSIL AREA

The Lance Creek Fossil Area (LCFA) is located in eastern Wyoming along the southeastern margin of the Powder River Basin just beyond the southwestern edge of the Black Hills. It is entirely within Niobrara County and extends from the Weston County border south almost to the small town of Lance Creek. Although the majority of bedrock in the LCFA is Lance Formation, the area also encompasses some outcrops of Fox Hills Sandstone, Pierre Shale, the White River Formation, and the Fort Union Formation.

Huge numbers of fossils collected from the LCFA are now scattered to museums and other institutions all over the globe. In one of the earliest collecting expeditions Hatcher spent several years collecting tons of fossils and hauling them by wagon to the railroad at Lusk, Wyoming, for shipment to Yale University. Upon recovering the first *Triceratops* skull found in the Lance Creek Fossil Area, Hatcher reported to Marsh:

> "The big skull is ours . . . It is badly broken up, but was in good condition when found three years ago. They (the discoverers) broke the horn cores off it (with a lariat) and rolled it down the bluff and broke lots of it into small pieces some of which we found over 100 yards below . . . lower jaws were there . . . when packed (in four boxes) it will weigh 1,000 lbs. or over " (Schuchert and Levene, 1940).

The Lance Creek Fossil Area is also known for the *Edmontosaurus* mummy the Sternbergs found in 1908 (Osborn, 1912). Although Sternberg was working under contract for the British Museum of Natural History in London, he sold the fossil to the American Museum of Natural History in New York for $2000. He found a second *Edmontosaurus* mummy a few years later and shipped it to the Senckenberg Museum in Frankfurt, Germany. Studies of the fossil flora from the LCFA began in the 1930s (Dorf 1940; 1942). These were some of the first significant studies of Late Cretaceous vegetation and led to the discovery that plants also went extinct at the end of the Cretaceous (Johnson, 2007). In the 1950s, the University of California conducted a substantial microvertebrate screen-washing effort, which recovered more than 30,000 small vertebrate specimens representing over 75 species, with many new genera and species recognized (Estes, 1964; Clemens, 1960; 1963; 1966; 1973).

In order to ensure that the world-famous locations where ceratopsian dinosaurs were collected in the late 1800s would be preserved from unscientific exploitation (Boyd 1987), the National Park Service (NPS) designated the Lance Creek Fossil Area as a National Natural Landmark (NNL) in 1966. A later proposal to expand the Landmark boundaries evaluated the area as significant for producing some of the first horned dinosaurs and Cretaceous mammals in North America and recommended extending the northern boundary to include locations where several important fossils had been found (McGrew and Hager, 1972). As expanded in 1973, the boundaries encompassed an area 3 miles east–west by 5.25 miles north–south. The new area included 4.75 square miles to the north as well as a strip of two half sections and a whole section on the south where outcrops included Pierre Shale, White River Formation, and some Lance Formation. The area designated consisted of approximately 15.75 sections (9,920 acres) and was a mixture of public lands, split estate, and private lands and minerals. The report recommending expansion of the Landmark indicated that there were up to 70 landowners in the designated area (McGrew and Hager, 1972). The northern boundary was arbitrarily set at the Niobrara /Weston county border. Most of the historically well-known areas where vertebrates and plants had been collected were within the designated area.

More recent research, though, demonstrates that important fossils continue to be found north of the NNL. In 1994, archeologists surveying in the US Forest Service (USFS) Thunder Basin National Grassland discovered pieces of fossil bone in Lance Formation sandstone in Weston County. The USFS notified the University of Wyoming (UW) Geological Museum and the South Dakota School of Mines and Technology (SDSM) Museum of Geology of the new finds. A crew from SDSM returned to the site the following summer and recovered the first associated partial skeleton of a nodosaurid ankylosaur from eastern Wyoming. The specimen was prepared and catalogued at the SDSM Museum of Geology laboratory. Close examination indicated that the specimen represents the armored dinosaur *Edmontonia* (Finlayson, 1997). During the fieldwork, several microvertebrate sites were found in the region and collected for screen-washing (see Martin and Finlayson, 1997). In 1999, this material was transferred to the UW Geological Museum for use during the Passport-In-Time (PIT) Microvertebrate Fossil Project (the first paleontology PIT project ever developed). Volunteers learned standard microvertebrate wet screen-washing techniques (Hibbard, 1949; McKenna, 1962; McKenna et al., 1994) and discovered an interesting Late Cretaceous microvertebrate fauna (Breithaupt, 2001). Also in the 1990s, a partial *Tyrannosaurus rex* skeleton was found on private land in the Lance Formation near these sites in Weston County.

MANAGEMENT OF THE LANCE CREEK FOSSIL AREA

Although the Lance Creek Fossil Area was listed as a NNL, a memorandum to the BLM from the NPS stated that the status was complex (Ugolini 1978). LCFA was retained on the Landmark register because of its national significance, but it was never "registered" by all of the landowners due to the complex land ownership and large number of landowners. In a 1975 memorandum, the BLM agreed to "register" the BLM parcels in the Landmark, indicating intent to manage them to protect the fossil resources. BLM surface amounted to only 12% of the area, although the BLM managed approximately 70% of the mineral estate within the NNL.

Because the BLM was charged with protecting BLM lands within the LCFA, a Casper District archaeologist and geologist asked University of Wyoming paleontologist Paul McGrew to show them fossil localities within the LCFA that should be monitored. On the field trip in 1978, McGrew showed them four localities—two on private land and two on BLM-administered land. The group could not inspect one of the private locations due to lack of access and observed only a single vertebrate rib fragment at the second location. One of the federal sites was a quarry that had been excavated in 1946 and had no fossil material exposed on the quarry face or in adjacent outcrops at the time of the site visit. At the other Federal location they observed a dinosaur vertebral column and scattered ribs and vertebrae. The BLM concluded from this very limited field trip that few fossils were currently exposed and possibly most of the museum quality material had been removed during years of excavation and collection.

In the 1980s and 1990s, the NPS usually inspected the LCFA every other year for a report to congress on the condition of National Natural Landmarks. BLM management directed employees to assist the Park Service by providing information concerning anything they had heard from informants or observed in the LCFA while working on other tasks. In preparing their report, NPS representatives often called the BLM to ask if anyone had observed changes in the condition of the fossil resources in the NNL and occasionally they drove around the NNL. Although fossils had been collected from numerous locations in the distant past, the Newcastle Field Office knew of only one vertebrate fossil location on BLM-administered land that could be monitored. The main sources of information that the BLM received regarding the condition of fossil resources in LCFA were reports from professional paleontologists conducting surveys in the area and occasional reports by local ranchers.

During development of the BLM Newcastle Field Office Resource Management Plan (RMP) in the 1990s, the BLM proposed designating the BLM lands within the NNL as an Area of Critical Environmental Concern (ACEC). As a result of this proposal, many private landowners became aware for the first time that their ranches were inside an NNL. Public outcry led to de-designating the NNL in 2006. Considering BLM's lack of survey information on the current exposure and location of fossils, the proposal to manage the area as a fossil ACEC may indeed have been premature. In addition, the plan lacked specifics on how fossil resources would be protected and an analysis of the potential impacts. Furthermore, the map of the proposed ACEC in the draft plan appeared to include private land, which led to public protest. As a result, the proposal of an ACEC designation was dropped from the BLM RMP signed in 2000, due in part to lack of survey data indicating where fossils were currently exposed, as well as the fact that no specific management measures were proposed other than the designation.

The large amount of split estate and private lands and the scattered locations of BLM-administered lands make it difficult to manage paleontology resources on these public lands. Much of the Lance Creek Fossil Area is remote and requires driving interminably on dirt roads in variable condition. An excerpt from Johnson (2007:55) describes the area well, including the time it takes to get anywhere:

> "We turned off to the west onto ranch roads that seemed to go on forever. We lost track of the turns and gates. Finally, we drove through the Fox Hills Formation and into the Lance Formation, with its characteristic rusty sand beds. Here and there, the sand formed huge, elaborately swirled concretions that were as large as our truck. Some of these weathered out to form garish hoodoos in stark contrast to the conservative landscape. By now, the sun was low in the sky and the shadows were lengthening."

The remoteness of the Lance Creek Fossil Area would make it easy to remove fossils without detection, although local ranchers generally notice when non-local people are in the area for any length of time. A rumored illegal collecting ploy is to tell local ranchers that the fossils are on BLM land (so that the excavator does not have to pay the rancher for them), but then tell any official that they are on private land (thus do not require a permit). Unfortunately, theft of fossils does occur. Following a widely publicized fossil theft trial in 1995, fossils documented as removed from Federal lands were returned to the BLM. Fossils removed from BLM lands included a LCFA *Triceratops* (represented by two large plaster jackets and four boxes of fossil fragments), turtles, crocodile bones, and a large museum quality ammonite. The BLM negotiated an assistance agreement with the South Dakota School of Mines and Technology to curate the specimens. Unfortunately, in cases of illegal activity, by the time that the BLM receives a report of someone excavating fossils, they have usually finished the fieldwork and departed. In two locations where unauthorized excavations were reported by a professional paleontologist who was surveying in LCFA, some of the fossils had been collected and others had been partially jacketed, protected by tarps, and reburied. No one ever returned to finish the excavation. Subsequently, the BLM encouraged the Tate Geological Museum in Casper to complete the excavations at one of these locations, where they recovered a portion of a *Triceratops*.

Large numbers of fossils, many of museum quality and scientific importance, are still collected from the Lance Creek Fossil Area, reputedly from private lands. The amount of material on the commercial market indicates the potential abundance of fossils still to be found in the area. Internet searches on 'Lance Formation fossils' will show links to a variety of commercial fossil companies, such as Black Hawk Fossils or Black Hills Institute, where numerous fossils from the LCFA are available for sale. Over the last 20 years skeletons of *Triceratops* and *Edmontosaurus*, as well as skulls of *Tyrannosaurus* and *Pachycephalosaurus*, have been collected and sold from the LCFA. Sometimes these fossils are sold to private individuals or organizations and are not available for study. In other cases, these fossils have been sold to museums that make them available to scientists and use them for public education. An example of the latter is the *Triceratops* "Kelsey," which was excavated from private land within the LCFA and now resides at the Indianapolis Children's Museum, where it contributes to an excellent education program. The Zerbst Ranch, source of this fossil as well as a second *Triceratops* with preserved sections of skin impressions, has developed an educational center called PaleoPark.

Although many tons of fossils have been removed from the LCFA since the 1880s, the area also continues to produce fossils of significance and scientific information on BLM-administered land. In recent years professional paleontologists have excavated and collected several *Triceratops* specimens from the BLM portion of the LCFA. Christian Sidor (Burke Museum of Natural History and Culture in Seattle, Washington) collected a partial *Triceratops* skull in 2008. Luis Chiappe (Natural History Museum of Los Angeles County-LACM) surveyed portions of the LCFA during 2001–2003 and collected partial *Triceratops* skeletons as well as hadrosaur and ankylosaur fossils from several locations. The most important specimen collected by LACM crews (consisting of students from six universities as well as paleontologists from Argentina) was a 35–40% complete *Triceratops* post-cranial skeleton, which Chiappe described as being in an exquisite state of preservation. The specimen was immediately used for public education as preparation took place in a viewable laboratory at the Natural History Museum of Los Angeles County. Staff in the exhibit hall explained how fossils are collected and what interpretations can be made from the material. Currently, this specimen is part of a newly exhibited *Triceratops* skeleton in the museum. A partial *Triceratops* skull from the LCFA was also placed on exhibit in the museum's Discovery Center for children.

Paul Sereno (University of Chicago) surveyed in the LCFA from 2000 to 2004 with teams of graduate and undergraduate students. In addition, he ran college field schools in the area and provided a paleontology educational experience for advanced high school students participating in Chicago's Project Exploration, which targets minority students with a strong interest in science. In 2001 these students helped remove a partial *Tyrannosaurus* skeleton from a site known to the BLM since 1978. This specimen contributed useful scientific information as well (see Lipkin et al., 2007). University of Chicago crews also collected remains of *Triceratops, Edmontosaurus, Thescelosaurus,* marsupials, and two fairly complete turtle specimens (baenid and trionychid) including skulls. This material has been used in the Dinosaur Lab at the University of Chicago. Based on data acquired during several years of survey in the LCFA, Sereno provided the BLM with a database of over 200 fossil localities. This information has helped the BLM to better manage fossil resources in the area.

CONCLUSIONS

The 2009 Omnibus Public Land Management Act-Paleontological Resource Preservation Section (OPLMA-PRP) formally defines paleontological resources as "any fossilized remains, traces, or imprints of organisms, preserved in or on the earth's crust, that are of paleontological interest and that provide information about the history of life on earth." The legislation states that paleontological resources on Federal land shall be managed and protected using scientific principles and expertise. The Act directs that appropriate plans for inventory, monitoring, and scientific and educational use of these resources shall be developed. "These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public." The Act further directs that the Federal agency shall "establish a program to increase public awareness about the significance of paleontological resources." Vertebrate fossils are especially in need of protection, because of their rarity and unique educational and scientific values.

BLM lands contain important paleontological resources and paleontology partnerships are an essential management tool for the protection of these resources. Fossils on public lands can help document the rich history and diversity of life on our planet. The BLM's responsibility for the management and protection of public lands includes stewardship of its scientific resources. To better protect and manage paleontological resources for present and future generations, the BLM works closely with paleontologists at museums and universities to discover, document, and interpret the fossils found on public lands. The fossils in the LCFA are among many paleontological resources that are best studied through the collaborations of scientists, students, volunteers, and land managers.

The BLM is working to establish projects that are beneficial to proper management of paleontological resources on public lands. One such objective is to get the public involved with paleontology through participation in scientific research, in the hope of increasing understanding of the management of fossil resources on Federal lands. Dinosaur projects run by various paleontologists have accomplished this in recent years. In addition to large dinosaur remains, Lance Formation microvertebrate fossils represent important components of the latest Mesozoic vertebrate faunas of the Western Interior, and the USFS PIT project introduced volunteers to this type of resource. This PIT project was an excellent example of how paleontological resources can be studied through the collaborations of scientists, students, volunteers, and land managers. As the public becomes more involved in the scientific process, people gain a better understanding of fossil resources and the importance of studying them. Programs like PIT encourage people with different backgrounds to become partners in paleontological resource management.

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ARTICLE

ANCHISAURUS FROM SPRINGFIELD ARMORY

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ABSTRACT—The term "dinosaur" was only 13 years old in 1855 when blasting operations at the Water Shops of Springfield Armory in Massachusetts uncovered the partial fossil skeleton of an extinct reptile. Paleontological discoveries were not new to the area; the Connecticut River Valley, which includes the Armory, was an early hotbed of vertebrate paleontology thanks to the combination of Late Triassic–Early Jurassic-age footprints and interested naturalists. The Armory specimen, now the holotype of *Anchisaurus polyzelus*, has passed through several generic names and been classified with theropods, prosauropods, and sauropods. Views on its paleobiology have changed from an active carnivore, to an herbivore, to an omnivore. Along the way, it has been discussed in print by numerous well-known figures in paleontology.

The holotype of *A. polyzelus* is one of a handful of tetrapod body fossils from the Hartford Basin. As part of the history of Springfield Armory National Historic Site, it is also one of many historically and scientifically significant fossil specimens associated with National Park System areas.

KEYWORDS—*Anchisaurus*, Springfield Armory National Historic Site, Portland Formation, Hartford Basin, History of Paleontology

INTRODUCTION

Although today Western states are better known for having fossils, the history of American paleontology started in the Northeast. In the United States, the first fossils now ascribed to dinosaurs were found in New England's Deerfield and Hartford basins. The uppermost Mesozoic rock unit in the Hartford Basin—the Early Jurassic-age Portland Formation—boasts North America's earliest-reported dinosaur tracks (1802) (Olsen et al. 1992) and the first dinosaur bones collected (1818) and published (1820) (Santucci 1998). Among other historic finds from the Portland Formation is a partial skeleton of a basal sauropodomorph (prosauropod in traditional usage) discovered at Springfield Armory in 1855. This specimen later became the holotype of *Anchisaurus polyzelus*.

Springfield Armory, a manufacturing site for U.S. military small arms from 1794–1968, located in Springfield, Massachusetts (Point1 in Fig. 1), was the nation's first federal armory. It included two main sites: the Hill Shops (or Hillshops), which were used as a storage depot during the American Revolutionary War era and have been partly protected as Springfield Armory National Historic Site since1974; and the Water Shops (or Watershops)—three locations on the Mill River approximately 1.6 km (1 mile) south of the Hill Shops, constructed as heavy manufacturing sites around the turn of the 19th century and presently under private ownership. Although the Water Shops are not formally administered or managed by the National Park Service as part of the National Historic Site, the national historic site maintains a relationship with the owners and interprets the Water Shops (A. MacKenzie, pers. comm., March 2010). The *Anchisaurus* skeleton was discovered when the three Water Shops were consolidated in 1855 .

The Springfield Armory complex is located in the Connecticut River Valley just east of the Connecticut River in the Hartford Basin, an early Mesozoic-age structural feature (Fig. 1). The underlying geology consists of red sandstone and siltstone bedrock (the Portland Formation) (Zen et al. 1983) overlain by much younger surficial deposits of Quaternary till and glacial lake delta outwash (Hartshorn and Koteff 1967).

GEOLOGICAL CONTEXT: THE HARTFORD BASIN

The Hartford Basin formed with the breakup of the supercontinent Pangaea during the Late Triassic. The Deerfield Basin to the north was probably continuous with it (P. Olsen, pers. comm., November 2010). The two basins belong to a series of rift basins paralleling the Appalachian Mountains from northern South Carolina to Nova Scotia. Sediments deposited in the rift basins are together known as the Newark Supergroup and record 35 million years of continental rifting (Olsen 1980a). The supergroup's formations are divided into three groups, in ascending order: the Chatham Group, Meriden Group, and Agawam Group (including the Portland Formation) (Weems and Olsen 1997). Structurally, the Hartford Basin is a half-graben that is tilted to the east and bounded on one side by a major fault (Hubert et al. 1978). Because the fault is on the east side of the basin, the formations within thicken to the east, and the younger formations, including the Portland Formation, are found in the eastern portion of the basin (Horne et al. 1993).

Flood basalts, faulting, and folding accompanied the rifting (Olsen 1980b). The eruption of the Newark Supergroup's flood basalts probably occurred over fewer than 600,000 years at about 201 Ma (Olsen et al. 1996, 2003b), straddling the Tri-

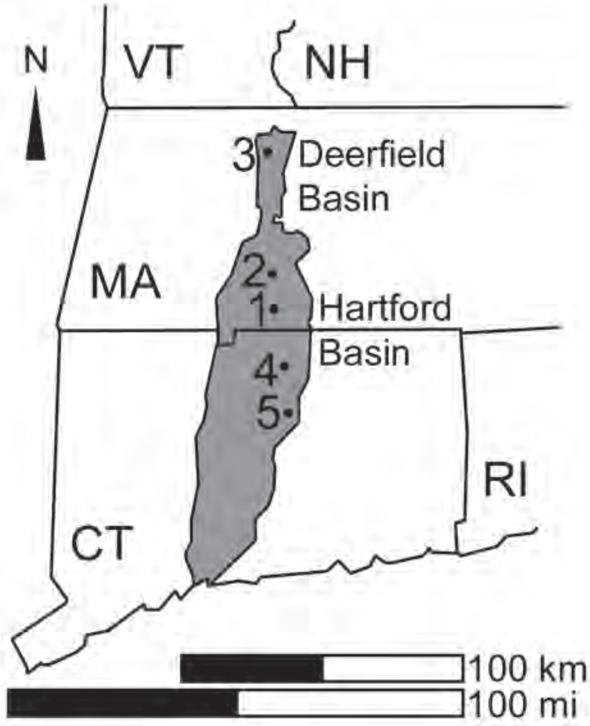

FIGURE 1. A schematic diagram of the Hartford Basin and smaller Deerfield Basin to the north, with significant locations discussed in the text denoted by points as follows: 1 represents Springfield, 2 represents South Hadley, 3 represents Greenfield, 4 represents East Windsor, and 5 represents Manchester. After Robinson and Kapo (2003), Fig. 1, courtesy of the U.S. Geological Survey.

assic–Jurassic boundary (Kozur and Weems 2010). Current research indicates an age of approximately 201.4 Ma for the oldest basalts of the Supergroup and approximately 201.3 Ma for the Triassic–Jurassic boundary (Schoene et al. 2010). The volcanic rocks are part of the Central Atlantic Magmatic Province (CAMP), one of the largest known volcanic provinces on Earth, found in outcrops from Europe and West Africa to central Brazil and eastern North America (Marzoli et al. 1999).

The Newark Supergroup is known for its cyclic depositional patterns, shifting between mud flat, shallow lake, and fluvial deposition (Olsen 1980c). Such cycles are evidence of ancient Milankovitch cycles (Olsen 1997), which are keyed to various characteristics of Earth's movement in space (Olsen and Whiteside 2008). Their modern durations can be used to establish chronologies in the rocks. The foundational cycle is the Van Houten cycle of lake transgression and regression, interpreted as representing the approximately 20,000-year cycle of the precession of the equinoxes (Olsen 1986; Olsen and Kent 1996). Several other cycles are also evident in the Hartford Basin rocks, including cycles with durations of approximately 100,000 years, 405,000 years, and 1.75 million years (Olsen 1997; Olsen and Kent 1999; Olsen et al. 2002).

THE PORTLAND FORMATION

The Portland Formation is composed of arkosic and nonarkosic sandstone, siltstone, conglomerate, and shale (Krynine 1950), deposited on top of the uppermost volcanic units of the basin, the Hampden Basalt (Hubert et al. 1978) and Granby Tuff (Olsen 1997), and dated to the first half of the Early Jurassic (Weems and Olsen 1997; Olsen et al. 2002; Kent and Olsen 2008; Kozur and Weems 2010). It varies substantially in composition vertically and horizontally (LeTourneau and McDonald 1985), and has distinct lower and upper portions: the lower half is mostly composed of fine- to medium-grained red arkose and siltstone, with some dark shale, while the upper is mostly medium- to coarse-grained red arkose with conglomerate (Krynine 1950). Cyclical rocks including lacustrine deposition are found in the lower half, while the upper half lacks cyclical rocks and is composed of fluvial rocks (Olsen et al. 2003a). Conglomerates generally represent alluvial fans, sandstones braided river systems or distal alluvial fans, siltstones floodplains, gray sandstones and siltstones lake margins, and dark siltstones and shales rift lake deposits (LeTourneau 1985). The lower Portland Formation can be interpreted as a closed basin where subsidence exceeded deposition, allowing for the formation of large lakes. The opposite was true of the upper part (Olsen 1997)—as subsidence decreased, fluvial processes came to dominate (Hubert et al. 1992). Springfield Armory's bedrock is sandstone-dominated (LeTourneau and McDonald 1985) and is from the upper, entirely fluvial part of the formation (P. Olsen, pers. comm., February 2010).

The paleogeography of the Portland Formation has been described in some detail (see for example LeTourneau and McDonald 1985). Large alluvial fans accumulated along the eastern margin of the depositional basin, near the border fault. Most of the sediment came from a narrow band of rocks to the east, immediately adjacent to the fault (Krynine 1950). During wet periods, lakes and rivers were common, whereas alluvial fans and ephemeral streams were the major depositional environments during dry periods (Horne et al. 1993). Lakes were deepest and longest-lived in the deeper eastern part of the basin, while much of the western and central basin was occupied by broad, low-gradient plains with shallow alkaline lakes (McDonald and LeTourneau 1988).

Paleoclimatological interpretations of the formation emphasize seasonality and semi-aridity (Lull 1912; LeTourneau and McDonald 1985). Deposition occurred at tropical paleolatitudes of approximately 21° to 23° N (Kent and Tauxe 2005) and the climate oscillated between humid and semi-arid over long periods (McDonald and LeTourneau 1988). Relatively arid conditions prevailed for the lower Portland Formation, but the upper part of the formation was deposited under a more humid and possibly cooler climate, perhaps due to regional uplift (Cornet 1989).

The Portland Formation boasts a diverse fossil assemblage. Microbial and plant fossils include oncolites and stromatolites (McDonald and LeTourneau 1988; McDonald 1992), palynomorphs (including fern spores and cycad pollen; Cornet and

Traverse 1975), the horsetail *Equisetites* (LeTourneau and McDonald 1985), bennettitales (McMenamin and Ulm 2004), and conifers (Cornet 1989), particularly *Brachyphyllum, Hirmeriella,* and *Pagiophyllum* (Huber et al. 2003). Significant turnover in the floral assemblage occurred midway through deposition, when plants from the Deerfield Basin spread south (Cornet 1989). Invertebrates are represented by bivalves, conchostracans, ostracodes, beetles, cockroaches, possible orthopterans, insect fragments and larvae (Huber et al. 2003), and arthropod burrows and trails, including possible crayfish and insect traces (Olsen 1980d, 1988).

Vertebrates known from body fossils include the semionotid fish "*Acentrophorus*" and *Semionotus*, the redfieldiid fish *Redfieldius*, the coelacanth *Diplurus*, the crocodylomorph *Stegomosuchus*, the coelophysoid theropod *Podokesaurus*, and *Anchisaurus* (here including *Ammosaurus*) (Olsen 1980d, 1988; LeTourneau and McDonald 1985; McDonald 1992). Tetrapod body fossils are rare in the formation, limited to eight published specimens of more than one bone and a few isolated bones (Galton 1976). They are mostly known from the formation's coarse red beds, which formed in floodplain or alluvial fan settings (McDonald 1992) in the upper fluvial part of the formation (Olsen et al. 2003a). Vertebrate trace fossils include the ichnogenera *Batrachopus* (from crocodylomorphs), *Anchisauripus*, *Eubrontes*, *Grallator* (from theropods, although a theropod maker for *Eubrontes* is not universally accepted; see Weems 2003 and 2006), *Otozoum* (from sauropodomorphs), and *Anomoepus* (from ornithischians), as well as coprolites (Olsen 1988; LeTourneau and McDonald 1985). The taxonomy of the Portland Formation tracks is convoluted (Olsen et al. 1998; Olsen and Rainforth 2003): at one point there were 98 ichnospecies in 43 ichnogenera (Lull 1912) for what are now recognized as a half-dozen common ichnogenera. Restudy has greatly simplified the taxonomy (Weems 1992; Olsen and Rainforth 2003; Rainforth 2005). Most footprints are found in shoreline or mudflat rocks immediately above or below lake sequences (Olsen and Rainforth 2003).

EARLY PALEONTOLOGY

The history of fossil discovery in the Portland Formation dates to 1802, when Pliny Moody found tracks at his family's farm in South Hadley, Massachusetts (Point 2 in Fig. 1), about 16 km (10 miles) north of Springfield. At the time, the tracks were identified with "Noah's Raven" of Biblical fame; they are now known today as examples of the ichnogenus *Anomoepus* (Olsen et al. 1992). These tracks represent the earliest report of dinosaur tracks in North America (Olsen et al. 1992).

Scientific study of fossil footprints in the Connecticut River Valley began during the 1830s. In 1835, tracks were reported at Greenfield, Massachusetts (Point 3 in Fig. 1), 53 km (33 miles) north of Springfield in what is now known as the Turners Falls Formation. The finds attracted the attention of Edward B. Hitchcock of Amherst College, who made the study of the valley's tracks his life's work (Weishampel and Young 1996). Most of Hitchcock's work was done in the Turners Falls Formation (Olsen et al. 1992), a unit older than the Portland Formation in the Deerfield Basin to the north (Weems and Olsen 1997). As the title of one of his early works made clear (Hitchcock 1836), Hitchcock first conceived of the trackmakers as birds. In hindsight, this is understandable—he was dealing with tracks of bipedal bird-like tridactyl dinosaurs. By the end of his life, Hitchcock had described enough tracks and traces to envision a diverse bestiary of invertebrates and bipedal and quadrupedal vertebrates (Hitchcock 1858, 1865).

In 1818, workmen blasting a well through Portland Formation rocks at Ketch's Mills, East Windsor, Connecticut (Point 4 in Fig. 1), 24 km (15 miles) south of Springfield, discovered what would become the first collection of dinosaur bones found in North America (Santucci 1998). Because the value of the fossils was not immediately recognized, some were accidentally partially destroyed before recovery while others were taken by workmen. Solomon Ellsworth retained most of what was left and brought the bones to the attention of Nathan Smith, who made the first published description (Smith 1820). His identification of the material as possibly human was rejected by Jeffries Wyman (1855), who described the bones as reptilian and crocodile-like but hollow. Othniel Charles Marsh later identified them as dinosaurian (Marsh 1896). The specimen, now YPM 2125 (Peabody Museum of Natural History, Yale University, New Haven, Connecticut), consists of at least three partial caudal vertebrae, part of the left femur, traces of the lower leg bones, and an articulated partial arm (Galton 1976). While at one time assigned to *Anchisaurus colurus* (Lull 1912; see below), it is now regarded as an indeterminate sauropodomorph (Galton 1976; Yates 2010). Several details of the arm and hand suggest that it is distinct from the other Portland Formation sauropodomorphs (Yates 2004, 2010).

ANCHISAURUS FROM SPRINGFIELD ARMORY

The second dinosaur body fossil from the Portland Formation is the Springfield Armory specimen of *Anchisaurus*, now reposited at Amherst College's Pratt Museum of Natural History as ACM 41109 (Fig. 2) (K. Wellspring, Pratt Museum of Natural History collections manager, pers. comm., December 2009; AM 41/109 in some sources). The specimen consists of eleven dorsal and caudal vertebrae, a partial scapula, an almost complete right manus, portions of the right forearm, a partial left hindlimb (femur, partial tibia, fibula, and pes), and two partial Ischia, some partially damaged. Its publication history spans more than 150 years (Hitchcock 1855, 1858, 1865; Cope 1870; Huene 1906; Ostrom 1971; Galton 1976; Galton and Cluver 1976; Santucci 1998; Yates 2004, 2010; Fedak and Galton 2007; Sereno 2007): ACM 41109 was found during blasting operations for improvements to the Water Shops at Mill Pond (Santucci 1998) in 1855 (A. MacKenzie, pers. comm., March 2010) in a rock unit earlier referred to as the Longmeadow Sandstone (Galton 1976). Most of the remains were discarded (Hitchcock 1855) or taken by workmen before the intervention of an excavation superin-

FIGURE 2. Among the bones recovered from Springfield Armory are a femur (**A**) and fused ischia (**B**). Photos by Kate Wellspring, courtesy of Amherst College Museum of Natural History, The Trustees of Amherst College.

tendent, William Smith. General James S. Whitney, the superintendent of the Armory, ordered further investigation, so Smith gathered as much as he could and sent the remains to Hitchcock (Hitchcock 1858). The press at the time took little notice of the find: dinosaurs had yet to enter the American consciousness (Santucci 1998) (the term itself had just been coined in 1842); moreover, the specimen was not identified as dinosaurian until fifteen years later (Cope 1870).

Hitchcock was the first to publish notice of the fossils (1855), then Wyman described them for Hitchcock's seminal 1858 work. As with the Ketch's Mills specimen, he recognized them as reptilian and drew attention to the hollowness of the bones, which he considered very bird-like. After consulting Sir Richard Owen, Hitchcock's son, Edward Jr., named the bones *Megadactylus polyzelus* in an appendix to the supplement to Hitchcock's 1858 work (Hitchcock 1865). Later, the skeleton was briefly described by Edward Drinker Cope (Cope 1870), but his rival Marsh, who described similar skeletons from Connecticut, was responsible for its current name. When *Megadactylus* proved to have already been used for another animal, Marsh renamed the genus *Amphisaurus* and created the family Amphisauridae (Marsh 1882). *Amphisaurus* was also already in use, so he substituted Anchisaurus and Anchisauridae (Marsh 1885). ACM 41109 is the specimen upon which *Anchisaurus polyzelus* was founded, making it the holotype for the genus and species.

THE BUCKLAND QUARRY SAUROPODOMORPHS, PORTLAND FORMATION

During the 1880s, three sauropodomorph skeletons were found at the Buckland Quarry (or Wolcott Quarry) in Manchester, Connecticut (Point 5 in Fig. 3), 35 km (22 miles) south of Springfield (Hubert et al. 1982) in a locality interpreted as a setting of ephemeral braided streams with occasional high-energy shallow floods, just west of the large alluvial fans that formed on the eastern border of the Hartford Basin. The climate at the site was seasonal and semi-arid, and streams flowed from south to north (Hubert et al. 1982). Although the Buckland Quarry is the most productive locality for dinosaur skeletons on the East Coast to date (Weishampel and Young 1996), today the quarry is overgrown and abandoned (P. Olsen, pers. comm., November 2010) and the area has been developed for a shopping mall.

All three specimens are individuals of the same taxon, probably *Anchisaurus*, and each was first described as its own species by Marsh. When quarriers discovered the first skeleton in October 1884, Charles Wolcott, the quarry owner, set it aside for Marsh. Unfortunately, the block thought to contain the anterior half and skull was incorporated into an abutment for the Hop Brook bridge in south Manchester before Marsh could take possession. When the bridge was demolished in the summer of 1969, a diligent search by a crew working for John Ostrom of Yale University recovered the missing half of the right femur and some miscellaneous dinosaur bones, but the rest of the bones reputed to have been present remain missing (Hubert et al. 1982). Marsh initially named the specimen *Anchisaurus major* in 1889 and gave it its own genus, *Ammosaurus*, two years later (Marsh 1891). Today, the specimen, YPM 208, consists of six dorsal vertebrae, the sacrum, ribs, most of the right scapula, most of the pelvis, the left leg, right femur, and right pes (Galton 1976).

In the same paper in which he named *Ammosaurus*, Marsh named another specimen from the quarry *Anchisaurus colurus* (Marsh 1891). Believing *Anchisaurus polyzelus* to be a species of the European genus *Thecodontosaurus* (Huene 1932), Friedrich von Huene coined the genus *Yaleosaurus* in 1932. The name *Yaleosaurus* was accepted by Lull (1953) and was commonly seen in dinosaur books from the middle of the 20th century, but was synonymized with *Anchisaurus* (and *A. colurus* with *A. polyzelus*) by Galton (1971, 1976). Although YPM 1883, the partial skeleton on which *A. colurus* was based, is missing much of the neck, the tail, and much of the left side (Galton 1976), the specimen is more complete than ACM 41109 and is often refer-enced for depictions of *Anchisaurus* and used in phylogenetic analyses.

Marsh named the third skeleton from the quarry *Anchisaurus solus* in 1892. This specimen, YPM 209, consists of a nearly complete but poorly preserved skeleton of a young individual, with only the end of the tail and part of the right arm missing (Galton 1976; Fedak and Galton 2007). Galton synonymized *Anchisaurus solus* with *Ammosaurus major*, regarding *A. solus* as a juvenile of that species (Galton 1971, 1976; Galton and Cluver 1976).

TAXONOMY AND SYSTEMATICS OF ANCHISAURUS AND AMMOSAURUS

The separation of *Anchisaurus* and *Ammosaurus*, as proposed by Marsh and later detailed by Galton (Galton 1971, 1976; Galton and Cluver 1976), was generally accepted until the late 1990s. Of recent studies to consider the matter, one favors retaining separate genera (Galton and Upchurch 2004) while five find the foot and pelvic details cited by Galton's earlier works to be inadequate and conclude that only one genus and species is represented (Sereno 1999, 2007; Yates 2004, 2010; Fedak and Galton 2007). These five publications agree that the three Buckland Quarry specimens represent one taxon; assessments of ACM 41109, however, vary. Yates (2004, 2010) and Fedak and Galton (2007) unite ACM 41109 and the Buckland Quarry specimens under *Anchisaurus polyzelus*, but Sereno (2007) considers ACM 41109 to be undiagnostic and recommends classifying the Buckland Quarry specimens as *Ammosaurus major*. Yates (2010) disagrees, finding the form of the ischia and first sacral rib in ACM 41109 to be diagnostic.

Anchisaurus is currently regarded as a basal sauropodomorph (Yates 2010), though its classification has changed as researchers piece together the evolution of dinosaurs. Marsh thought that both *Anchisaurus* and *Ammosaurus* were theropods (Marsh 1896) while Huene assigned *Ammosaurus* to Ornithischia (1906), then back to Theropoda in Ammosauridae (1914). Further complicating matters, he later assigned *Anchisaurus* and *Yaleosaurus* to Prosauropoda and transferred *Ammosaurus* to the theropod group Coelurosauria (1932), where it remained for decades (Galton 1971). The name of the ichnogenus *Anchisauripus*, which is now seen as tracks left by theropod dinosaurs (Galton 1971), reflects this confusion

Anchisaurus recently attracted attention as potentially the most primitive and smallest sauropod (Yates 2004), though Yates revised this assessment as part of ongoing research on basal sauropodomorph relationships (2010). *Anchisaurus* "became" a sauropod when the definition of Sauropoda (all sauropodomorphs more closely related to the sauropod *Saltasaurus* than to the prosauropod *Plateosaurus*) did not take into account the possibility that the traditional prosauropods did not form a group. Thus, when Yates (2004) found Anchisaurus to be closer to sauropods than to *Plateosaurus*, it became a sauropod by definition. Similar work has resulted in other prosauropods becoming sauropods, so Yates (2010) favored a modification of the definition of Sauropoda to better conform to the traditional content of the group. This would leave Anchisaurus out of Sauropoda. Complicating matters is the possibility that all known specimens of *Anchisaurus* and *Ammosaurus* represent immature individuals (Fedak and Galton 2007 [but see Yates 2004]).

PALEOBIOLOGY OF ANCHISAURUS

Views on the paleobiology of *Anchisaurus* have changed substantially since Cope described "*Megadactylus polyzelus*" in the 1870s as a leaping carnivore that dispatched prey with its claws (Cope 1870). *Anchisaurus* and *Ammosaurus* were interpreted as carnivores well into the 20th century (Lull 1912, 1953; Krynine 1950), though anchisaurs, like other basal sauropodomorphs, had iguana-like teeth and probably were mostly herbivorous, supplementing their diet with carrion and small prey (Barrett 2000). Known specimens of *Anchisaurus* were of modest size for dinosaurs. The femurs of ACM 41109, YPM 1883, and YPM 208 are 18.0 cm (7.1 in) (estimated), 21.1 cm (8.3 in), and 22.1 cm (8.7 in) long, respectively (Carrano 2006; Fedak and Galton 2007), with the length of the largest specimen (YPM 208) estimated at 3 m (10 ft) (Galton 1976). If indeed all known specimens are immature, the adult size is not yet known. Although commonly interpreted as quadrupeds, basal sauropodomorphs like *Anchisaurus* were probably unable to walk on all

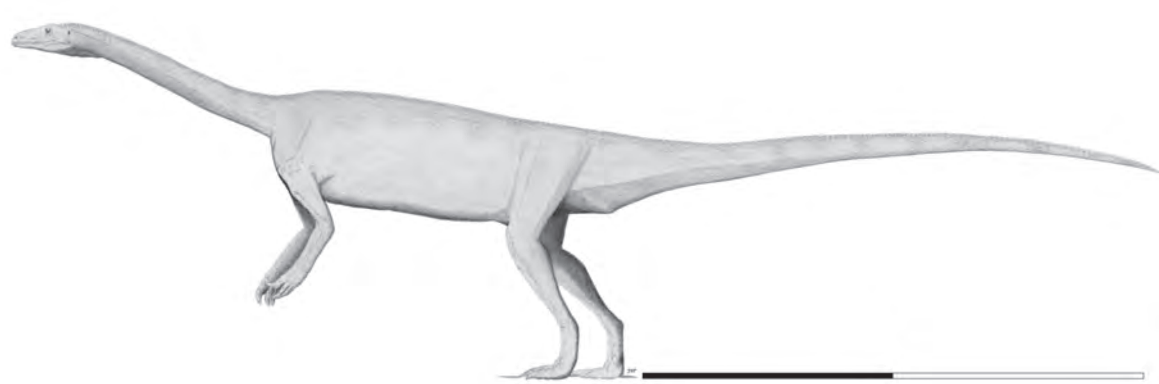

FIGURE 3. A modern restoration of Anchisaurus polyzelus as a biped, primarily after Yates (2010), with reference to Marsh (1893), Galton (1976), Carpenter (reproduced in Glut [1997]), and Paul (2010). Scale bar represents 1 m.

fours, based on their arm anatomy (Fig. 3) (Bonnan and Senter 2007). Anchisaurs may have been members of a rarely preserved upland fauna (Galton and Cluver 1976). They are known from the upper, fluvial part of the Portland Formation, along with the crocodylomorph *Stegomosuchus* (Olsen et al. 2003a).

ANCHISAURUS AMONG NATIONAL PARK SERVICE FOSSIL RESOURCES

ACM 41109 is unusual in several ways among fossil resources associated with National Park Service areas, especially in comparison to other National Park System units in the East. As a Mesozoic dinosaurian fossil, it is virtually unique among units east of 100° W longitude. Furthermore, it is the holotype specimen of a well-known genus and species. As a Portland Formation specimen, it dates from a time when tetrapods were undergoing diversification after an extinction event, representing a region with few contemporary tetrapod body fossils. Historically, ACM 41109 is among the fossils discovered and described during the formative years of American vertebrate paleontology, and is one of the first partial dinosaur skeletons found in the nation. It has been described and discussed by noted paleontologists from Hitchcock through to Cope and Marsh, von Huene, Lull, and Ostrom, as well as an assortment of contemporary workers.

At the same time, ACM 41109 is among a wealth of fossil resources associated with National Park System lands, including many other historically significant finds such as Hiram Prout's "*Palaeotherium*" in Badlands National Park (Prout 1846) and dozens of mammals described by Joseph Leidy from an area now including Niobrara National Scenic River (Leidy 1858). If recent finds are any indication (Chure et al. 2010), important fossils will be discovered in National Park System areas for as long as the National Park Service exists.

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FIELD TRIP GUIDE

PALEONTOLOGY AND STRATIGRAPHY OF THE MIDDLE EOCENE BRIDGER FORMATION, SOUTHERN GREEN RIVER BASIN, WYOMING

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ABSTRACT—The middle Eocene Bridger Formation is located in the Green River basin in southwest Wyoming. This richly fossiliferous rock unit has great scientific importance and is also of historic interest to vertebrate paleontologists. Notably, the Bridger Formation is the stratotype for the Bridgerian North American Land Mammal Age. The fossils and sediments of the Bridger provide an important record of biotic, environmental, and climatic history spanning approximately 3.5 million years (49.0 to 45.5 Ma). Additionally, the high paleontological sensitivity of the formation, in combination with ongoing energy development activity in the southern Green River Basin, makes the Bridger Formation a paleontological resource management priority for the Bureau of Land Management. This paper features a detailed field excursion through portions of the Bridger Formation that focuses on locations of geologic, paleontologic and historical interest. In support of the field excursion, we provide a review of current knowledge of the Bridger with emphasis on lithostratigraphy, biochronology, depositional and paleoenvironmental history, and the history of scientific exploration.

"A large part of the collection in this region was of the remains of small animals. The fossils were generally found in the buttes, and on account of their minuteness, their discovery was attended with much difficulty. Instead of riding along on the sure-footed mule and looking for a gigantic tell-tale vertebra or ribs, it was necessary to literally crawl over the country on hands and knees…Often a quarter of a mile of the most inviting country would be carefully gone over with no result, and then again someone would chance upon a butte which seemed almost made of fossils."

—A description of fossil collecting in the Bridger Formation written by an unnamed member of the 1871 Yale College Expedition, led by paleontologist O.C. Marsh.

INTRODUCTION AND STRUCTURAL SETTING

Situated to the north of the Uinta Mountains in the southern Green River basin, Wyoming, the Bridger Formation is of great scientific importance and is of historic interest to vertebrate paleontologists. The Bridger Formation has been the focus of paleontological investigations for the last 140 years. Because of its economic importance and exquisitely preserved vertebrate, invertebrate and plant fossils, the Green River Formation is perhaps the most familiar of the rock units within the Green River basin. Despite the geological and paleontological importance of this world-renowned lacustrine rock unit, this field excursion is focused on the stratigraphically adjacent and overlying fluvial and lacustrine Bridger Formation, best known for its middle Eocene vertebrate fossils. The Bridger Formation is the stratotype for the Bridgerian North American Land Mammal "Age" (NALMA) (Gunnell et al., 2009; Wood et al., 1941). The fossils and sediments of the Bridger provide a critically important record of biotic, environmental, and climatic history spanning approximately 3.5 million years (49.0 to 45.5 Ma).

The greater Green River basin occupies 32,187 km^2 of southwestern Wyoming and northwestern Colorado (Roehler, 1992a). Structurally, it is a large asymmetrical syncline with mostly gently dipping flanks (3º to 5º) with steeper dips along the southern margin of the basin, and an approximately north-south axis (Koenig, 1960; Roehler, 1992a). The greater Green River basin is divided into four smaller basins by three intrabasin arches. The largest of these arches, the north-south trending Rock Springs uplift, divides the basin into roughly equal halves, with the Green River basin to the west, and the Great Divide, Sand Wash, and Washakie basins to the east. The Bridger basin is located within the southern part of the Green River basin. The term Bridger basin (Hayden, 1871) traditionally refers to an area located north of the Uinta Mountains and south of the Blacks Fork of the Green River in Uinta and Sweetwater counties, Wyoming, and is a physiographic, not a structural basin (Figure 1).

The greater Green River basin began forming during the Laramide orogeny, a period of tectonism in western North America that was initiated during the late Cretaceous and continued for approximately 30 million years until the late Eocene. In addition to the uplifting of surrounding mountain ranges, Laramide tectonism resulted in rapid subsidence in basin depositional centers, and lacustrine and fluvial deposition in the intermontane basins was mostly continuous. Lacustrine deposition was characterized by a complex history of expansions and contractions in response to basin subsidence, climatic conditions, and volcanic activity (Murphey, 2001; Murphey and Evanoff, 2007; Roehler, 1992b).

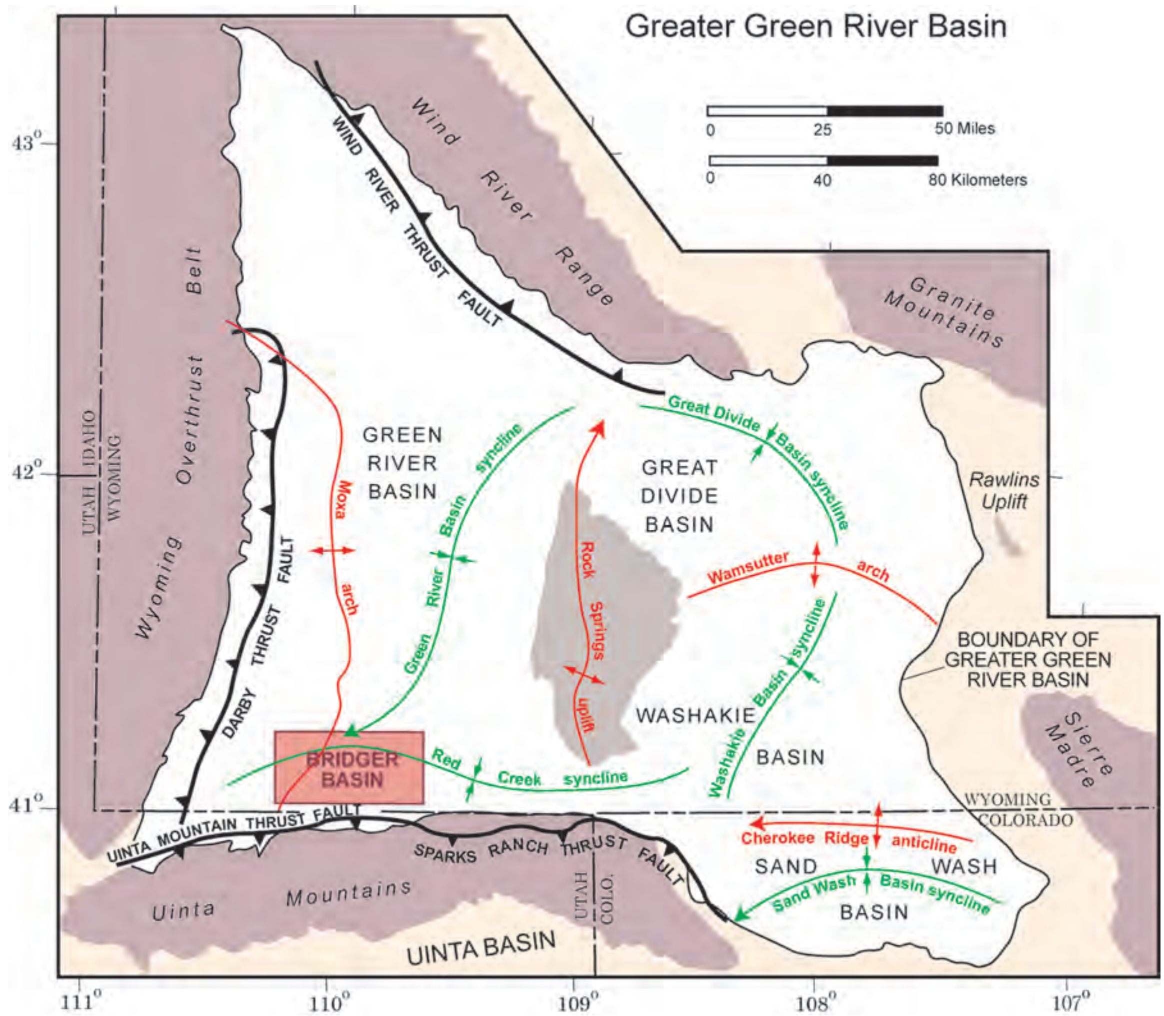

FIGURE 1. Index map of the Greater Green River Basin showing the approximate location of the Bridger basin (type area of the Bridger Formation), major structural features, and surrounding uplifts (modified from Murphey and Evanoff, 2007).

With its abundant and diverse vertebrate fossils and extensive exposures, the Bridger Formation provides an excellent opportunity to study middle Eocene continental environments of North America. The dramatic and picturesque Bridger badlands are an 842 meter (2,763 feet) thick sequence dominated by green-brown and red mudstone and claystone, with interbedded scattered ribbon and sheet sandstone, widespread beds of micritic, sparry, and silicified limestone, and thin but widespread beds of ash-fall tuff (Evanoff et al., 1998; Murphey and Evanoff, 2007).

From a resource management perspective, the richly fossiliferous Bridger badlands present a challenge to land managers—in particular the Wyoming Bureau of Land Management. With a Potential Fossil Yield Classification (PFYC, BLM 2008-007) ranking of 5 (very high paleontologic potential) (Murphey and Daitch, 2007), the Bridger Formation contains fossils in both surface accumulations and subsurface occurrences, and both are vulnerable to direct impacts as the result of surface disturbing actions and indirect impacts from increased public access to public lands. Fortunately, as will be discussed during the field trip, well documented fossil distribution patterns in the upper Bridger Formation provide a reliable source of information upon which to base management decisions.

This field trip offers participants the opportunity to examine paleontologically significant strata of the Bridger Formation in the southern Green River basin. The following sections of the field trip guide provide a summary of the Cenozoic geologic history of the Green River basin, as well as the history of investigations, stratigraphy, depositional and paleoenvironmental history, and fossils of the Bridger Formation. This is followed by a detailed road log. Discussions during the field trip will also focus on some of the resource management issues that relate to the exquisite fossils of this world renowned rock unit.

PALEOGENE GEOLOGIC HISTORY OF THE GREEN RIVER BASIN, WYOMING

The greater Green River basin was filled with Paleocene and Eocene fluvial and lacustrine sediments; sedimentation appears to have been continuous in most of the basin during the Eocene. The oldest Cenozoic rock units in the greater Green River basin—the Paleocene Fort Union Formation and the early Eocene Wasatch Formation—are exposed mostly along its eastern and western flanks. During the Paleocene and earliest Eocene, deposition in the greater Green River basin was predominantly fluvial, with epiclastic sediments accumulating in river drainages and on adjacent floodplains. The onset of lacustrine deposition associated with the Green River lake system may have commenced as early as the late Paleocene (Grande and Buchheim, 1994). Lake sediments accumulated on broad floodplains of low topographic relief, and the lake waters expanded and contracted numerous times over the next approximately five million years in response to climatic changes, tectonic influences, and episodic volcanic activity.

Occupying the center of the basin in the shape of a large, irregular lens (Bradley, 1964; Roehler, 1992b, 1993), the Green River Formation is the result of at least five million years of lacustrine deposition lasting from about 53.5 to 48.5 Ma (Smith, 2003), although lacustrine deposition may have persisted later in the southernmost part of the basin along the Uinta Mountain front (Murphey and Evanoff, 2007). The Green River Formation was deposited in a vast ancient lake system that existed from the late Paleocene to the middle Eocene in what is now Colorado, Utah, and Wyoming. The smallest and oldest of these lakes, Fossil Lake, was deposited in Fossil basin, which is located in the Wyoming overthrust belt just to the west of the Green River basin in southwestern Wyoming. Lake Gosiute was deposited in the greater Green River basin, which includes the Green River and Washakie basins in southwestern Wyoming, and the Sand Wash basin in northwestern Colorado. Fossil Lake and Lake Gosiute may never have been physically connected (Surdam and Stanley, 1980). Lake Uinta was deposited in the Uinta basin in northeastern Utah and the Piceance Creek basin in northwestern Colorado. Lithologically, the Green River Formation in the greater Green River basin is a complex sequence of limestone, shale, and sandstone beds with a maximum thickness of approximately 838 meters (2,750 feet) (Roehler, 1993). It was deposited lateral to and above the predominantly fluvial Wasatch Formation, and lateral to and below the fluvial and lacustrine Bridger and Washakie formations. The Laney Member is the uppermost member of the Green River Formation in Wyoming and represents the final expansion of Lake Gosiute.

Most volcaniclastic sediments deposited in the Green River basin during the middle Eocene were apparently transported from the Absaroka Volcanic Field in what is now northwestern Wyoming. These sediments were washed into the basin in rivers and streams. Some volcaniclastic sediments were transported into the basin via eolian processes and deposited as ash fall in lakes and on floodplains. A large influx of fluvially transported volcaniclastic sediment is believed to have led to the final middle Eocene filling of Lake Gosiute (Mauger, 1977; Murphey, 2001, Murphey and Evanoff, 2007; Surdam and Stanley, 1979). Mauger (1977) and Surdam and Stanley (1979) estimated that Lake Gosiute was ultimately extinguished by about 44 Ma.

The Bridger, Green River, and Washakie formations are locally and unconformably overlain by the Oligocene Bishop Conglomerate and the middle-to-late-Miocene Browns Park Formation. Since the Eocene, the greater Green River basin has been modified by erosion, regional uplift, and normal faulting, but the basic structure of the basin remains the same as it was during deposition of the Wasatch, Green River, Washakie, and Bridger formations.

HISTORY OF PALEONTOLOGICAL INVESTIGATIONS IN THE BRIDGER FORMATION

John Colter, who traveled to the headwaters of the Green River in 1807, was probably among the first non-Native Americans to visit the Green River basin (Chadey, 1973). Hundreds of subsequent trappers and explorers traversed the basin during the first half of the nineteenth century, and a number of records of these early explorations make reference to fossils and coal (Roehler, 1992a). The earliest scientific observations on the geology of the Green River basin were made by Army Lt. John C. Fremont. After entering the basin through South Pass at the southern end of the Wind River Mountain, Fremont (1845) described varicolored rocks (now known as Eocene-age Wasatch Formation) along the Big Sandy and New Fork rivers. He also collected fossil shells from near Cumberland Gap (Veatch, 1907). The earliest vertebrate fossils reported from the Green River basin were fishes discovered in the Green River Formation. In 1856, Dr. John Evans collected a specimen of a fossil fish from an unknown Green River Formation locality west of Green River City. He sent this specimen to paleontologist Joseph Leidy in Philadelphia for study, and Leidy named it *Clupea humilis* (later renamed *Knightia humilis*) (West, 1990). Hayden (1871) described the discovery of a locality he referred to as the “petrified fish cut” along the main line of the Union Pacific Railroad about 2 miles west of Green River. Employees of the railroad had initially discovered the locality and later turned many specimens over to Hayden. Paleontologist Edward Drinker Cope described the fish fossils from the petrified fish cut in Hayden’s (1871) expedition report.

The initial discovery of mammalian fossils in the Green River basin was probably made by a long-time local resident. Trapper Jack Robinson (also called Robertson) found what he described as a “petrified grizzly bear” sometime in the late 1860s in what is now called the Bridger Formation but had initially been named the “Bridger Group” by Ferdinand V. Hayden in 1869. This story was related to Joseph Leidy by Judge William Carter of Fort Bridger as an explanation for the name “Grizzly Buttes,” an area 10 to 15 miles southeast of Fort Bridger where fossils were particularly common (the name Grizzly Buttes has since disappeared from the local geographic vocabulary).

Several government geological and topographical surveys with specific but overlapping territories were operating in the southern Green River basin between 1867 and 1879. Hayden and his party collected along the Henrys Fork valley and further north in the vicinity of Church Buttes in 1870 as part of the 1867 to 1878 U.S. Geological and Geographical Survey of the Territories (Hayden, 1873). Fossils collected by Hayden's group were sent to Joseph Leidy in Philadelphia for study and were described in his 1873 monograph on fossil vertebrates. Later paleontological studies for the Hayden Survey were carried out by E. D. Cope. Under the direction of John Wesley Powell, the U.S. Geological and Geographical Survey of the Territories, Second Division (1875–1876), worked along the Henrys Fork River in 1869, and in a corridor 10 to 20 miles wide on either side of the Green River in 1871 (Powell, 1876). The U.S.Geological Survey of the Fortieth Parallel (1867–1872), directed by Clarence King, worked in the Green River basin in 1871 and 1872. The fossils collected by the King Survey were sent to Othniel Charles Marsh for description. Most of the fossils collected during these surveys were discovered in the Bridger Formation.

Many of the early scientific expeditions to the Green River basin were based out of Fort Bridger that was originally set up as a trading post in 1843 by trapper and guide Jim Bridger and his partner Louis Vasquez. The fort became an army post after the 1857 Mormon War. Judge Carter and Dr. J. Van A. Carter, later residents of Fort Bridger, maintained an active correspondence with Joseph Leidy in Philadelphia during the late 1860s and early 1870s. This correspondence included mailing fossils to Leidy, which were described in subsequent publications (Leidy, 1869, 1871, 1872a,b, 1873). Leidy, who is often regarded as the father of North American vertebrate paleontology (Lanham, 1973), named the first Bridger Formation fossil to be formally described, the omomyid primate *Omomys carteri*, after Dr. Carter (Leidy, 1869). *Omomys carteri* was also the first-described fossil primate from North America.

Early reports of fossils from the Green River basin did not go unnoticed by rival paleontologists O. C. Marsh and E. D. Cope. The incidents that set the stage for the long and bitter conflict between these two men began in the Green River basin while they were prospecting in the Bridger Formation in 1872. Sometimes referred to as the "bone wars," the dispute between Marsh and Cope lasted for more than 30 years and included efforts by each man to destroy the scientific reputation and integrity of the other. This conflict soured Leidy's interest in paleontology and led to his eventual abandonment of the discipline after 1872.

Professor Marsh was the first professional paleontologist to collect fossils from the Bridger Formation; he brought crews with him from Yale College for four consecutive summers from 1870 to 1873. Leidy's only excursion to the West took place in 1872, when he visited the Bridger badlands guided by the Carter brothers of Fort Bridger. Cope's only visit to the Bridger badlands occurred in 1872, while Cope was attached to the Hayden survey as the paleontologist. This visit infuriated Marsh, who, at the time, considered the Green River basin and Bridger Formation his exclusive fossil-collecting territory. By the late 1870s, Cope and Marsh had left the Green River basin for good, although both men independently and at different times retained the services of paid fossil collector Sam Smith (West, 1990).

Other early fossil collectors who visited the Green River basin in 1877 and 1878 included Henry Fairfield Osborn, William Berryman Scott, and Francis Speir for Princeton University. Scott returned to the area with Speir in 1886. Jacob Wortman and James W. Gidley collected for the American Museum of Natural History (AMNH) in 1893. The early fossil-collecting expeditions to the Green River basin resulted in large collections of fossils primarily from the Bridger Formation at the Philadelphia Academy of Natural Sciences (Leidy), Yale University (Marsh), the AMNH (which purchased Cope's collection just before the turn of the century), and Princeton University (Osborn, Scott, and Speir). Unfortunately, these early collectors paid little attention to the stratigraphic provenance of the fossils they collected. Their collections do, nevertheless, contain the holotypes of most presently recognized Bridgerian mammal taxa.

In 1902, H. F. Osborn, who was then the USGS paleontologist, initiated the first program of stratigraphic fossil collection to take place in the Green River basin and one of the first in North America. Osborn charged Walter Granger and William Diller Matthew of the AMNH with the task of carrying out the study. Matthew was also directed to find a uintathere to display at the AMNH. The AMNH party, led by Granger, worked in the Bridger basin from 1902 to 1906 (Matthew, 1909). The second halves of the 1903 and 1905 field seasons were devoted to mapping and describing the stratigraphy of the Bridger Formation, while the remainder of the time was spent searching the badlands for fossils. The efforts of the AMNH parties over these four years resulted in an excellent fossil collection that was, for its time, very well documented stratigraphically.

These AMNH expeditions also resulted in the first paper to be published on the geology of the Bridger Formation, which was authored by William J. Sinclair (1906), who had joined the AMNH field party for the summer of 1905. In Matthew's classic 1909 monograph, *The Carnivora and Insectivora of the Bridger Basin, Middle Eocene*, the geology of the Bridger Formation was described briefly, and a system of stratigraphic subdivisions for the formation was introduced. These subdivisions, Bridger A–E, were based on areally extensive limestone beds, which Matthew called "white layers."

Following the early fossil-collecting expeditions of the nineteenth century and initial scientific field studies conducted by AMNH crews in the early twentieth century, the Bridger Formation in the Green River basin has remained the focus of almost continuous paleontologic inquiry because of its abundant and diverse vertebrate fossils, although Matthew's (1909) original stratigraphy was only recently refined. West (1990) wrote an excellent historical summary of vertebrate paleontological work in the Green River basin from 1840 to 1910.

H.F. Osborn (1929) devoted considerable discussion to the Bridger Formation and its fossils in his monograph, *The Titanotheres of Ancient Wyoming, Dakota, and Nebraska*. Horace Elmer Wood (1934) divided the Bridger Formation into two members. The Blacks Fork Member corresponds to Matthew's Bridger A and B, and the Twin Buttes Member corresponds to Matthew's Bridger C and D, with the Sage Creek White Layer marking their boundary. Contrary to rules of stratigraphic nomenclature, these members were defined on perceived faunal differences rather than lithologic differences. The informal usage of the terms “Blacksforkian” and “Twinbuttean” as land mammal subages derives from the names of the two Bridger members. Under the direction of J. W. Gidley, followed by C. Lewis Gazin, the Smithsonian Institution began an active collecting program in the Bridger Formation beginning in 1930. Gazin was active in the Green River basin from 1941 to 1968. This period of activity resulted in a relatively large and well-documented collection that was the subject of numerous publications by Gazin focused primarily on the systematic paleontology of Bridgerian mammal fossils (e.g., 1934, 1946, 1949, 1957, 1958, 1965, 1968, and 1976).

Paul O. McGrew and Raymond Sullivan worked on the stratigraphy and paleontology of the Bridger A in the late 1960s and published the results of their work in 1970. Robert M West began an active collecting program for the Milwaukee Public Museum in 1970 and worked in the basin until the late 1970s. West’s work, which also resulted in a large number of paleontological publications, included the use of screen-washing techniques to collect microvertebrates, a portion of the fauna that had not been previously well sampled. Like Wood (1934) and Koenig (1960), West (1976) noted difficulties with the correlation of Matthew’s white layers across the basin and suggested that a bipartite division of the Bridger into upper (Twin Buttes) and lower (Blacks Fork) members was most appropriate. West and Hutchison (1981) named Matthew’s Bridger E the Cedar Mountain Member, adding a third member to the Bridger Formation. Paleontological and geological studies of Tabernacle Butte, an isolated remnant of the Bridger Formation of late Bridgerian age with an important fossil fauna, were published by McGrew (1959), McKenna et al. (1962), and West and Atkins (1970).

Evanoff et al. (1998), Murphey (2001), and Murphey and Evanoff (2007) significantly refined Matthew’s (1909) Bridger Formation stratigraphic scheme. Their work included the addition of newly described marker units; the establishment of new stratigraphic subdivisions and correlation of marker units across the southern part of the basin where the most complete stratigraphic sequence is exposed; descriptions of detailed stratigraphic sections measured through the Bridger B, C, D, and E; renaming of the Cedar Mountain Member to the Turtle Bluff Member in order to conform with the rules of stratigraphic nomenclature; stratigraphic positioning of more than 500 fossil localities; isotopic dating of four ash-fall tuffs; and geologic mapping of more than 600 miles of the southern Green River basin at the scale of 1:24,000. Geologic maps and publications relating to the Bridger Formation are available at http://www.rockymountainpaleontology.com/bridger.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE BRIDGER FORMATION

The Bridger Formation was named the “Bridger Group” by Hayden (1869). The first stratigraphic framework for the Bridger Formation was established by W.D. Matthew (1909) of the AMNH in the southern Green River basin where the formation is thickest and best exposed. Matthew’s (1909) stratigraphic subdivisions of the Bridger Formation were based primarily on five areally extensive limestone beds. These he named the Cottonwood, Sage Creek, Burnt Fork, Lonetree, and upper white layers, and some were used to subdivide the formation into five units: Bridger A, B, C, D, and E, from lowest to highest. Matthew’s intent was to make it possible to stratigraphically locate the numerous known fossil localities in the formation. Because they are the most fossiliferous, the Bridger B, C, and D were further divided into five subunits corresponding to basal, lower, middle, upper, and top levels (e.g., B1, B2, B3, B4, B5). Because Matthew (1909) did not define the upper and lower boundaries of these subunits with stratigraphic markers or measured sections, correlations between them and the later subdivisions proposed by Evanoff et al. (1998), Murphey (2001), and Murphey and Evanoff (2007) are uncertain. See Figure 2 for the history of stratigraphic nomenclature for the Bridger Formation.

In his 1909 monograph, Matthew (1909:296) gave a brief description of his proposed five members and his white layers. “Horizon A” was 200 ft thick, composed primarily of calcareous shales alternating with tuffs, and with rare fossils. “Horizon B” was 450 ft thick, consisting of two benches separated by the Cottonwood white layer and containing abundant and varied fossils. He went on to note that the largest number of complete skeletons from the entire formation was found in the lower part of Horizon B (B2). “Horizon C” was 300 ft thick, “defined inferiorly” by the Sage Creek white layer, with the Burntfork white layer occurring at about its middle, and with abundant and varied fossils. He also noted that the Sage Creek white layer was the “heavy and persistent calcareous stratum” at Sage Creek Spring, thus designating a type locality where this unit had been previously described and illustrated, but not named, by Sinclair (1906). “Horizon D” was 350 ft thick, composed of harder gray and greenish-gray sandy and clayey tuffs, “defined inferiorly” by the Lonetree white layer, with the upper white layer about 75 ft from the top, and with abundant and varied fossils. “Horizon E” was 500 ft thick, composed of soft banded tuffs with heavy volcanic ash layers, with a high gypsum content and nearly barren of fossils. The total thickness of the Bridger reported by Matthew was 1,800 ft. Despite the lithologic descriptions of the five horizons made by Matthew (1909), subsequent workers have not been able to subdivide the Bridger Formation on the basis of lithologic differences (Bradley, 1964; Evanoff et al., 1998; Murphey, 2001, Murphey and Evanoff, 2007; Roehler, 1992a). Furthermore, with the exception of the Bridger B–C and D–E boundaries, Matthew’s subdivisions do not correspond to major faunal changes (Murphey, 2001; Murphey and Evanoff, 2007; Simpson, 1933; Wood, 1934).

The Bridger Formation has been subdivided into three members. The Blacks Fork Member, or lower Bridger, is equivalent to Matthew’s Bridger A and B; the Twin Buttes Member, or upper Bridger, is equivalent to Matthew’s C and D; and the Turtle Bluff Member, also considered part of the upper Bridger, is equivalent to Matthew’s Bridger E. A detailed history of geo-

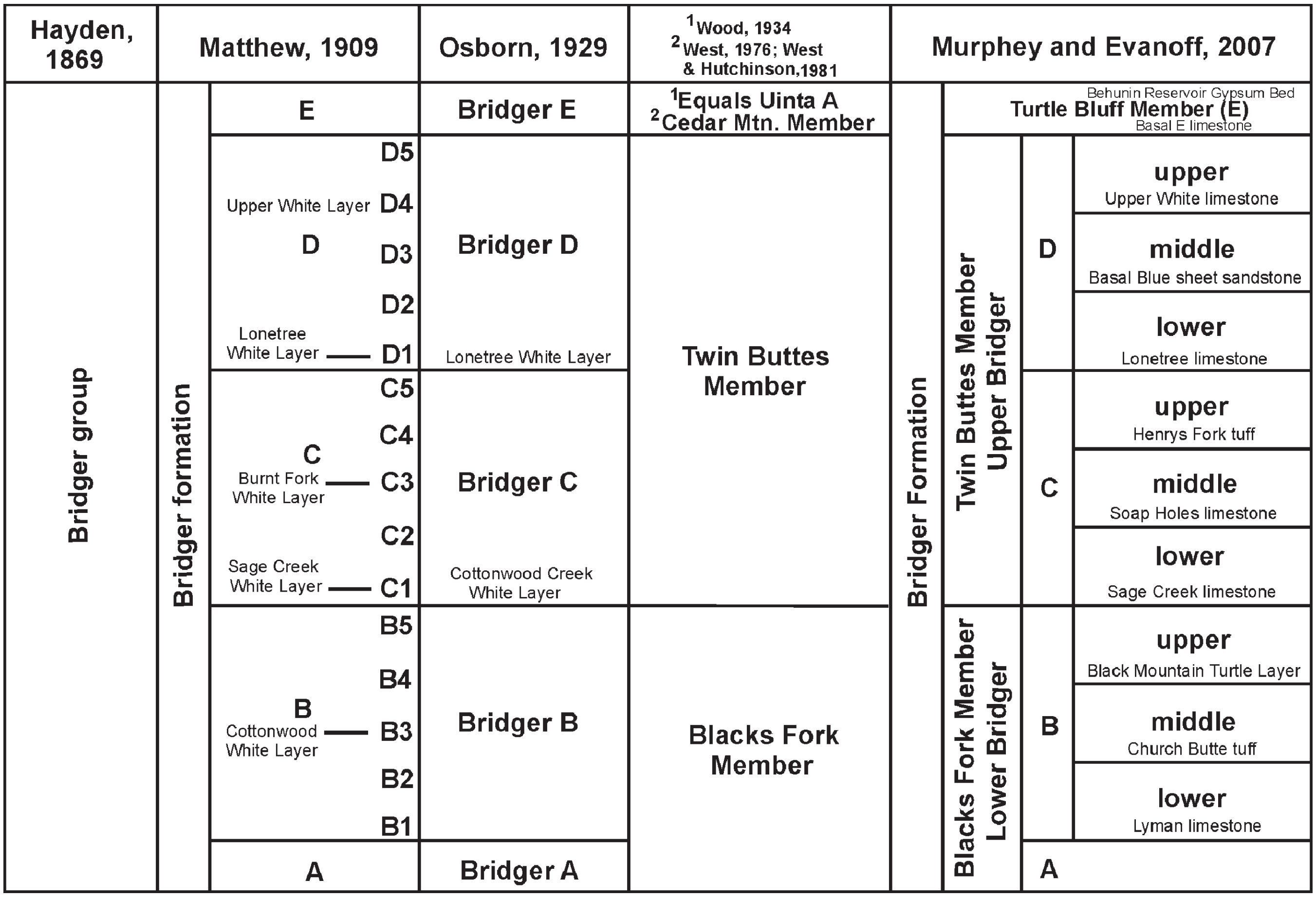

FIGURE 2. History of Bridger Formation stratigraphic nomenclature Bridger from 1869 until present. The correlation between Mathew's (1909) subdivisions (1–5) and the lower, middle, and upper subdivisions of Murphey and Evanoff (2007) are uncertain.

logic and paleontologic investigations focusing on the Bridger Formation, and the history of stratigraphic nomenclature for this unit, are provided by Murphey and Evanoff (2007).

Evanoff et al. (1998), Murphey (2001), and Murphey and Evanoff (2007) published the first major stratigraphic revision of the Bridger Formation since Matthew's (1909) stratigraphy. The most recent stratigraphic subdivisions are based on widespread limestone beds, tuffs, and tuffaceous sheet sandstones which are used as marker units. Fifteen such units were described, and seven of these were considered major markers. These were used to subdivide the Bridger C and D (Twin Buttes Member) into lower, middle, and upper informal subdivisions (Figs. 2 and 3). Two additional markers were used to redefine the base and define the top of the Bridger E (Turtle Bluff Member). Four of Matthew's original "white layers" were included in the stratigraphy of the Bridger C and D, and these were mapped and redescribed in detail. In conjunction with the latest stratigraphic revision, geologic mapping of ten 7.5-minute quadrangles which cover the area encompassed by the upper Bridger Formation was completed, and these maps are available from the Wyoming State Geological Survey. Because many marker units are not continuously exposed or traceable across the entire basin (from Hickey Mountain, Sage Creek Mountain, and Cedar Mountain east to Twin Buttes and Black Mountain), a distance of approximately 40 miles, accurate correlation was made possible by using the mineralogically diagnostic Henrys Fork tuff as a datum.

Rock accumulation rates, isotopic ages of ash-fall tuffs (Murphey et al., 1999), and fossils indicate that the 842-meter (2,763-feet) thick Bridger Formation was deposited over an approximately 3.5-million-year interval from about 49.09 to 45.57 Ma, and that the faunal transition from the Bridgerian to the Uintan Land Mammal Age was underway by about 46 Ma as indicated by fossils collected from the Turtle Bluff Member (Evanoff et al., 1994; Gunnell et al., 2009; Murphey, 2001; Murphey and Evanoff, 2007; Robinson et al., 2004). Recognized depositional environments of the Bridger Formation include fluvial, lacustrine, playa lacustrine, paludal, marginal mudflat, basin margin, and volcanic. Murphey and Evanoff (2007) concluded that an influx of fluvially transported volcaniclastic sediment to the Green River basin during middle Eocene time led to the filling of Lake Gosiute and the development of muddy floodplains of low topographic relief, which persisted for up to 85% of the time during which the upper Bridger was deposited. Occasional lapses in the flow of sediment to the basin permitted the development of shallow, mostly groundwater-fed lakes and ponds, which accumulated up to four times as slowly as floodplain deposits. These

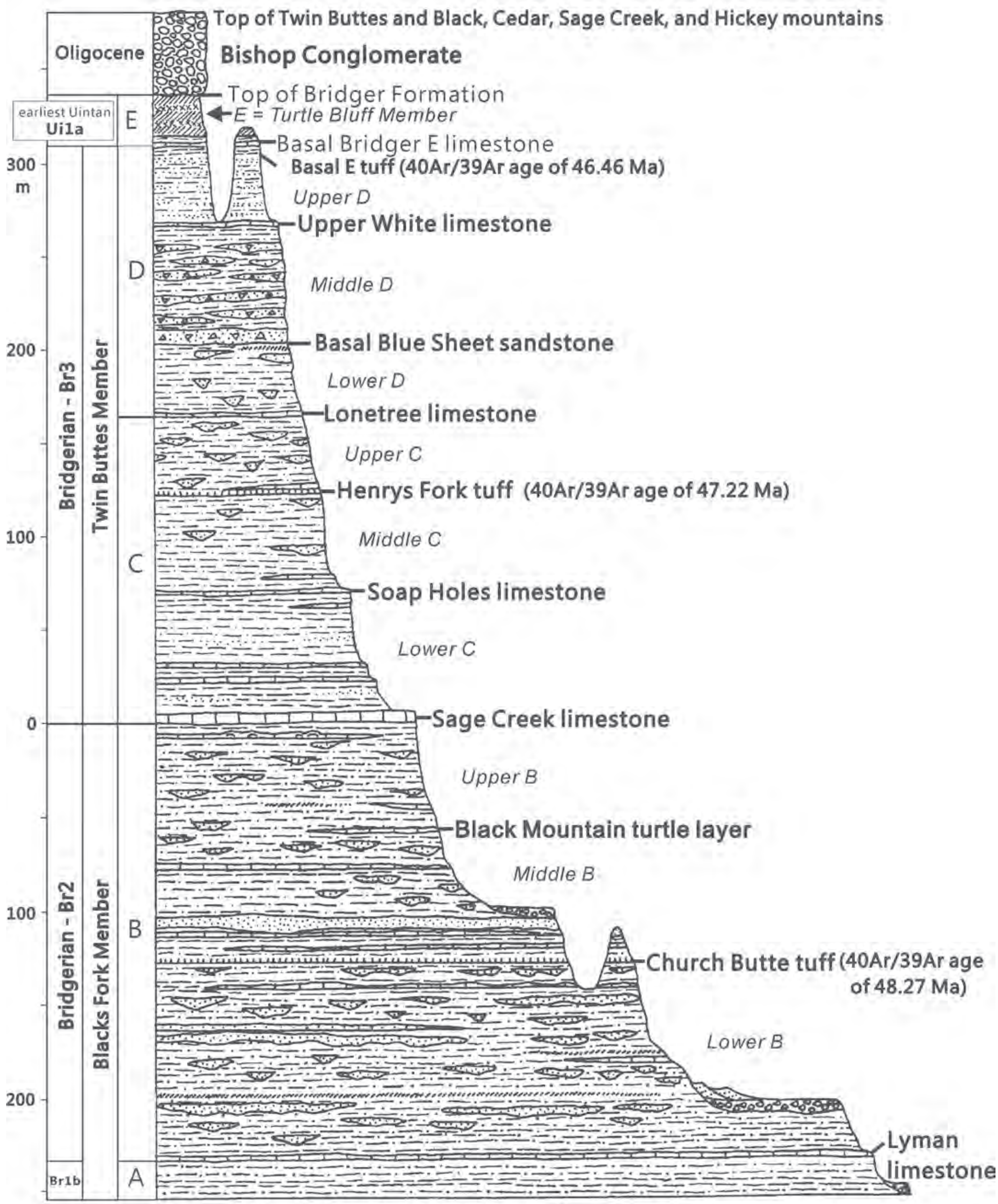

FIGURE 3. Generalized stratigraphic section of the Bridger Formation in the southern Green River Basin. Isotopic ages reported by Murphey et al. (1999) have been recalculated using the current 28.201 Ma sanidine standard for the Fish Canyon Tuff (Renne et al., 1998).

lapses decreased in frequency throughout deposition of the upper Bridger Formation. As indicated by fossil distribution and diversity, lakes and their margins provided favorable habitats for both aquatic and terrestrial organisms during deposition of the Bridger Formation.

MIDDLE EOCENE PALEOENVIRONMENTS OF THE GREEN RIVER BASIN

Numerous studies based on paleontological and geological evidence have concluded that the Eocene-age rock units in the greater Green River basin were deposited in warm temperate, subtropical, and tropical climatic conditions (Roehler, 1993). Perhaps the most reliable information concerning paleoclimates comes from analysis of plant mega- and micro-fossils. According to Leopold and MacGinitie (1972), early Eocene floras (based on palynology of samples collected from the Niland Tongue of the Wasatch Formation and the Luman and Tipton tongues of the Green River Formation) suggest a humid subtropical to warm temperate climate with summer rainfall and only mild frost and with a mean annual temperature of 55°F. Nichols (1987) concluded that the climate of the basin floor during deposition of the Niland Tongue was subtropical, without freezing temperatures.

The earliest middle Eocene climates pertaining to the Cathedral Bluffs Tongue of the Wasatch Formation and the Wilkins Peak Member of the Green River Formation were interpreted as generally hot and dry (Leopold and MacGinitie, 1972). Climatic conditions in the early–middle Eocene during deposition of the lower part of the Laney Member of the Green River Formation were characterized as warm and humid with tropical affinities. Floras of the upper part of the Laney Member indicate a change to cooler, subhumid conditions (Leopold and MacGinitie, 1972). Both pollen and leaf data from the Washakie Formation indicate a dry but temperate climate (Leopold and MacGinitie, 1972). Roehler (1993) reported in a written communication that MacGinitie reinterpreted temperature and precipitation ranges on the basis of palynology of samples collected from the Washakie basin by Roehler (1992a). His reinterpretation estimated mean annual temperatures of 65°F during the early Eocene, 63°F during the earliest middle Eocene, and 62°F during the middle Eocene. Average annual precipitation was estimated at more than 40 inches during the early Eocene, 25 to 35 inches during the earliest middle Eocene, and 15 to 20 inches in the middle Eocene. Sedimentological evidence of a more arid climate during the middle Eocene (transitional Uintan NALMA) includes massive beds of gypsum capping the Turtle Bluff Member of the Bridger Formation (Murphey, 2001; Murphey and Evanoff, 2007). The shift from dominantly tropical forest environments to more-open, savanna-like conditions in the Eocene intermontane basins during late Bridgerian (early middle Eocene) and Uintan (middle Eocene) times has also been studied by using ecological diversity analysis applied to mammalian faunas (Murphey and Townsend, 2005; Townsend, 2004).

As indicated by fossil distribution and diversity, the Green River lakes and their forested margins provided highly favorable habitats and preservational environments for both aquatic and terrestrial organisms. Lake margin habitats, riparian corridors, and adjacent floodplains were apparently vegetated during much of the time of Green River Formation deposition, as indicated by a paleoflora that includes a variety of trees and bushes such as palm, cinnamon, oak, maple, lilac, and hazel, as well as cattails and rushes. Insects of many varieties lived in the lakes and forests and are locally well preserved in lake sediments. A variety of terrestrial and aquatic mollusks (clams and snails) are also known to have inhabited the Green River lakes (Hanley, 1974). Crayfish, prawn, and ostracods inhabited the warm lake waters, as did a diversity of fish species, including relatives of the herring, perch, paddlefish, bowfin, gar, catfish, and stingray (Grande, 1984; Grande and Buchheim, 1994; McGrew and Casilliano, 1975). Frogs, crocodiles, and turtles were common residents of shallower proximal shoreline waters. A diversity of reptile species, including tortoise, lizards, and snakes, inhabited the forests surrounding Eocene lakes and ponds. Flamingos, hawks, rails, stone curlews, and other bird species frequented the forests, wetlands, and lakes (Murphey et al., 2001). The forests teemed with the primitive ancestors of many modern mammalian groups, including rodents, insectivores, bats, primates, perissodactyls (horse, rhinoceros, and tapir), and carnivores, as well as more bizarre archaic forms such as creodonts, brontotheres, and massive six-horned uintatheres (Gazin, 1976; Grande and Buchheim, 1994; Gunnell and Bartels, 1994; McGrew and Casilliano, 1975; Murphey et al., 2001).

FOSSILS AND BIOCHRONOLOGY OF THE BRIDGER FORMATION

The Bridger Formation preserves one of the world's most abundant and diverse middle Eocene vertebrate faunas, with more than 86 recognized species representing 67 genera, 30 families, and 13 orders of fossil mammals (Gazin, 1976). Bridger fossils have been the subject of numerous publications, including many classic papers by pioneers of American vertebrate paleontology (Cope 1872, 1873; Granger, 1908; Leidy, 1869, 1871, 1872a; Marsh, 1871, 1886; Matthew, 1909; Osborn, 1929). Like other highly fossiliferous formations, the Bridger contains an abundance and diversity of fossils that make it well suited for paleontological research, most of which has focused on the phylogenetics, systematic paleontology, and biostratigraphy of the vertebrate fauna (Covert et al., 1998; Evanoff et al., 1994; Gazin, 1957, 1958, 1965, 1968, 1976; Gunnell et al., 2009; Krishtalka et al., 1987; McGrew and Sullivan, 1970; Robinson et al., 2004; West and Hutchison, 1981). These fossils, which are preserved in a variety of sedimentary environments, preservational states, associations, and in locally varying abundances, include primarily vertebrates and mollusks, with less common plants and ichnofossils. Plant fossils include leaves, seeds, and wood, which is sometimes algal covered (see Murphey et al., 2001). Ichnofossils include solitary bee cases, earthworm pellets, caddis fly larvae, and fish pellets. Vertebrate fossils include fish, amphibians, reptiles (lizards, snakes, turtles, and crocodilians), a diversity of birds (see Murphey et al., 2001), and mammals. Mammalian fossils include apatotheres, artiodactyls, chiropterans, carnivores, condylarths, dermopterans, dinoceratans (uintatheres), edentates, insectivores, leptictids, marsupials, pantolestids, perissodactyls, primates, rodents, taeniodonts, and tillodonts (Gazin, 1976, Woodburne et al., 2009a,b; unpublished paleontological data, University of Colorado Museum, compiled in 2002). Despite the relative ease with which diverse and statistically significant fossil samples can be collected and the large historical collections of Bridger vertebrates available in many museums, relatively few taphonomic and paleoecologic studies of Bridger vertebrate faunas have been completed (Alexander and Burger, 2001; Brand et al., 2000; Gunnell, 1997; Gunnell and Bartels, 1994; Murphey et al., 2001; Murphey and Townsend, 2005; Townsend, 2004; Townsend et al., 2010).

Over the last twenty years, stratigraphically-documented fossil collections made by workers from the University of Colorado Museum, Denver Museum of Nature and Science, University of Michigan Museum of Paleontology, and more recently by the San Diego Natural History Museum, have added significantly to existing biostratigraphic knowledge of the Bridger Formation. These collections, together with precise provenance data, have made it possible to define formal biochronologic units for the Bridgerian NALMA, most of which are based upon stratotype sections that are located in the Bridger Formation. Gunnell et al. (2009) have divided the Bridgerian into four "biochrons." Formerly referred to as Gardnerbuttean land mammal sub-age, or Br0, biochron Br1a is the only Bridgerian biochron not found in the Bridger Formation. Its stratotype section is the *Eotitanops borealis* interval zone of the Davis Ranch section of the Wind River Formation. Biochron Br1b is equivalent to the lower Blacksforkian, and its stratotype spans the Bridger A (lower part of the Blacks Fork Member). Biochron Br2 is equivalent to the upper Blacksforkian, and its stratotype section spans the Bridger B (upper part of the Blacks Fork Member). Biochron Br3 is equivalent to the Twinbuttean, and its stratotype section spans the entire Bridger C and D (Twin Buttes Member). The uppermost member of the Bridger Formation the Turtle Bluff Member, or Bridger E, is the stratotype section for the earliest Uintan biochron, Ui1a (Gunnell et al., 2009; Walsh and Murphey, 2007). In summary, the mammalian fauna of the Bridger Formation has been used to formally define biochrons Br1b, Br2, Br3, and Ui1a.

The fossil assemblages of the Bridger Formation and other Eocene rock units in the greater Green River basin provide an unprecedented opportunity to study ancient communities and environments. Studies of these fossils and the rocks in which they are preserved are the source of much of our knowledge of the Eocene Epoch of North America. The vertebrate faunas are of particular scientific importance because they represent an exceptional record of early Tertiary mammalian evolution and diversification spanning the Wasatchian, Bridgerian, and earliest Uintan NALMAs.

BRIDGER FORMATION FIELD TRIP STOPS

The field trip route travels through the Bridger basin in an approximately stratigraphic manner. After leaving historic Fort Bridger, the staging area for many of the early fossil collecting expeditions to the Bridger Formation, the route travels east along Interstate 80 crossing through badland outcrops of the Bridger B that are stratigraphically close to the Bridger A–B boundary (Blacks Fork Member). We examine the base of the Bridger B, defined by the Lyman limestone, near Little America. Travelling back west along I-80, we then visit exposures of the Bridger B near historic Church Butte. We then continue west to Lyman and then head south along Wyoming State Highway 414 to the historic Grizzly Buttes badlands in the Bridger B. We continue south along Wyoming 414, climbing stratigraphically through the Bridger C and D (Twin Buttes Member), and examine exposures of this interval in the vicinity of Sage Creek and Hickey mountains, and at the "Lonetree Divide" (base of Bridger D). Weather permitting, we will then make our way to the southwest rim of Cedar Mountain and visit exposures of the Bridger E (Turtle Bluff Member). Finally, we will head east along Highway 414 along the south side of Cedar Mountain with excellent vistas of the Bridger C, D, and E that are overlain by the Oligocene Bishop Conglomerate. The field trip concludes after visiting exposures of the Bridger C at the base of Black Mountain.

Note that all field trip distances are provided in statute (miles), whereas stratigraphic thicknesses are provided in both statute and metric units. All distances were measured using a handheld GPS device calibrated to the NAD27 datum.

STOP 1

Fort Bridger State Historic Site parking lot
(0.0 miles, cumulative 0.0 miles)

Fort Bridger was originally established as a trading post in 1843 by trapper Jim Bridger and his guide Louis Vasquez. The U.S. Army acquired the trading post in 1857 during the Mormon War. It was located along the emigrant trail to Oregon, California and Utah, and more than twenty years after the establishment of the trading post, the route of the newly constructed Union Pacific Railroad passed not far to the north. As discussed in greater detail above, many of the early scientific expeditions to the Bridger Formation were based out of Fort Bridger. Yale University paleontologist O.C. Marsh and his field classes stayed at Fort Bridger before heading out to the Bridger badlands in 1870, 1871, and 1873. Rival paleontologist E.D. Cope stayed at the fort in 1872 during his only fossil collecting expedition to the Bridger. Joseph Leidy, often regarded as the father of North American Vertebrate Paleontology and the first paleontologist to formally describe a Bridger Formation fossil, made his only fossil collecting trip to the west in 1872, and also stayed at Fort Bridger. Today, Fort Bridger is a state historical site and has been partially reconstructed.

The low butte just to the west of Fort Bridger is Bridger Butte, which is capped with Quaternary gravels and is composed of Bridger B strata.

Turn west out of the fort parking lot along the Interstate 80 business loop and then turn east onto I-80 (towards Green River). Drive for approximately 32 miles and take the Granger Junction exit (Exit 66) heading north along US Highway 30. Follow US 30 for 1.8 miles after exiting the interstate. Then turn east and cross the cattle guard onto a dirt road for 0.2 miles at which point you will arrive at the route of old Highway 30 (unmarked gravel road that is still paved in places). Park immediately after turning right (southeast) onto old Highway 30. Outcrops of the Lyman limestone are located just to the east.

STOP 2

The Lyman Limestone at Granger Junction
(36.3 miles from Stop 1, cumulative 36.3 miles)

This stop provides a close up look at the Lyman limestone, which marks the boundary between the Bridger A and the lower Bridger B within the Blacks Fork Member (Figs. 2 and 3). Here, the Lyman limestone is a gray limestone with locally abundant shells of the gastropod *Goniobasis*. The presence of this high-spired snail is a useful diagnostic indicator for this marker unit at many localities in the Bridger basin. The Lyman limestone is widespread in its distribution. It is exposed to the west where it forms the bench that is visible to the south of I-80 upon which its namesake the town of Lyman is situated, almost as far east as the Rock Springs uplift, at least 15 miles north of Granger, and almost as far south as the town of Manila, Utah.

Stratigraphically below the Lyman limestone are strata of the Bridger A. This interval has been problematic for paleontologists because it is sparsely fossiliferous. P.O. McGrew and R. Sullivan worked on the stratigraphy and paleontology of the Bridger A in the late 1960's and published the results of their work in 1970. More recently, Gregg Gunnell and colleagues from the University of Michigan Museum of Paleontology have greatly expanded the known diversity of the Bridger A (Gunnell, 1998; Gunnell and Bartels, 2001). This has made possible the recent formalization of new biochronologic units (Gunnell et al., 2009). As discussed above in "Fossils and Biochronology," the Bridger A contains a mammalian fauna (biochron Br1b) that is biostratigraphically distinct from the fauna of the Bridger B (Br2).

OPTIONAL STOP

Approximately 18 meters (59 feet) stratigraphically above the Lyman limestone 1.7 miles to the southeast along Old Highway 30 is an unusual type of deposit for the Bridger Formation. Park approximately one third of the way up the hill and look for abundant dark brown rock fragments littering the slopes underlain by a thick green mudstone interval. The thin dark brown bed contains abundant fossil caddis-fly larval cases and other more enigmatic fossils preserved in what appear to be algal covered logs (SDSNH Loc. 5783). The taphonomy and paleoecology of this unit has yet to be adequately studied. The fossil bearing bed is overlain by a 2.8 meter (9 feet) thick sequence of green to tan, well-indurated, platy, fine-grained, silty sandstone. It is underlain by a 1.5 meter (5 feet) thick, platy, grayish-brown, non-fossiliferous, mudstone with a distinct top contact. Insect and plant fossils are sparse in the Bridger Formation, and this bed contains the most abundant insect fossils known from the formation.

Return to I-80 and head west (note that throughout this field trip guide the mileages given refer to the prior stop unless specified otherwise). Heading west along I-80, the first prominent butte you come to south of the interstate is Jagged Butte, which is capped by the Jagged Butte limestone. The second prominent butte you come to (approximate highway milepost 56.5) is Wildcat Butte, which is capped by the Sage Creek limestone (Sage Creek white layer of Matthew, 1909), and which forms the base of the Twin Buttes Member. Exit I-80 at the Church Butte exit (Exit 53) and turn north onto Church Butte Road (no sign). At 19.2 miles from Stop 2, with Church Butte just to the east of your location, turn left (southwest) onto Granger Road, Uinta County Road (CR) 233. At mile 21.0, turn southeast off of CR 233 onto a two track road heading towards the westernmost point of Jackson Ridge. Park where the two track road crosses the pipeline right-of-way at 21.2 miles from Stop 2.

STOP 3

Church Butte and Jackson Ridge
(21.2 miles from Stop 2, cumulative 57.5 miles)

Church Butte is a large-linear badland knob formed by the erosion of rocks of the middle Bridger Formation (lower Bridger B beds, Figs. 3, 5 and 6a). The butte was a landmark along the old Oregon-California-Mormon Trail, now Uinta County Road 233. Just to the west of the butte is a north-south trending rim separating Porter Hollow on the east with the valley of the Blacks Fork River on the west. The trail dropped off the rim just to the southwest of Church Butte, and the outcrops of Bridger Formation below the rim were easily accessed by early geologists and paleontologists who travelled along the trail.

Church Butte and the rim exposures are all within the middle part of the Blacks Fork Member of the Bridger Formation of Wood (1934), or the lower Bridger B of Matthew (1909). The rocks in the area are primarily interbedded brown to green mudstone sheets and brown to gray sandstone ribbons and sheets. The sequence includes two sandstone-dominated intervals and three mudstone-dominated intervals (Fig. 4). Four thin but regionally widespread marker units occur in the sequence that is 120 meters (394 feet) thick. The following descriptions are of the Bridger exposures along the west side of the rim, over an area approximately three square miles south of where the county road crosses the rim.

The two sandstone-dominated intervals are characterized by a series of thick ribbons to broadly lenticular sheet sandstone bodies within a sequence of stacked, thin, muddy sandstone and

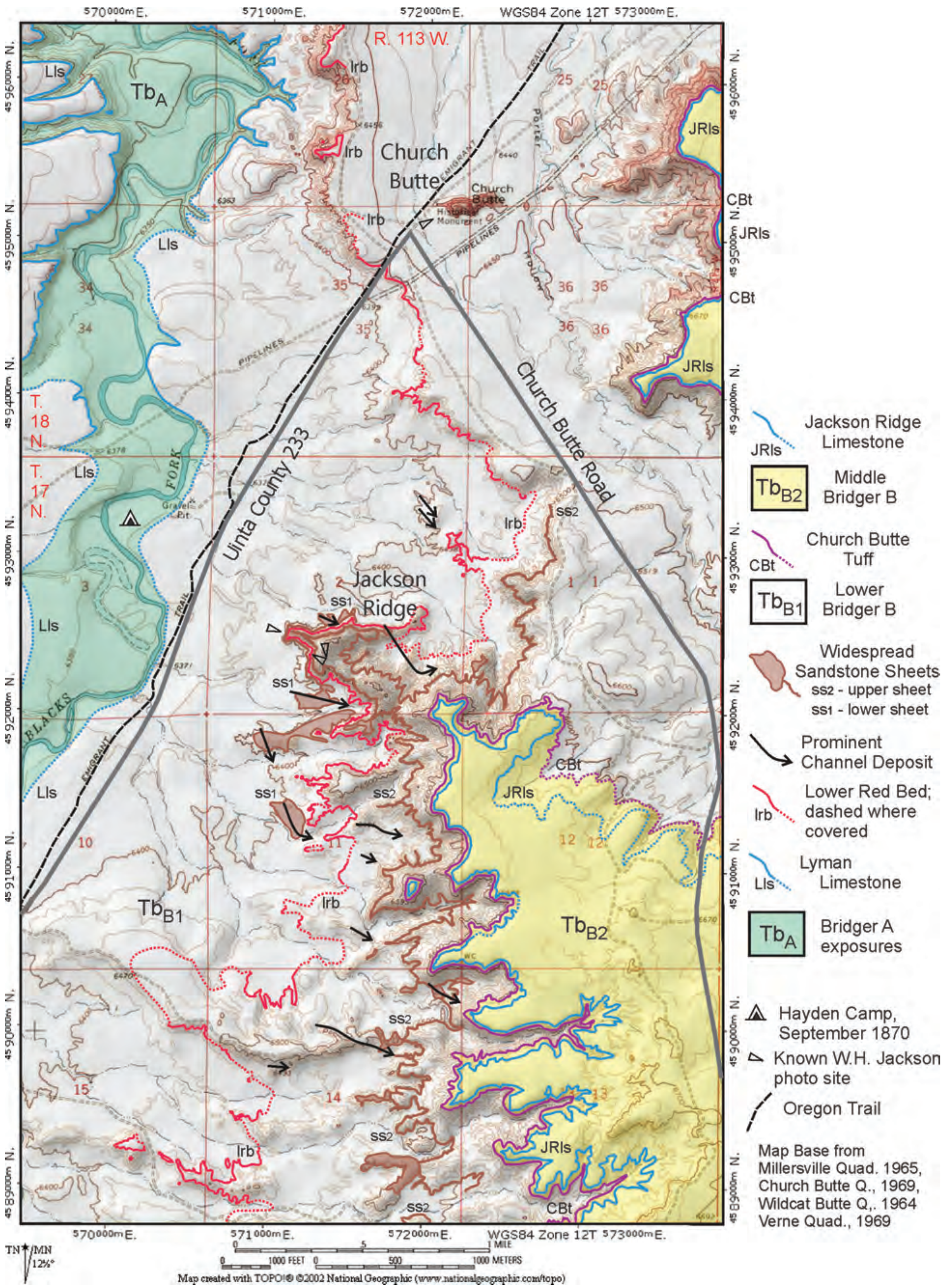

FIGURE 4. Geologic map of the Church Butte – Jackson Ridge area showing major marker beds in the lower Bridger B interval, laterally extensive sandstone sheet intervals, and trends of major sandstone channel-belt deposits. Also shown are important sites of the Hayden 1870 expedition, including known sites where W.H. Jackson took photos. See the text for details.

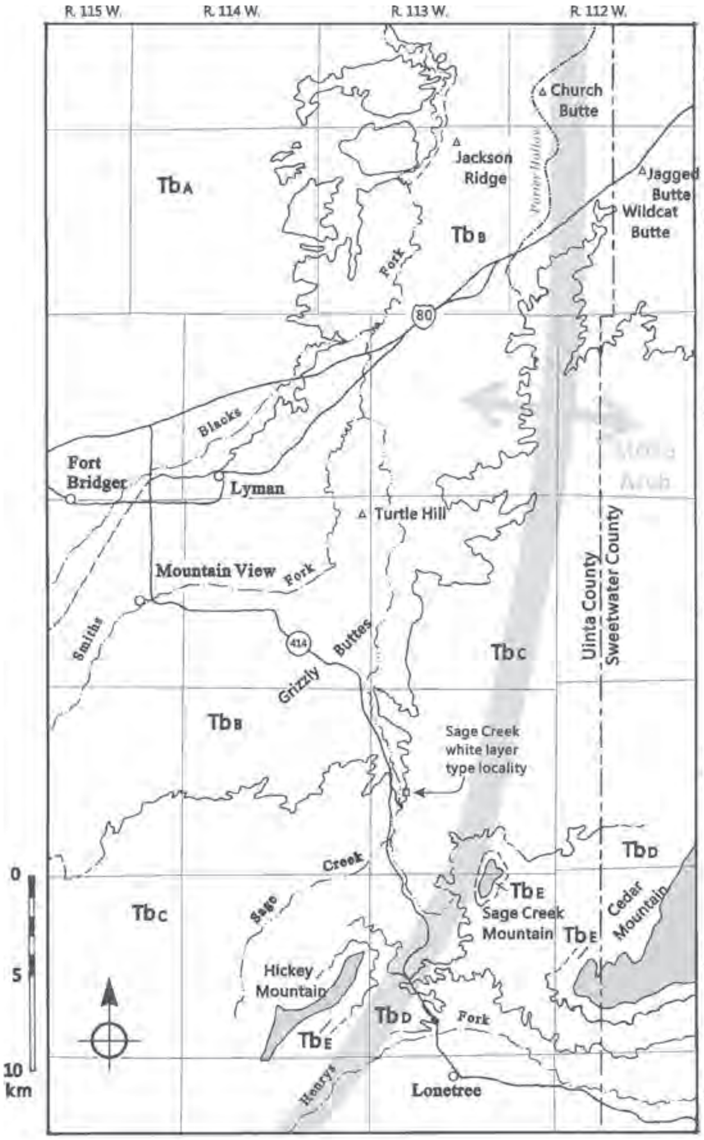

FIGURE 5. Index map of the western Bridger basin, Uinta and Sweetwater counties, Wyoming.

mudstone sheets. Sandstones can comprise 100% of the total thickness within the sandstone-dominated interval, but the lower interval averages 58% sandstone and the upper interval averages 84% sandstone within a minor amount of mudstone. The thick sandbodies within these sandstone-dominated sequences are highly connected both laterally and vertically. The thick sandbodies have a reticulate pattern, with some sandbodies oriented toward the south-southeast (vector mean of 173°) and others oriented toward the east-southeast (vector mean 118°). The sinuosities of the individual sandbodies are low (mean 1.02). These sandstone-dominated intervals represent a river system with numerous splays and local avulsions. The two intervals outcrop as cliffs in the badland exposures.

The mudstone-dominated intervals are characterized by thick ribbon sandstone bodies that are typically separated from adjacent sandstones by extensive mudstone beds. Mudstone-dominated intervals have sandstone contents that range from 10% to 35% of total interval thickness. The sandstone ribbons represent large channels carrying mostly medium sand within a mud-dominated system. The paleocurrent indicators in these ribbons (mostly medium- to thick-trough cross-bed sets) and sandbody orientations indicate an original flow toward the east-southeast (vector mean of 120°). The sinuosities of the sandstone bodies are low (mean 1.03) and their geometry is in a "broken stick" pattern with long straight reaches and short sharp bends. Sandbody widths and thicknesses are relatively small in straight reaches, but at bends the sandbodies are thicker and wider and contain well-developed lateral accretion sets. Fossil bones typically accumulate near the bases of these bends. Thin sandstone sheets representing overbank splay deposits are rare and are limited to near their source channels. The mudstone-dominated intervals outcrop as benches and slopes in the badland exposures.

The Eocene streams which deposited the lower Bridger B channel sandstones in this area were perennial and flooded every year. This is indicated by the abundance of freshwater turtles, gar-pike scales (and other fish bones), and a large freshwater snail fauna in the overbank deposits. The channel-belt deposits also contain the shells of numerous freshwater mussels (unionid clams), which indicate perennial, well-oxygenated waters in streams and rivers. Fossil plants of this time (MacGinitie and Leopold, 1972) indicate subtropical temperatures and mesic moisture with seasonal precipitation.

There are four regionally widespread marker beds in the Bridger exposures in this area. Two widespread thin limestone sheets occur at the base and top of the section in the Church Butte area. The lower limestone is the Lyman limestone at the base of the Bridger B (along the Blacks Fork), and in this area it is a brown to gray ostracodal limestone with scattered catfish bones. The upper limestone occurs on the flat-surface on top of the rim, just south of the county road. This upper limestone is a brown micrite with brown to black banded chert masses and scattered large planorbid snail shells (*Biomphalaria* sp.). Both limestone beds can be mapped over much of the Bridger basin in lower Bridger B exposures. The predominantly fluvial sequence preserved in the Church Butte area was bracketed by these widespread lacustrine deposits.

Two lithified volcanic ashes (tuffs) occur in the section. The lower tuff is represented by a red clayey mudstone that ranges from 0.2 to 0.6 meters (0.6 to 2 feet) thick, 33 meters (108 feet) above the Lyman limestone. The bed does not contain euhedral crystals in this area, but in other parts of the Bridger basin this bed thickens and is white with euhedral biotite crystals. This bed has not been radiometrically dated. This red tuff has been mapped over much of the western Bridger basin. A second tuff bed occurs between 10.1 and 11.7 meters (33 and 39 feet) below the upper limestone and ranges in thickness from 0.5 to 0.7 meters (1.6 and 2.3 feet) thick. It is a tan to olive clayey mudstone bed that weathers gray and contains abundant euhedral crystals of biotite and hornblende. Sanidine in this tuff has produced a 40Ar/39Ar age of 48.27 Ma (Murphey et al., 1999, given as 47.96±0.13 Ma) recalculated using the current 28.201 Ma sanidine standard for the Fish Canyon Tuff (Renne et al., 1998). This upper tuff is called the Church Butte tuff, with the type locality located at the north side of the point on the east end of the long ridge called Jackson Ridge (UTM coordinates of Zone 12T, 572123mE, 4592105mN, WGS 84). The Church Butte tuff occurs throughout the Bridger basin wherever lower Bridger B rocks are exposed.

Many of the first fossils collected from the Bridger Formation came from the Church Butte area. The first geologist known to have collected fossils from the area was Ferdinand V. Hayden. In 1868 he collected fragments of a fossil turtle that were later described as *Trionyx guttatus* by Leidy (1869). Hayden returned to the area as part of the Geological and Geographical Survey of the Territories of 1870. The survey camped just to the west of the area along the Blacks Fork River and collected fossils in the Church Butte area on September 10 and 11 of 1870 (Hayden,

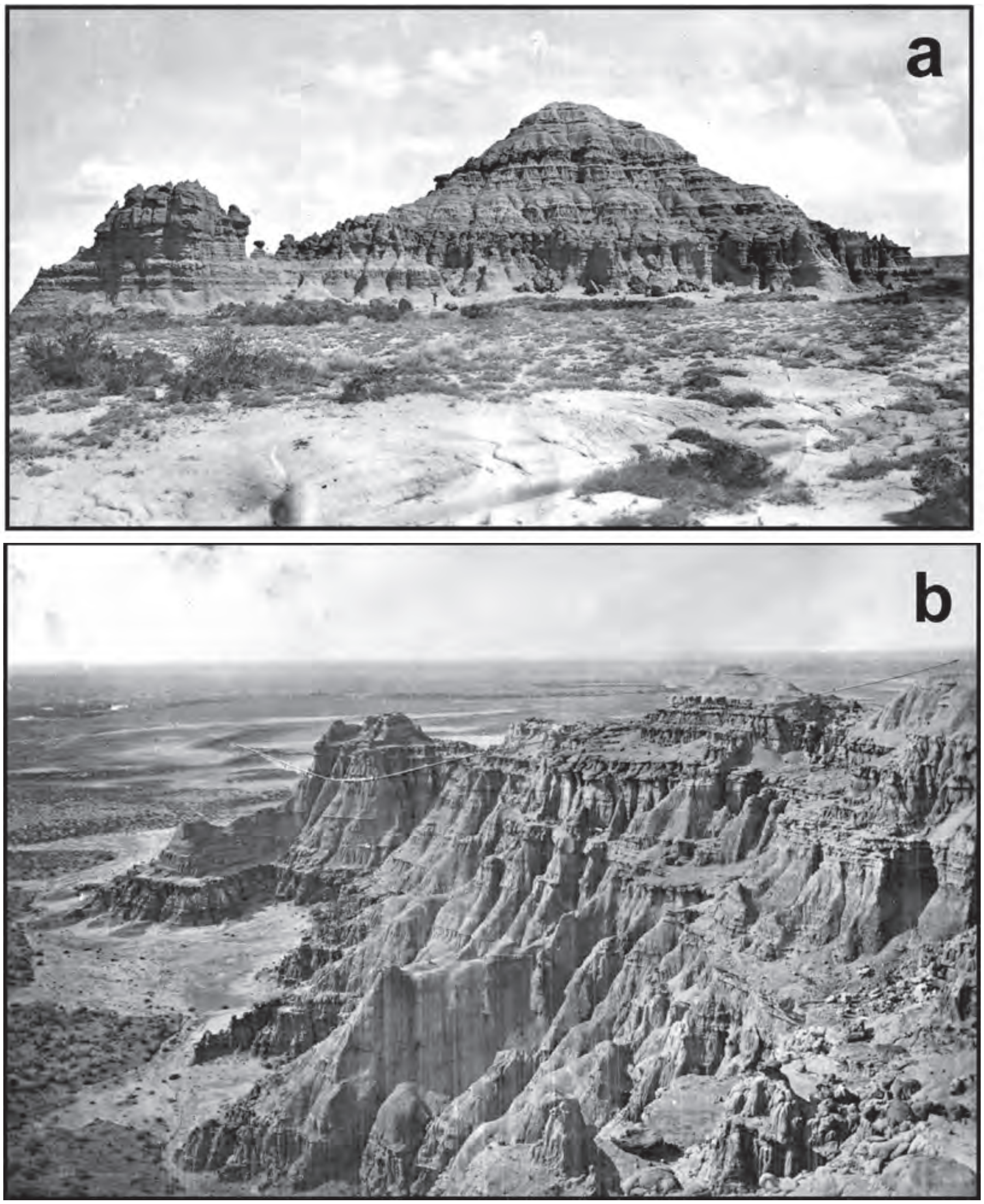

FIGURE 6. **A**, William H. Jackson photo of Church Butte taken on September 10 or 11, 1870. The view is to the east northeast. The UTM location of the photo site is Zone 12T, 571955mE, 4595101mN, WGS84 datum (USGS photo jwh00462);**B**, William H. Jackson photo of the west end of Jackson Ridge, taken mid-day either on September 10 or 11, 1870. The view is toward the northwest, and includes the Hayden Survey campsite along the Blacks Fork River. Notice the crack that was in the original glass-plate negative. The UTM location of the photo site is Zone 12T, 571318mE, 4592360mN, WGS84 datum (USGS photo jwh00309).

1872, p. 41). The 1870 survey was the first time the pioneer photographer W.H. Jackson accompanied Hayden. Years later, Jackson recalled these two days:

> "Twelve miles farther on we came to Church Buttes, a remarkable formation in the Bad Lands and a famous landmark along the old trail. While Gifford [an artist of the 1870 expedition who assisted Jackson] and I were making pictures of the interesting scenes, the geologists under the lead of Dr. Hayden were digging for fossils. They collected a wagon load of ancient turtles, shell fish, and other creatures... For my part, I made seventeen negatives during the day, something of a record for wet plate work, considering the many changes of location I had to make in getting the different views" (Jackson and Driggs, 1929, p. 89,91).

The best known of Jackson's photos from the area (Fig. 6b) was taken near the end of a long badlands ridge that is herein named Jackson Ridge in honor of the photographer. The upper limestone bed marker in the area is named the Jackson Ridge limestone.

TABLE 1. Type Species of Fossils from the Church Butte - Blacks Fork area. Data compiled from Leidy, 1872a; Meek, 1872; Henderson, 1935; and Gazin, 1976

MAMMALS		
	Marsupialia	
		Peratherium innominatus (Simpson) 1928
	Pantolesta	
		Pantolestes longicaudus Cope 1872
	Primates	
		Notharctus tenebrosus Leidy 1870
	Tillodontia	
		Tillodon fodiens (Marsh) 1875
	Rodentia	
		Microparamys minutus (R.W. Wilson) 1937
		Sciuravus bridgeri R.W. Wilson 1937
	Carnivora	
		Miacis parvivorus Cope 1872
	Hyaenodontida	
		Sinopa major Wortman, 1902
	Condylarthra	
		Hyopsodus paulus Leidy 1872
	Perissodactyla	
		Orohippus major Marsh 1874
		Palaeosyops paludosus Leidy 1870
	Cetartiodactyla	
		Microsus cuspidatus Leidy 1870
TURTLE		
	Trionychidae	
		"Aspideretes" guttatus Leidy 1869
MOLLUSKS		
	Bivalvia, Unionidae	
		"Unio" leanus Meek 1870
	Gastropoda, Pulmonata	
		Physa bridgerensis Meek 1872
		"Viviparus" wyominensis Meek 1871

Jackson's photos of the area document the type area of such fossil mammals as *Notharctus tenebrosus*, *Palaeosyops paludosus, Hyrachyus agrestis*, and *Microsus cuspidatus*, all described by Leidy (1870, 1872b) and illustrated in 1873. The mollusk type specimens collected at Church Butte by the Hayden survey include *Physa bridgerensis, "Viviparus" wyomingensis* (a land snail that is similar in form to the aquatic *Viviparus*), and *"Unio" leanus* described by Meek (1870, 1871, 1872). Seven other species of fossil mammals have their type area in or near the Church Butte area, and these were collected by such paleontologists as E.D. Cope, O.C. Marsh, and J. Wortman. Type species of fossil mammals collected from the Church Butte area are listed in Table 1.

Drive back onto CR 233, and turn left (southwest) towards Lyman. Turn left at mile 5.5 onto CR 237 which then crosses the Blacks Fork River, winding south to I-80. Turn westbound (towards Evanston) onto I-80 at mile 7.4. Pass the Lyman exit and drive to the Mountain View-Fort Bridger (Exit 39, 15.5 miles from Stop 3). Turn south onto Wyoming State Highway (SH) 414, crossing the Blacks Fork River and climbing up onto the Lyman limestone at the top of the hill. Continue through Urie and Mountain View, where the highway will bend to the east near the center of town. Refer to Figure 7 for a map that shows the major geographic features of the remainder of the field trip route. As you drive east from the center of Mountain View along Highway 414, the badlands to the south that are visible beginning at SH 414 milepost 105 were known to the early residents and explorers as "Grizzly Buttes" (lower and middle Bridger B). The north end of the badlands to the northeast constitute the type area of the Blacks Fork Member. Continue southeast on Highway 414 and the highway rises onto the Cottonwood Bench. Immediately after reaching the top of this bench, at 29.7 miles from Stop 3, turn east and then immediately north. At 0.2 miles from the turn off, do not turn east on Burnt Fork Road (BLM 4315) and instead continue traveling north. At mile 30.4 mile from Stop 3, turn west onto the two track road and follow it for 0.6 miles to the Grizzly Buttes overlook.

STOP 4

Grizzly Buttes
(31.0 miles from Stop 3, cumulative 88.5 miles)

Heading southeast from Mountain View, Wyoming State Highway 414 rises through a panel of badland exposures and climbs onto a high flat, called the Cottonwood Bench. The bench is capped by gravels derived from the Bishop Conglomerate and transported to the area by Cottonwood and Sage Creeks. Below the gravel-flat is a series of badlands cut by Leavitt Creek, Little Dry Creek and their tributaries. The badland hills directly west of the overlook comprise the traditional "Grizzly Buttes" of the early explorers, but the name is not known to the modern popu-

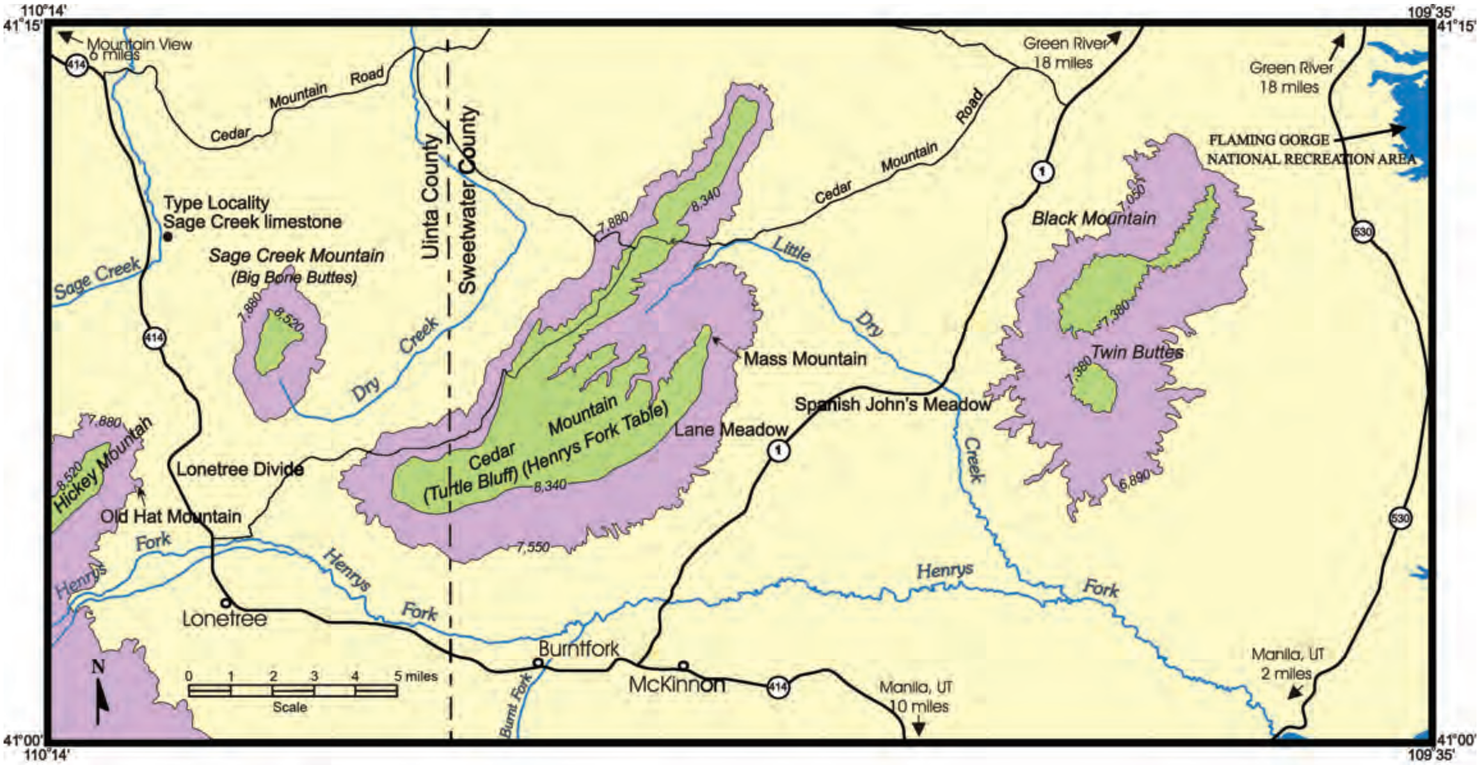

FIGURE 7. Map of a part of the southern Green River basin encompassing most of the area of outcrop of the upper Bridger Formation. Map shows both modern and historic geographic terminology (from Murphey and Evanoff, 2007).

TABLE 2. Type Species of Fossil Mammals from Grizzly Buttes. Data compiled from Gazin, 1976.

Lipotyphla
- *Entomolestes grangeri* Matthew 1909
- *Nyctitherium serotinum* (Marsh) 1872
- *Nyctitherium dasypelix* (Matthew) 1909

Plesiadapiformes
- *Mycrosyops elegans* (Marsh) 1871

Primates
- *Smilodectes gracilis* (Marsh) 1871

Tillodontia
- *Trogosus castoridens* Leidy 1871

Pholidota
- *Metacheiromys marshi* Wortman 1903
- *Metacheiromys tatusia* Osborn 1904
- *Metacheiromys dasypus* Osborn 1904

Rodentia
- *Thisbemys plicatus* A.E. Wood 1962
- *Leptotomus parvus* A.E. Wood 1959
- *Reithroparamys delicatissimus* (Leidy) 1871
- *Pseudotomus robustus* (Marsh) 1872
- *Ischyrotomus horribilis* A.E. Wood 1962
- *Mysops minimus* Leidy 1871
- *Mysops parvus* (Marsh) 1872
- *Sciuravus nitidus* Marsh 1871
- *Tillomys? parvidens* (Marsh) 1872

Hyaenodontida
- *Sinopa rapax* Leidy 1871
- *Sinopa minor* Wortman 1902
- *Tritemnodon agilis* (Marsh) 1872
- *Limnocyon verus* Marsh 1872

Carnivora
- *Thinocyon velox* Marsh 1872
- *Viverravus gracilis* Marsh 1872
- *Oödectes proximus* Mattehw 1909
- *Vulpavus profectus* Matthew 1909

Perissodactyla
- *Palaeosyops major* Leidy 1871
- *Limnohyops priscus* Osborn 1908
- *Helaletes nanus* (Marsh) 1871

Cetartiodactyla
- *Helohyus plicodon* Marsh 1872

lation of the Smith's Fork valley (see history of paleontological investigations). Matthew (1909, p.297) stated about the buttes: "This is the richest collecting ground in the basin; thousands of specimens have been taken from it, and many skulls and skeletons more or less complete." Type species of fossil mammals collected from the Grizzly Buttes area are listed in Table 2.

The lower half of the Bridger B is exposed in the Grizzly Buttes and along the Cottonwood Bench escarpment. Not far below the Quaternary gravels at this overlook is a widespread limestone that was named by Matthew (1909) the Cottonwood white layer (now known as the Cottonwood limestone). It is a white micritic limestone that is very widespread but is locally absent in the Church Butte area. The Cottonwood limestone is typically 5 meters (16 feet) above the Church Butte tuff, but in this area it is 10.4 meters (34 feet) above the tuff. The thickness of intervals between the widespread marker beds increases from the Church Butte area toward the southwest. The Jackson Ridge limestone has been eroded by Cottonwood Creek on the bench, but in this area it is typically 6 meters (20 feet) above the Cottonwood White Layer. The Church Butte tuff is a prominent gray band about half way down the escarpment. Notice that channel sandstones are not as abundant in the lower Bridger B rocks below you as they are in the Church Butte area.

To the east is a prominent escarpment rising far above the Cottonwood Bench. This escarpment is capped by the Sage Creek White Layer, the boundary between the Blacks Fork and Twin Buttes members of the Bridger Formation (the boundary between Matthew's Bridger B and C). Almost all the upper half of the Bridger B is exposed in the west face of the escarpment.

Return to Wyoming State Highway 414 and travel north for 5.7 miles. Then turn east and drive for 0.2 miles and park on the north side of the road. A short walk to the northeast will lead you to Sage Creek Limestone and the type locality of the Sage Creek white layer.

FIGURE 8. Photograph of the Sage Creek white layer taken by W.H. Sinclair in 1906 (Sinclair, 1906, Plate 38). Note the unit numbers penned in near the left edge of the photo.

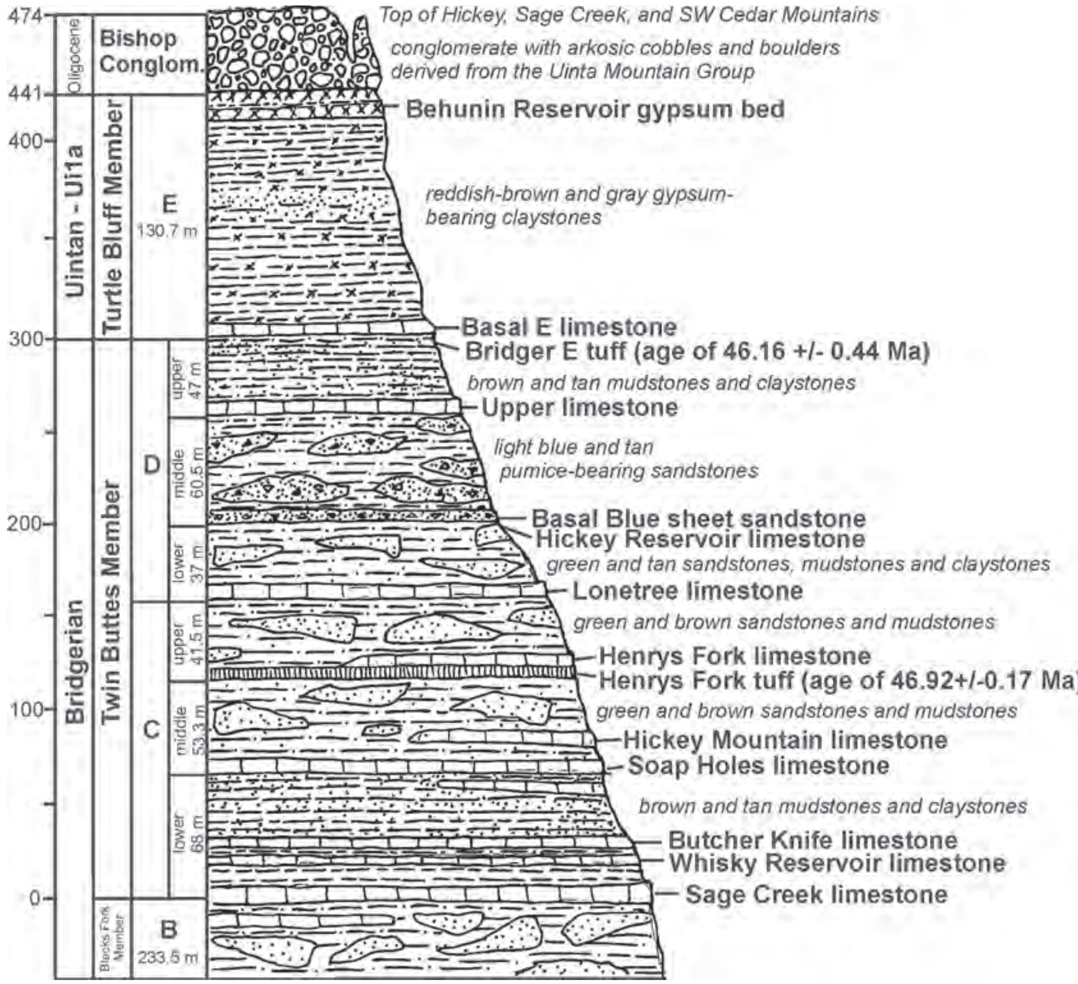

FIGURE 9. Generalized stratigraphic section of the upper Bridger Formation in the Sage Creek Mountain area, Uinta County, Wyoming. The diagram shows widespread and more localized markers, as well as informal submembers of Matthew (1909). Thicknesses taken from the reference section of the Twin Buttes Member and the type section of the Turtle Bluff Member (from Murphey and Evanoff, 2007).

STOP 5

Sage Creek white layer type locality
(5.9 miles from Stop 4, cumulative 94.4 miles)

This outcrop of the Sage Creek white layer is located next to site of the old Sage Creek stage station and Sage Creek Spring along the old Lonetree stage road. It was first described and photographed by Sinclair in 1906 (Fig. 8), and then named and mapped by Matthew (1909). The Sage Creek white layer is the base of Matthew's Bridger C, the base of the Twin Buttes Member, and the base of the upper Bridger Formation as presently defined. Since Matthew's (1909) work, this unit has been renamed the Sage Creek limestone, and is the base of the lower Bridger C of Evanoff et al. (1998), Murphey (2001), and Murphey and Evanoff (2007). The general stratigraphy of the upper Bridger Formation in the Sage Creek Mountain area is illustrated in Figure 9.

At its type locality, the Sage Creek limestone is 4.1 meters (13.5 feet) thick. It consists of a lower massive tan micritic limestone, a middle shaly limestone with dark gray to black chert bands, and an upper platy to shaly limestone. Elsewhere, it includes massive to blocky marly and micritic limestone, ledgy marlstone, and platy calcareous shale, and is locally interbedded with green to brown mudstone and claystone and thin carbonaceous shale. Fossils of this unit consist of scattered gastropods, bone fragments (mostly fish), and turtle shell fragments, and the limestone within it is locally stromatolitic. The Sage Creek limestone supports a very widespread bench, and it is the thickest and most widespread lacustrine deposit in the upper Bridger Formation.

Stratigraphically overlying the Sage Creek limestone within the lower Bridger C are two other limestone beds that are much thinner but are also widespread, the Whisky Reservoir limestone and the Butcher Knife limestone (see Fig. 9). The lower Bridger C is the least fossiliferous subunit of the upper Bridger Formation (Twin Buttes and Turtle Bluff members), despite the fact that it is by far the most geographically widespread.

Continue south along Highway 414 for 3.2 miles. Travelling south, the highway route travels up section through the lower Bridger C and into the middle Bridger C. Sage Creek Mountain is the highest point on the west side of the highway and Hickey Mountain is the highest point on the east side of the highway. Both of these mountains are capped by the Oligocene Bishop Conglomerate. At 3.2 miles from Stop 5, pull into the Henry #1 gas well pad on the east side of the road.

STOP 6

Soap Holes and Hickey Mountain and limestones (3.2 miles from Stop 5, cumulative 97.6 miles)

The Soap Holes limestone, the lower of the two thin rusty brown limestone beds visible at this cliffy exposure, is a widespread marker unit that forms the base of the middle Bridger C (Evanoff et al., 1998; Murphey, 2001; Murphey and Evanoff, 2007). It is believed that Matthew (1909) considered this bed to be equivalent to his Burnt Fork limestone, which is a lithologically similar unit that is exposed to the southeast in the Henrys Fork Valley but is actually not present in the section in this part of the basin. In the Henrys Fork Valley, however, it is in fact is 33 meters (108 feet) higher than the Soap Holes limestone. The Soap Holes limestone contains few fossils, but it is noteworthy that it is stratigraphically closely associated with fossil logs at several localities. Fossils of the Soap Holes limestone include isolated, disarticulated and poorly preserved bones of fish, reptiles (especially turtles), and mammals within and on top of the unit. In the Black Mountain area it is locally underlain by thin carbonaceous shale beds which preserve plant fragments. The Sage Creek and Soap Holes limestones have yielded the fewest vertebrate fossils of any upper Bridger lacustrine deposits.

Situated within the middle Bridger C 10.5 meters (34 feet) above the base of the Soap Holes limestone (in the upper Bridger Formation reference section, Murphey and Evanoff, 2007), the Hickey Mountain limestone is a well studied and very important unit paleontologically. It has a relatively limited areal distribution, occurring over a distance of approximately 5.6 miles north of Hickey Mountain and west of Sage Creek Mountain, and is the upper limestone bed exposed on the cliff at this stop. This unit provides an excellent example of one of the most paleontologically prolific depositional settings in the upper Bridger Formation.

The early fossil collectors were the first to notice the close association between vertebrate fossils and the “white layers,” which are typically limestone and marlstone beds that were deposited in shallow lakes and ponds. More recently, paleontologists observed that it is not the marlstone beds that contain the majority of vertebrate fossils, but the immediately overlying and underlying mudstone beds. These mudstones, which are occasionally carbonaceous, are inferred to have been deposited along lake margins during lake transgressions and regressions (Murphey, 1995; Murphey et al., 2001). Typically, the limestone and marlstone beds contain the remains of mostly aquatic organisms such as snails, clams, fish, amphibians, pond turtles, and crocodilians. The lake margin mudstones contain a mixed aquatic and terrestrial assemblage, and the terrestrial elements include locally abundant reptiles such as lizards, as well as bird bones and mammal bones and teeth. One particularly prolific fossil locality, the *Omomys* Quarry, is located approximately ½ mile west of this stop in the Hickey Mountain limestone and overlying mudstone. This unusual fossil accumulation has produced over 2,300 specimens of vertebrates, gastropods, and plants from an 8–10 centimeter thick deposit in a 4 square meter area (Murphey et al., 2001). What makes the assemblage so unusual is that it contains a high concentration of dental and post-cranial remains of the primate *Omomys*, avian skeletal remains, and eggshell fragments. The unusual components of the fauna are superimposed on a more typical Bridger fauna that occurs at the quarry and lateral to it in the same stratigraphic interval. Four taphonomic agents have been postulated for the formation of the *Omomys* Quarry fossil accumulation: 1) an attritional accumulation of aquatic taxa in lacustrine sediments; 2) an attritional accumulation of both aquatic and terrestrial taxa in shoreline sediments;

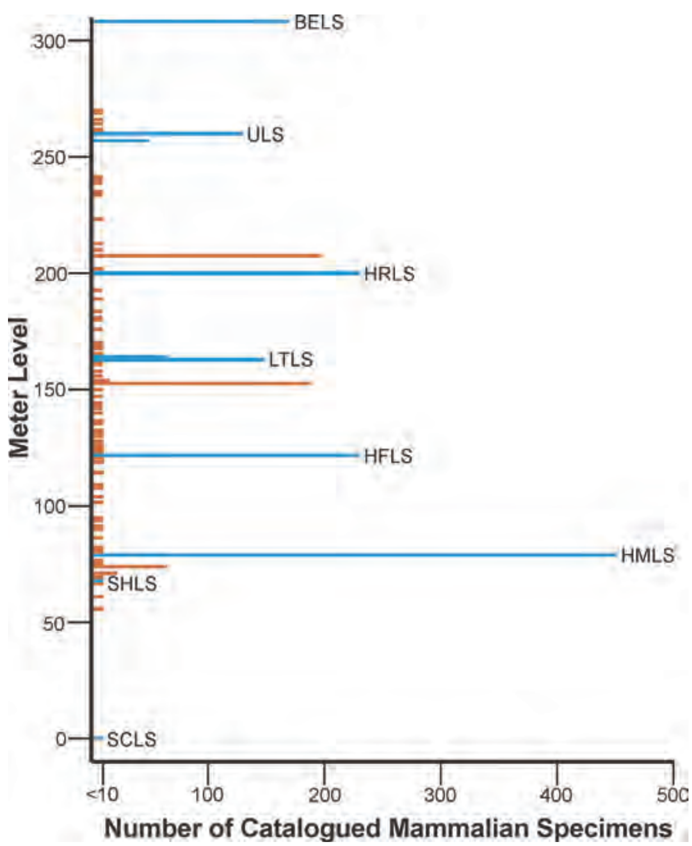

FIGURE 10. Stratigraphic distribution of catalogued mammalian specimens from the upper Bridger Formation (University of Colorado Museum collections) (SCLS, Sage Creek limestone; SHLS, Soap Holes limestone; HMLS, Hickey Mountain limestone; HFLS, Henrys Fork limestone; LTLS, Lonetree limestone; HRLS, Hickey Reservoir limestone; ULS = Upper White limestone; BELS, Basal Bridger E limestone).

TABLE 3. Fauna and flora of the Omomys Quarry with number of identifiable specimens for vertebrates shown in right column. Eggshell is not included. From Murphey et al., 2001

TAXA	NISP
PLANTAE	
Division Chlorophyta	
Chara sp.	
Division Tracheophyta	
Dennstaedtiopsis aerenchymata (fern)	
2 types of dicotyledenous wood	
ANIMALIA	
Phylum Mollusca	
Class Gastropoda	
Order Lymnophila (freshwater pulmonates)	
Biomphalaria sp.	
Omalodiscus sp.	
Stagnicola? spp.	
Physa spp.	
Order Geophilia (land pulmonates)	
Gastrocopta spp.	
Oreoconus? sp.	
Phylum Chordata	
Coprolites	4
Class Osteichthyes	
Osteichthyes undet.	200
Order Amiiformes	
Amia sp.	8
Order Lepisosteiformes	
Lepisosteus sp.	98
Order Siluriformes	14
Class Amphibia	
Amphibia undet.	4
Order Anura	
Anura undet.	4
Class Reptilia	
Order Chelonia	
Chelonia undet.	5
Trionychidae undet.	1
Echmatemys sp.	1
Palaeotheca sp.	2
Order Squamata	
Lacertilia undet.	117
Iguanidae undet.	3
Tinosaurus sp.	1
Saniwa sp.	1
Serpentes undet.	2
Order Crocodilia	
Allognathosuchus sp.	34
Crocodilia undet.	4
Class Aves	
Order Ciconiiformes	
Juncitarsus gracillimus	4
ANIMALIA, Chordata, Aves	
Order Falconiformes	
Accipitridae (2 species)	7
Order Charadriiformes	
Burhinidae	5
Order Gruiformes	
Rallidae	5
Geranoididae	8
Total Aves	
includes undet. specimens not listed above	(191)
Class Mammalia	
Mammalia undet.	150
Order Marsupialia	
Peratherium sp.	13
Peradectes sp.	1
Order Rodentia	
Rodentia undet.	13
Paramys sp.	1
Thisbemys sp.	1
Microparamys sp.	1
Ischyromyidae undet.	1
Sciuravus sp.	9
Pauromys sp.	2
Sciuravidae undet.	6
Order Apatemyida	
Apatemys sp.	1
Order Lipotyphla	
Lipotyphlan undet.	28
Scenopagus sp.	2
Entomolestes sp.	7
Centetodon sp.	6
Apternodontidae undet.	1
Nyctitherium sp.	4
Order Plesiadapiformes	
Uintasorex sp.	1
Order Primates	
Notharctus sp.	2
Omomys sp. nov.	214
Order Condylarthra	
Hyopsodus sp.	22
Order Cetartiodactyla	
Cetartiodactyla undet.	1
Homacodon sp.	1
Order Perissodactyla	
Hyrachyus sp.	1
TOTAL	**1,183**

3) an attritional accumulation consisting primarily of bird bones and eggshell formed in close proximity to a nesting area; and 4) a predator accumulation dominated by *Omomys* but probably including other vertebrates formed by owls in close proximity to a nest, day roost or night feeding station. The fauna and flora of the Omomys Quarry is listed in Table 3.

The same pattern of fossil distribution observed in the Hickey Mountain limestone occurs throughout the upper Bridger Formation (see Fig. 10). Most fossils are found in association with lacustrine deposits, although stream channels are also productive. Least productive are the volcaniclastic mudstone and claystone beds that were deposited on low relief floodplains; together with stream channel deposits, they comprise 95% of the total thickness of the upper Bridger. Examples of the floodplain deposits, here consisting of green and gray mudstone and claystone beds, are well exposed at this stop above and below the Soap Holes and Hickey Mountain limestones. Both the Soap Holes and Hickey Mountain limestones are better exposed, with some minor faulting, on the east side of the highway just to the north of this location.

Continue south on Highway 414 for 1.1 miles and turn east onto the gas well road. Follow this road to the east and it will bend to the north for a total distance of 1.6 miles from Stop 6. Park on the north side of the Henry #10 well pad. The Henrys Fork limestone (type locality of this unit) and the underlying Henrys Fork tuff are exposed above the well pad on the badland hill just to your north. Look for the gray weathered bed near the top of the badland slope and an overlying thin light gray marlstone. Bring a shovel to examine the tuff.

STOP 7

Type locality of the Henrys Fork Limestone
(1.6 miles from Stop 6, cumulative 99.2 miles)

The Henrys Fork limestone (and associated shore margin deposits) is another highly fossiliferous unit and has produced hundreds of fossil mollusks and vertebrates across its distribution. It is quite widespread, covering an area of approximately 402 kilometers^2 (250 miles^2), and was deposited in an elongate east-west trending basin which formed in the downwarp along the Uinta Mountain front. At this location, which is near the western edge of ancient Henrys Fork Lake, the deposit is only 3 centimeters (1.2 inches) thick, but it attains a maximum thickness of 1.65 meters (5.4 feet) on the south side of Cedar Mountain near the center of its depositional basin. It is of taphonomic interest that the upper Bridger Formation with its abundant vertebrate fossils preserved in lacustrine and associated shore margin deposits contains few articulated skeletons or even partially articulated vertebrate remains, most of which have been collected in the Bridger B (see Alexander and Burger, 2001).

Immediately underlying the Henrys Fork limestone is the Henrys Fork tuff, a unit that was first discovered by Emmett Evanoff while conducting field work in the Sage Creek Mountain area in 1991. This ash fall tuff is the most analyzed tuff in the Bridger Formation, and it is beyond the scope of this paper to report the various ages that have been published. However, Murphey et al. (1999) and Murphey and Evanoff (2007) reported a 40Ar/39Ar age of 46.92±0.17 Ma based on single crystal laser fusion analysis of sanidine, plagioclase, and biotite. Recalculated using the current 28.201 Ma sanidine standard for the Fish Canyon Tuff (Renne et al., 1998), the age of the Henrys Fork tuff is 47.22 Ma. Ash fall tuff deposits comprise less than 1% of the total thickness of the upper Bridger Formation, and based on their mineralogy, are believed not to have originated in the Absaroka volcanic field to the north like other volcaniclastic Bridger Formation sediments, but rather in the Challis volcanic field located in central Idaho. At its type locality on the south side of Cedar Mountain, the tuff is 0.95 meters (3.1 feet) thick (Murphey and Evanoff, 2007). The tuff is a blocky, non-calcareous, gray to white biotitic claystone with a distinct bottom contact and a diffuse top contact. It contains biotite, zircon, allanite, and apatite crystals. Plagioclase is the most abundant feldspar. It typically consists of a structureless lower unweathered portion with coarse euhedral biotite (up to 1.3 mm in diameter) which grades upward into a reworked portion with less coarse and less abundant biotite.

The base of the Henrys Fork tuff forms the base of the upper Bridger C, and is 121 meters (397 feet) above the base of the Sage Creek limestone in upper Bridger Formation reference section (Murphey and Evanoff, 2007). Weathered badland exposures of the Henrys Fork tuff form a distinctive dark gray weathering bed that is readily discernable from other Bridger lithologies, especially when wet.

Return to Highway 414 and drive south for 3.0 miles (note the exposures of Henrys Fork tuff which is visible as a subtle gray bed on both sides of the highway just above road level after turning back onto the highway). Then turn west onto the access road for Conoco Fed # 20-2 gas well pad. Proceed to the well pad and park (3.2 miles from Stop 7). The route you just drove continued up section through the upper Bridger C to the level of the Lonetree limestone (base of lower Bridger D) which is at the approximate level of the highway at the Lonetree Divide. This is the stratigraphically highest point that Highway 414 attains in the Bridger Formation.

STOP 8

The Lonetree Divide
(3.2 miles from Stop 7, cumulative 102.4 miles)

This area provides some excellent vistas of the upper Bridger Formation and its marker units, especially from the top of the ridge just to your north. The base of the lower Bridger D, the Lonetree limestone (Lonetree white layer of Matthew, 1909), is well exposed at the base of the badland slopes at road level. The base of the middle Bridger D, the Basal blue sheet sandstone, is exposed on the slopes of the prominent conical butte to your west as well as on parts of the ridges to your north and south. The prominent butte, called “Old Hat Mountain” by the locals,

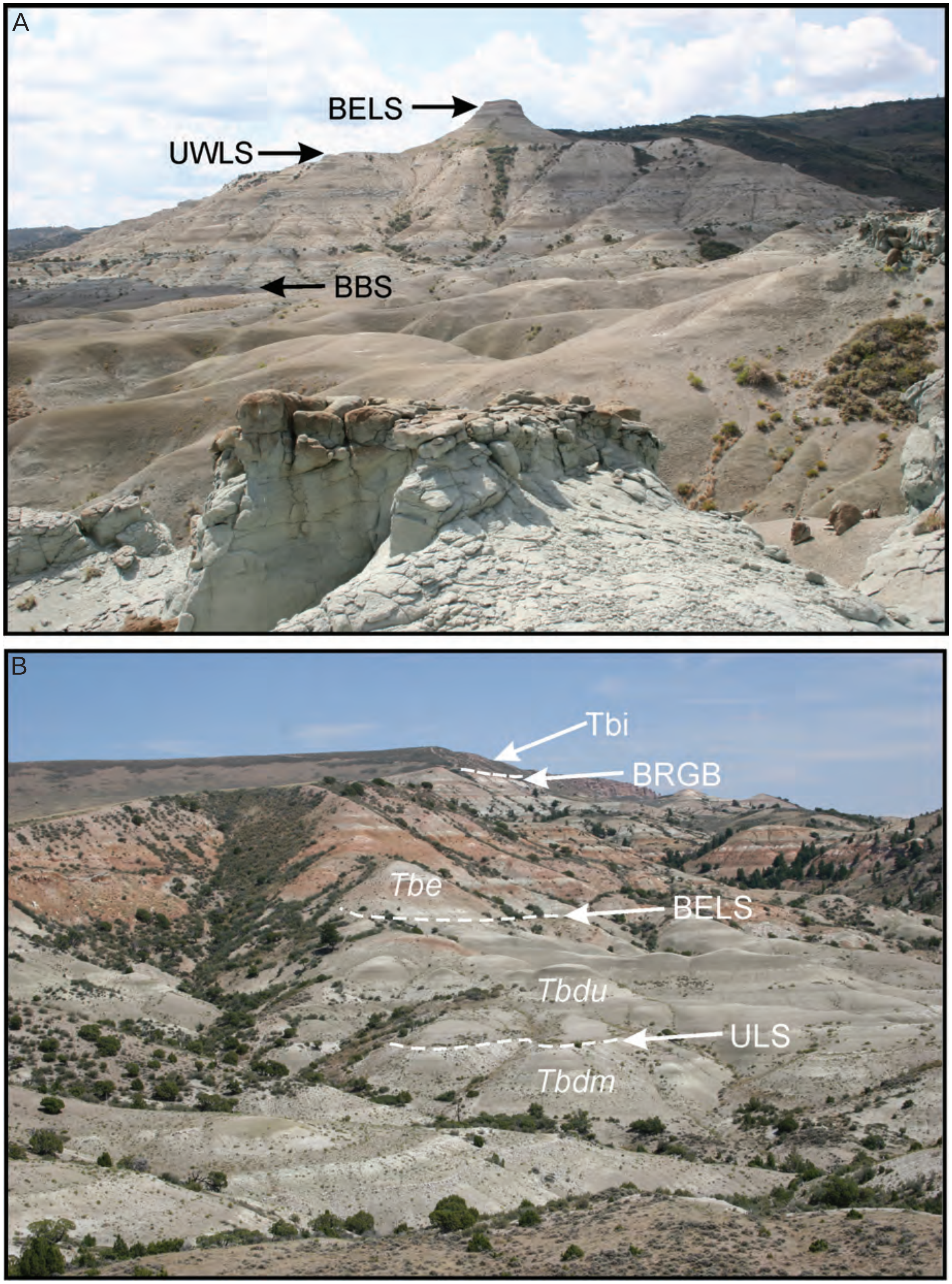

FIGURE 11. **A**, View of the Bridger D and E on "Old Hat Mountain," a prominent butte on the southeast flank of Hickey Mountain, Uinta County, Wyoming. Photo taken looking southwest (BBS, Basal blue sheet sandstone; ULS, Upper White limestone; BELS, Basal Bridger E limestone); **B**, View of the Bridger D and Bridger E on the southwest flank of Cedar Mountain, Uinta County, Wyoming. Photo taken looking east (ULS, Upper White limestone; BELS, Basal Bridger E limestone; BRGB, Behunin Reservoir Gypsum bed; Tbdm, middle Bridger D; Tbdu, upper Bridger D, Tbe, Bridger E; Tbi, Bishop Conglomerate.

is an erosional remnant of Hickey Mountain (Fig. 11a) to which it is still attached. The 'rim of the hat' is the Upper White limestone (Upper white layer of Matthew, 1909). The butte is capped by a thin interval of red mudstone of the Turtle Bluff Member (Bridger E of Matthew, 1909). To your northeast is Sage Creek Mountain, with a thick sequence of Bridger E (red beds overlying gray beds of Bridger D) visible near its summit. The Basal Bridger E tuff (40Ar/39Ar age of 46.16±0.44 Ma, Murphey and Evanoff, 2007) occurs just below the base of the Bridger E on Sage Creek Mountain. O.C. Marsh called Sage Creek Mountain "Big Bone Butte" because of the abundance of uintathere bones found in the area. Visible to your east is Cedar Mountain, with the thickest and best exposed sequence of Turtle Bluff Member. All three of the mountains in this area (Hickey, Sage Creek, and Cedar) are capped by Oligocene Bishop Conglomerate.

Numerous fossil localities have been documented in the Lonetree Divide area. These include the classic Lonetree localities of Matthew (AMNH expeditions of 1903–1906) and Gazin (USNM expeditions between 1941 and 1969. This area was also worked by Robert M. West of the Milwaukee Public Museum during the 1970's, and by crews from the University of Colorado Museum during the 1990's. Channel sandstones in this area indicate paleocurrent directions to the southeast.

Turn south on Highway 414 for 1.9 miles and turn east onto Cedar Mountain Rim road (BLM Road # 4314). At 2.8 miles from Stop 8, the road bends to the north and travels stratigraphically through the upper Bridger C, crossing the Lonetree limestone, and continuing up through the lower and middle Bridger D. At the junction of Cedar Mountain Rim Road and Sage Creek Mountain Road (5.2 miles from Stop 8), turn south onto a two track road. Drive south on the two track, keeping straight at miles 6.2 and 6.3 where other tracks diverge, until you reach the Turtle Bluff Member overlook (6.4 miles from Stop 8). Note that if the ground is wet, it is not advisable to leave the paved highway (SH 414).

STOP 9

The Turtle Bluff Member on Cedar Mountain
(6.4 miles from Stop 8, cumulative 108.8 miles)

Looking east from this location affords an excellent view of the upper Bridger D, the highest sub-unit in the Twin Buttes Member, overlain by the Turtle Bluff Member of the Bridger Formation (Matthew's Bridger E). The contact between the two members is shown on Figure 11b, and is defined on the basis of a limestone that occurs at the approximate level of the lowest red bed (note that some of the strata you see are slumped). The limestone that supports the bench that you are standing on is the Upper White limestone.

TABLE 4. Taxonomic Summary of the Turtle Bluff Member, Bridger Formation (Biochron Ui1a). LRD – lowest range datum; HRD = highest range datum.

DESIGNATION	NUMBER	TAXA
Index Species	2	*Hemiacodon engardae*, Oromerycidae gen. and sp. nov.
Genus LRD	6	*Epihippus*, *Pareumys*, Oromerycidae gen. & sp. nov., Sespedectinae indet., *Metanoiamys*, *Triplopus*
Genus HRD	7	*Entomolestes, Paramys, Hemiacodon, Taxymys*, Oromerycidae gen. & sp.nov., *Uintasorex, Mysops*
Species LRD	3	*Epihippus gracilis, Triplopus cubitalis, Metanoiamys* sp.
Species HRD	8	*Entomolestes grangeri, Sciuravus nitidus, Paramys delicatior, Taxymys lucaris, Pauromys perditus, Thisbemys corrugatus, Pontifactor bestiola, Uintasorex parvulus*
Range-Through	36	*Apatemys* sp., *Nyctitherium* sp., *Antiacodon* sp., *Omomys carteri, Brontotheriidae* spp., *Orohippus sylvaticus, Centetodon bembicophagus, Pantolestes longicaudus,* Chiroptera indet., *Pantolestes natans, Copedelphys innominatum, Pantolestes* sp., *Dilophodon minusculus, Pauromys* sp., *Harpagolestes* sp., *Peradectes chesteri, Helohyus* sp., *Scenopagus priscus, Herpetotherium knighti, Thisbemys corrugatus, Herpetotherium marsupium, Tillomys senex, Hyopsodus* sp., *Trogolemur* sp., *Hyrachyus eximius, Uintacyon vorax, Isectolophus* sp., *Uintaparamys bridgerensis, Mesonyx obtusidens, Uintaparamys caryophilus, Microparamys minutus, Uintatherium anceps, Microsyops annectens, Viverravus minutus, Notharctus robustior, Washakius* sp.

Consisting primarily of banded red, gray, and tan beds of gypsiferous claystone and mudstone, rocks of the Turtle Bluff Member are the least volcaniclastic in the Bridger Formation. Lithologically, the Turtle Bluff Member is somewhat distinct from the rest of the formation, being similar in appearance to the red and brown sandstone, mudstone, and claystone beds of parts of the Washakie and Uinta Formations of similar age. The Turtle Bluff member occurs only on Hickey Mountain, Sage Creek Mountain, the south end of Black Mountain, and Twin Buttes, but by far the most extensive and thickest exposures occur here on the southwest side of Cedar Mountain. The type section for the Turtle Bluff Member on Cedar Mountain is a 131.5 meter (431 feet) thick sequence of reddish-brown and gray claystone beds with a high gypsum content. This gypsum is both primary and secondary. Secondary gypsum consists of selenite and satin spar crystals which are abundant on the upper slopes of Cedar Mountain. Primary gypsum occurs in thin beds, but the Turtle Bluff Member on Cedar Mountain is capped by a thick and laterally extensive gypsum bed. The mostly fine-grained reddish Turtle Bluff sediments were probably derived from the adjacent Uinta Mountains based on their color, unlike those of the Bridger A–D, which were largely derived from more distal volcanic sources.

The Turtle Bluff Member contains two markers: The Basal Bridger E limestone, which marks the base of the member (base of Matthew's Bridger E), and the Behunin Reservoir Gypsum Bed, which is the youngest and stratigraphically highest well exposed rock unit in the Bridger Formation (note that Behunin is pronounced "Buhannan" by locals). Here on southwest Cedar Mountain, the Turtle Bluff Member contains four additional unnamed limestone bed, and on Twin Buttes there are three. A 2.3 meter (7.5 feet) thick laterally extensive, quartz arenite bed that lies 75 meters (246 feet) above the base of the member on Cedar Mountain is the only sandstone bed. Similar sandstone beds in the Turtle Bluff Member also occur on the northwest flank of Hickey Mountain and the south flank of Sage Creek Mountain, and may be roughly stratigraphically equivalent.

The Behunin Reservoir Gypsum Bed is lithologically unique for the Bridger Formation. Although other gypsum beds occur in the Turtle Bluff Member, they are much thinner. Restricted to just below the southwest rim of Cedar Mountain (below the Bishop Conglomerate), this unit consists of a 7 meter (23 feet) thick sequence of gray and tan unfossiliferous bedded gypsum beds interbedded with gypsiferous mudstones and marlstones. It is visible from a great distance as a prominent white bed high on Cedar Mountain. This bed is interpreted as an evaporitic playa lacustrine deposit, and may indicate changing climatic conditions near the end of Bridger Formation deposition.

Because of its sparse fossils and steep, limited exposures, the biochronologic affinity of the Turtle Bluff Member has been difficult to determine. Matthew was the first worker to comment on the age of the member, saying that its few mammal fossils prove sufficiently that it "belongs to the Bridger Age" (Matthew, 1909, p. 296). Osborn (1929) correlated the Bridger E with the Washakie B and Uinta B, although he cited no evidence to support this correlation. Simpson (1933), Wood et al. (1941), and Gazin (1976) also regarded the Bridger E as Uintan, although this was apparently not based on fossil evidence. Based on eight isolated rodent teeth identified as *Paramys* cf. *P. delicatior*, and "several" bone fragments identified as brontothere, West and Hutchison (1981) concluded that the Bridger E (their Cedar Mountain Member) was Bridgerian. Subsequent work during the 1990's by crews from the University of Colorado Museum (Evanoff et al., 1994; Murphey and Evanoff, 2007) and in the 2000's by crews from the San Diego Natural History Museum (Walsh and Murphey, 2007) have now documented a much more diverse faunal assemblage from multiple stratigraphic levels within the Turtle Bluff Member (Table 4). Donna's locality (UCM Loc. 92189) is located near the base of the member, and is the only locality thus far to produce specimens of the newly described species of omomyid primate *Hemiacodon engardae* (Murphey and Dunn, 2009). Located 105 meters (344 feet) above the base of the member, Roll the Bones (SDSNH Loc. 5844) and Red Lenses (SDSNH Loc. 5844) are the stratigraphically highest localities to yield identifiable fossils in the member. Hundreds of fossils have now been collected from these and other localities mostly via screenwashing of sedimentary matrix. Non-Bridgerian taxa include *Epihippus, Metanoiamys, Pareumys, Triplopus, Sespedectinae indet.*, and *Oromerycidae gen*. and sp. nov. The faunal assemblage of the Turtle Bluff Member is now considered to be earliest Uintan in age (biochron Ui1a of Gunnell et al., 2009), although efforts to obtain additional fossils from this biochronologically important interval member on Cedar Mountain and other locations within the Bridger basin are ongoing.

The Bridger Formation is unconformably overlain by the Bishop Conglomerate, which is visible from this stop capping Cedar Mountain. To the east of this location it forms massive cliffs and spectacular columns. This unit is a very coarse conglomerate composed primarily of arkosic cobbles and boulders derived from the Proterozoic Uinta Mountain Group, with locally common cobbles and boulders of Paleozoic limestone (Bradley, 1964). It is as much as 40 meters (131 feet) thick. The Bishop Conglomerate is unfossiliferous, but currently believed to be Oligocene in age (K/Ar 29.50 ±1.08 Ma, biotite) based on isotopic ages obtained from a tuff that occurs within it on the south side of the Uinta Mountains (Hansen, 1986).

Return to Wyoming State Highway 414, and continue south. The highway crosses the Henrys Fork of the Green River, passes by the hamlet of Lonetree, and bends to the east. There is an excellent view of the Henrys Fork tuff and Henrys Fork limestone on the north side of the highway at SH 414 milepost 128. The Henrys Fork tuff is the prominent gray bed exposed low on the slopes of Cedar Mountain not far above road level, and the Henrys Fork limestone is a prominent white bed immediately overlying the tuff. Continuing east, the highway passes through the hamlet of Burntfork. At highway milepost 130.6 there is a point of historic interest on the south side of the highway. This location is near the site of the first (1825) mountain man fur trading "rendezvous" led by General William Ashley and attended by a then "green" Jim Bridger and Jedediah Smith. At the McKinnon

Junction (16.6 miles from Stop 9), turn north onto Sweetwater County Highway 1. Proceed to 18.8 miles from Stop 9 and pull over on the east shoulder next to the road cut.

STOP 10

The McKinnon Roadcut
(18.8 miles from Stop 9, cumulative 127.6 miles)

This roadcut features the thickest lacustrine sequence in the upper Bridger Formation. The Sage Creek limestone is the thick blocky limestone near the top of the cut. Underlying it are at least 30 meters (98 feet) of lacustrine shale, mudstone, marlstone, and limestone, and the total thickness of the lacustrine sequence is unknown. It has been postulated that this sequence and underlying lacustrine strata of unknown thickness represents a final transgressive phase of Lake Gosiute (Laney Shale Member of Green River Formation) (Brand, 2007), although there is little supporting evidence. Whatever the case, this sequence, combined with evidence provided by other upper Bridger lacustrine deposits (thicknesses and areal distribution), suggests that lacustrine deposition during upper Bridger deposition was most prevalent just to the north of the Uinta Mountain front.

Continue north on Sweetwater County Highway 1. You will be driving through rocks of the lower Bridger C and will descend into upper Bridger B strata at approximate Sweetwater County Highway 1 milepost 16.7 before climbing stratigraphically again lower Bridger C strata at highway milepost 15.8. At mile 11.5 from Stop 10, turn east onto a two track road towards the north end of Black Mountain. Twin Buttes is the conical peak to the south of Black Mountain. Bear right at mile 12.1. Take the left fork at mile 13.0 (look for the BLM Wilderness Study Area sign). Park at the base of Black Mountain at mile 13.8. Note that if the ground is wet, it is advisable to stay on the paved highway.

STOP 11

Twin Buttes and Black Mountain
(13.8 miles from Stop 10, cumulative 141.4 miles)

Although the classic Bridger badlands and collecting areas we have already visited are located far to the west, the Twin Buttes Member and the Twinbuttean land mammal subage was named for Twin Buttes. Because of this, Murphey and Evanoff (2007) designated their type section of the Twin Buttes Member for the upper Bridger sequence on the south side of Twin Buttes,

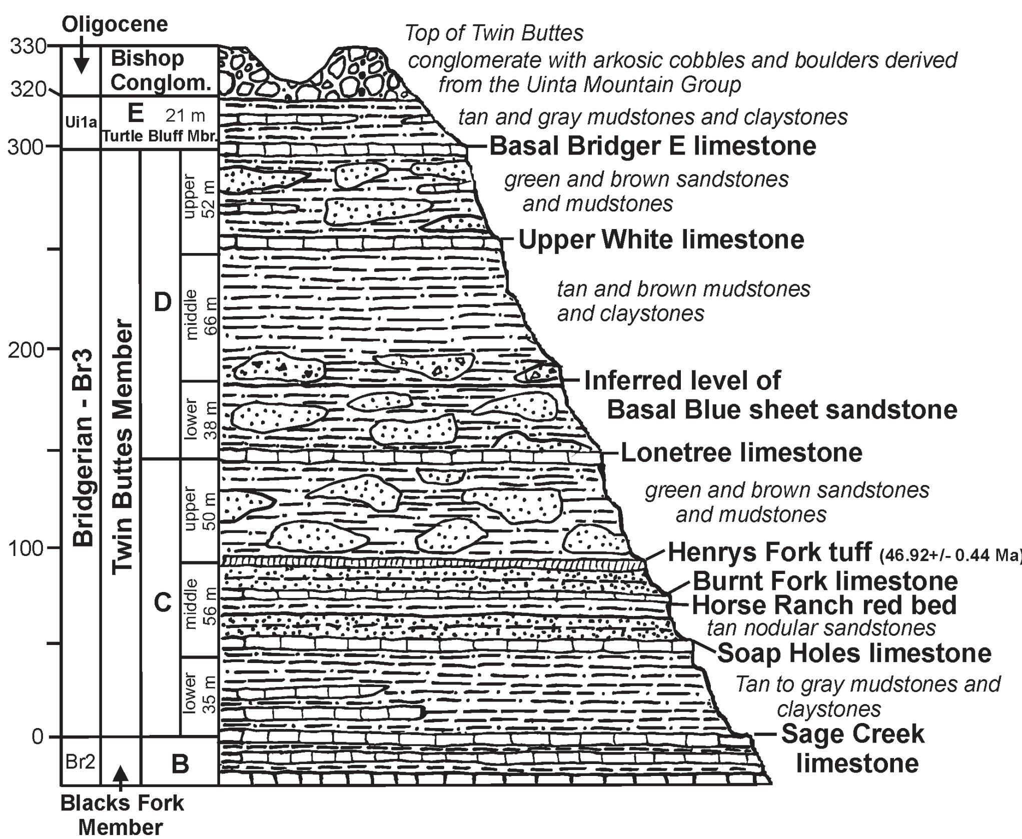

FIGURE 12. Generalized stratigraphic section of the upper Bridger Formation in the Twin Buttes area, Sweetwater County, Wyoming. The diagram shows widespread and more localized markers, as well as informal submembers of Matthew (1909). Thicknesses taken from the type section of the Twin Buttes Member, which includes the Turtle Bluff Member on Twin Buttes (from Murphey and Evanoff, 2007).

and established their Twin Buttes Member reference section of the upper Bridger for the sequence in the Sage Creek and Hickey Mountain area. However, the reference section is thicker and contains more marker units. The major stratigraphic features of the upper Bridger in the Twin Buttes and Black Mountain area are shown in Figure 12.

You are standing in front of another upper Bridger marker bed. The Horse Ranch red bed occurs only in the eastern part of the basin (east side of Twin Buttes [Mass Mountain], Black Mountain and Twin Buttes). It is an approximately 4 meter (13 feet) thick sequence of non-calcareous brick red, greenish-gray, and light brown claystone, blocky mudstone, and blocky fine-grained muddy sandstone (Murphey and Evanoff, 2007). It is locally fossiliferous.

For many years, paleontologists were vexed by the difficulty of correlating between Twin Buttes and Cedar Mountain to the west, especially considering the classic "layer cake geology" of the Bridger with very low dips and laterally persistent marker units. This was because the stratigraphic positions of the "white layers" did not align as expected when using the Sage Creek limestone as a datum. This problem was finally solved by locating the mineralogically diagnostic Henrys Fork tuff not far from here on Black Mountain, and using it as a stratigraphic datum. The reason that earlier workers had difficulties establishing a correlation between the Twin Buttes and Black Mountain area with exposures to the west using the "white layers" is that the lower Bridger C thins dramatically from the west to the east as evidenced on Twin Buttes, where the thickness between the Sage Creek limestone and Soap Holes limestone is 21 meters (69 feet) less than in the nearest correlative sequence to the west.

You are stratigraphically located within the middle Bridger C, and the Henrys Fork tuff is located 42 meters (138 feet above this level). In fact, all of the major marker units present in the Twin Buttes reference section are present in the Twin Buttes type section except for the Basal blue sheet sandstone (base of middle Bridger D). The Lonetree limestone is very well exposed in the saddle between Black Mountain and Twin Buttes, and the Upper white limestone is exposed near the top of Twin Buttes. Only 21 meters (69 feet) of Turtle Bluffs Member occurs at Twin Buttes, which is capped by a thin remnant of Bishop Conglomerate. The hike from this stop to the saddle between Twin Buttes and Black Mountain is well worth the effort if you have the time.

This is the end of the Bridger basin portion of the field trip. From here we will head south to Manila, Utah, via Sweetwater County Highway 1 and Wyoming State Highway 414, and then continue south over the Uinta Mountains to Vernal and the Uinta basin.

ACKNOWLEDGEMENTS

The authors wish to express their deepest gratitude to the many colleagues, students and volunteers that have assisted with our field work in the Bridger basin over the years. In particular, we are grateful for the participation of faculty, staff, and students from the University of Colorado Museum and San Diego Natural History Museum, especially Professor Peter Robinson (UCM) who was instrumental in the establishment of the Bridger Basin Project in the early 1990's. We also thank the Wyoming State Office of the USDI Bureau of Land Management, and the Kemmerer and Rock Springs BLM field offices. Without the support of the BLM, our field work would not have been possible. Finally, we thank Margaret Madsen for her assistance with the compilation of the field trip mileage log.

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NOTES

NOTES

MISSION STATEMENT

The Conference on Fossil Resources provides an opportunity for public land managers, professional scientists and interested amateurs to come together to discuss successes, discoveries and land management policies regarding paleontological resources. Through this collaboration, participants seek to maximize scientific, educational and recreational opportunities on public lands.

HISTORY

The Conference has convened periodically since 1986, when Dinosaur National Monument hosted a gathering focused primarily on issues related to the management of paleontological resources in National Park Service units. Subsequent conferences have expanded in scope to include the management, protection, and interpretation of paleontological resources on all public lands.

Fossil Butte National Monument welcomes attendees back to Kemmerer, Wyoming—site of the third conference.
Previous hosts include:

Dinosaur National Monument
Vernal, Utah (1986)

Petrified Forest National Park
Holbrook, Arizona (1989)

Fossil Butte National Monument
Kemmerer, Wyoming (1992)

Florissant Fossil Beds National Monument
Colorado Springs, Colorado (1994)

Badlands National Park and South Dakota School of Mines and Technology
Rapid City, South Dakota (1998)

Colorado Bureau of Land Management, Gunnison National Forest, and Colorado National Monument
Grand Junction, Colorado (2001)

New Mexico Museum of Natural History and the New Mexico Bureau of Land Management
Albuquerque, New Mexico (2006)

Utah Friends of Paleontology, the Utah Bureau of Land Management, and the Utah Geological Survey
St. George, Utah (2009)

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ORAL PRESENTATION

COLORADO BUREAU OF LAND MANAGEMENT FOSSILS SINCE 1865: A HISTORY OF FIELDWORK, PERMITS, AND FINDS

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ABSTRACT—General collection of fossils in Colorado predates 1865 and continues today. Scientifically, researchers have used available permissions and permits to collect fossils on public lands now administered by the Bureau of Land Management (BLM) in Colorado for over 150 years, making highly significant finds including taxa new to science that have proven useful in understanding past environments. Modes of exploration and collection for these fossils have included hiking, excavation, drilling, horses and other animals, mechanized terrain travel, aviation, ground sensing, satellite, and computer navigation. More than 250 permits have now been issued for the surface collection, sampling, excavation, and mitigation of impacts on paleontological resources on BLM lands in Colorado. Small to large specimens of plants (pollen and petrified wood, for example), invertebrates (ammonites and insects), vertebrates (dinosaurs and mammals), and trace fossils have been collected by a variety of researchers and their host institutions and are reposited across the nation in many museums, colleges, universities, and geologic surveys. These fossils provide many educational and economic benefits, including added interest for heritage tourism: Colorado BLM currently hosts five fossil-themed trails, highlights fossils in two National Byway auto tours, and locates fossils in at least eleven National Landscape Conservation Areas.

KEYWORDS—Colorado, Bureau of Land Management, Permits, Paleontological, Fossils

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ORAL PRESENTATION

COMPLETION OF THE GENERAL MANAGEMENT PLAN FOR THE SOUTH UNIT OF BADLANDS NATIONAL PARK: THE FIRST TRIBAL NATIONAL PARK IN NATIONAL PARK SERVICE HISTORY

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ABSTRACT—After 3 years of cooperative effort between Badlands National Park, the Oglala Sioux Tribe, and the National Park Service (NPS) Midwest Regional Office, the Badlands General Management Plan (GMP) is nearing completion for potentially the first Tribal National Park in our nation's history. The GMP includes seven management options, ranging from shared management between the NPS and the Oglala Sioux Tribe to deauthorization with management by the Oglala Sioux Tribe as a tribal park. The preferred management option for the new General Management Plan includes the development of a Tribal National Park over a series of stages, beginning with NPS employees mentoring tribal employees in resource management and visitor education. As tribal employees develop the necessary skills to manage a "National" park, they will step into positions previously held by NPS employees and assume responsibility for managing the nation's first Tribal National Park. Five of the proposed management options (including the preferred option) would require congressional legislation for full implementation. In addition to management options, there are four resource and visitor experience alternatives discussed in the GMP. The preferred alternative focuses on resource protection with expanded access and opportunities for visitors. Because of the premier fossil resources preserved within the South Unit, paleontological resources are considered a primary resource under the preferred alternative, with a special emphasis placed on inventory, monitoring, research and salvage collection. A visitor oriented paleontological excavation would also be considered under this alternative. Plans for the development of a Lakota Heritage and Education Center (LHEC) are proceeding in addition to the GMP. The LHEC would serve as a major visitor contact station as well as curatorial space for fossils and artifacts. Museum specimens would continue to be housed in trust for the tribe, in off-site NPS-approved collections. Where feasible, they would be transferred to the new facility. Additionally, the preferred alternative would protect fossils by increasing law enforcement staff, reducing cattle grazing, and increasing visitor education.

KEYWORDS—Vertebrate Paleontology, National Park Service, Oglala Sioux Tribe, Management Policies, Museum Collections

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ORAL PRESENTATION

THE PLANNING AND EXECUTION OF AN OPEN-TO-THE-PUBLIC EXCAVATION OF AN ALLOSAUR FROM THE SAN RAFAEL SWELL

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ABSTRACT—In December 2009, an articulated vertebral column was found during a survey east of Castle Dale, Utah, in the San Rafael Swell. The site was located near the main county road into the Swell, creating a security problem: how to keep the site safe until it could be properly excavated and how to excavate the fossils without attracting the attention of curious onlookers. The solution: open the excavation up to the public. During the five days the site was open, more than 2000 people visited.

From the time the site was found until it was excavated under a permit issued by the Bureau of Land Management (BLM), the Emery County Sheriff's Department regularly monitored the site during routine patrols. Because work at the site could not be concealed, the Prehistoric Museum decided, in conjunction with the state and local BLM offices, to publicize the excavation in order to allow continuous supervision of the site, educate the public about the importance of such discoveries, and highlight the partnership between the Museum and BLM. Parking areas, camping areas, trails, observation areas, vehicle access, crowd control, volunteer help, news releases, and tools and equipment were planned out in advance to deal with the expected crowds..

The success of this project was made possible by the cooperation of the BLM, CEU Prehistoric Museum volunteers, Carbon County Travel Bureau and others. Problems were identified, ideas were shared and solutions were found. The result was a successful, educational and enjoyable experience for everyone interested.

KEYWORDS—Collaboration, San Rafael Swell, excavation, interpretation

*Presenting author.

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ORAL PRESENTATION

PRESERVATION, MANAGEMENT, AND REINTERPRETATION OF AN EARLY JURASSIC DINOSAUR TRACKSITE IN WARNER VALLEY, WASHINGTON COUNTY, UTAH

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ABSTRACT—The Early Jurassic Warner Valley Dinosaur Tracksite (WVT), situated in the lower part of the Kayenta Formation, is located near St. George, Utah on public land administered by the St. George Field Office of the Bureau of Land Management (BLM). The site was discovered in 1982 and described in a preliminary scientific paper by paleontologists from Brigham Young University (BYU) in 1989. Shortly after its discovery, the BLM set up interpretive signage and opened the site for public educational use (Fig. 1A). Although the WVT has become well known, especially to the local population, it also became a target for vandalism and has been subjected to extensive off-highway vehicle (OHV) use.

Following the establishment of a paleontological site stewardship program by the St. George Field Office in 2007, the WVT received continual monitoring by trained BLM volunteers, who reported damage to the tracksite, OHV use on and around the site (Fig. 1B), and illegal replication of dinosaur tracks (Fig. 1C). The monitoring encouraged the BLM to better preserve and protect the site by erecting site etiquette signs, surrounding the site with range fencing, improving the parking area and access road, and installing new, updated signs (Fig. 1D–E).

In late 2010, the St. George Dinosaur Discovery Site at Johnson Farm (SGDS) was asked to help update the WVT signs. The preliminary map published by BYU documented 161 individual impression (natural mold) tracks pertaining to the ichnotaxa *Eubrontes* and *Grallator* in 23 trackways on two track-bearing horizons. Permission was granted by the BLM to expand the surface area of the WVT to include surfaces between the upper and lower track-bearing beds that previously had been covered. During this new cleaning, excavation, and remapping, many new specimens were discovered that were either covered at the time of the original mapping or consist of previously unrecognized compression tracks that are raised off the surface. At present, the WVT preserves 400 individual tracks and at least 25 trackways on five track horizons, greatly enhancing the significance of the site.

The new, more extensive signage at the WVT will include several items absent from the original signs, including an updated map of the entire tracksite alongside the original map, a paleogeographic map of the Early Jurassic of Utah, information on the original discovery, and generalized information about the kinds of tracks and the animals that produced the tracks, the geology of the area, the Kayenta Formation paleoenvironment, the future of the WVT, and what data may still be obtained with further study and protection.

The southern portion of the tracksite, where many of the better preserved *Eubrontes* tracks are situated, remains to be stabilized and repaired. The tracks in this area are on a thin bed that, when exposed, becomes friable and easy to remove. Hollow sounds under this layer are harbingers of future damage or, worse yet, theft of tracks that have broken free. Also, concrete residue from illegal and improper replication has yet to be removed. The BLM and the SGDS are jointly exploring the best options for both proper replication and possible stabilization of the tracksite with ethyl silicate. Photogrammetry may be used to record track data about specimens that may be damaged or destroyed (Fig. 1F).

Joint BLM-SGDS reevaluation of the WVT has provided the opportunity to raise public awareness about the importance of preserving this nonrenewable resource through interpretive signage that explicitly discusses the continuous, destructive conditions to which the site is subjected and the measures undertaken to counter them. This project demonstrates that a mutually beneficial agreement between the BLM and the scientific community can result in a well-maintained, well-protected, and educational public resource.

KEYWORDS—Warner Valley, Kayenta Formation, Dinosaur Tracks, Utah, Bureau of Land Management

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FIGURE 1. **A,** Original wooden sign at the WVT full of bullet holes and incorrect information based on 1989 misinterpretation of the site. **B**, Motocross rider driving across the WVT surface. **C**, *Grallator* footprint surrounded by concrete residue from illegal replication of track. **D**, New BLM sign at entrance to parking area at the WVT. **E**, New metal signage frame next to the tracksite surface. **F**, Neffra Matthews photographing a *Grallator* footprint for photogrammetric purposes at the WVT.

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ORAL PRESENTATION

PALEONTOLOGICAL RESOURCES IN THE VERMILION CLIFFS NATIONAL MONUMENT AND PARIA CANYON-VERMILION CLIFFS WILDERNESS: THE USE OF PHOTOGRAMMETRIC ICHNOLOGY IN THE 21ST CENTURY

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ABSTRACT—The Vermilion Cliffs National Monument and the Paria Canyon-Vermilion Cliffs Wilderness encompass nearly 400,000 acres of land managed by the BLM in Coconino County, Arizona and Kane County, Utah. In Early Jurassic times (~190 million years ago), a vast (~350,000 sq. km) sea of sand (erg) covered this area. Today, these sands, preserved as the Navajo Sandstone, create the picturesque geology of these National Landscape Conservation System (NLCS) units. In addition, this region contains a little-known record of thousands of fossil tracks preserved as underprints in convex hyporelief and concave epirelief on dune foreset beds and interdune bounding surfaces. Fossil footprints include tridactyl (*Grallator*) and tetradactyl (*Batrachopus* and *Navahopus*) forms, as well as unique invertebrate traces. These ichnites preserve a variety of interesting preservational and behavioral features related to a desert fauna of theropods, prosauropods, crocodylomorphs, protomammals, and arthropods moving up, down, and across dunes during the monsoonal summer season. Although the discovery of fossil tracks is on the rise worldwide, the general understanding of the complexities of vertebrate ichnology and significance of trace fossils remains remarkably low, resulting in misinformation and mismanagement. Fortunately, photogrammetric documentation incorporated with GIS can assist in the proper documentation, preservation, and assessment of these resources. In these NLCS units, valuable insights and interpretations can be made from these data, providing an ideal opportunity for the successful synergy of management, science, technology, interpretation, and recreation. Photogrammetrically derived 3D image datasets are providing valuable information for the understanding of the Early Jurassic desert ecosystem in the region, as well as understanding the kinematics of footprint formation in arid, eolian environments.

KEYWORDS—Trace Fossils, Photogrammetry, Navajo Sandstone, Vermilion Cliffs National Monument, Paria Canyon-Vermilion Cliffs Wilderness

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POSTER SESSION

WYOMING'S RED GULCH DINOSAUR TRACKSITE: PUBLIC PARTICIPATION, CONSERVATION, AND MANAGEMENT

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ABSTRACT—Public lands of the Rocky Mountain West contain some of the most important vertebrate paleontological remains of North America. Because these fossils are public resources, it is vital for the public to be activity involved with research projects when possible. An example of this type of partnership was the work done at the Red Gulch Dinosaur Tracksite (RGDT). Beginning in 1997, this project brought researchers, students, and volunteers from around the country to northern Wyoming, where they were responsible for determining the paleontological significance of a previously unknown dinosaur tracksite. The RGDT, located on readily-accessible land managed by the Bureau of Land Management (BLM), contains more than 1000 footprints from a population of theropod dinosaurs that walked across an ancient tidal flat 165 million years ago. Its size and complexity presented an opportunity for assistants of all ages to practice their data gathering skills in observation, description, critical thinking, and "footprint sleuthing." A variety of both classical and state-of-the-art documentation methodologies were tested, making this one of the most intensively documented dinosaur tracksites in the world. Through a partnership with the BLM, the needs of students, public, and media were accommodated without negatively impacting scientific research. The RGDT 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.

KEYWORDS—Red Gulch Dinosaur Tracksite, Public participation, Dinosaur tracks, Bureau of Land Management, Resource Management

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ORAL PRESENTATION

SCIENCE IN CONTEXT: PALEONTOLOGICAL METHODS IN THE NATIONAL PARKS

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ABSTRACT—National Park Service units play an important role in society by demonstrating the entirety of the scientific process in action. Well-managed paleontology parks and monuments afford a visitor experience unattainable virtually anywhere else. This is due largely to an under appreciated element of paleontology—that of context. The exact three-dimensional spot in the ground where a fossil is found is the most basic and crucial data point. The paleontological resource is more completely understood interpreted in context, in the park. However, the importance of a designated park diminishes to the extent that fossils and the science are often outsourced—removed, conserved, curated, and housed elsewhere.

Ideally, a protected locality would be fully equipped with facilities and management plans that would enable preservation and conservation of the fossil resource by highly experienced content specialists. In-house expertise is best equipped to coordinate the research necessary to provide the understanding required to care for fossil resources. By serving as self-contained research stations, these installations provide critical training to future generations of scientists, fulfill the mandate of the park service to educate the general public, generate scientific research, and most importantly, address the intent of the enabling legislation for the individual park or monument.

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Article, p. 40–42

PALEONTOLOGICAL RESOURCE MANAGEMENT AND THE OGLALA SIOUX TRIBE'S TRIBAL HISTORIC PRESERVATION OFFICE

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ABSTRACT—The Oglala Sioux Tribe has historically delegated responsibility for cultural/historic preservation and paleontological resource management to various Tribal agencies through Tribal Council Resolutions and Ordinances based on the need of each specific situation. In April 2008, a Tribal Council Ordinance established a Tribal Historic Preservation Office (THPO). This office was directed to: 1) develop a Tribal Historic Preservation Plan and Program, 2) obtain National Park Service (NPS) Historic Preservation Program approval for official status as a nationally recognized THPO, as provided by the National Historic Preservation Act, 3) negotiate a Memorandum of Agreement (MOA) with the NPS to acquire funding necessary to implement the Program, 4) assist in developing a paleontological resource management plan, and 5) create an Advisory Council to serve as an elder advisory group for all cultural and historical management. Since its inception, the Advisory Council has been called upon to address paleontological resource management issues on the Pine Ridge Reservation. Based on traditional teachings, it is believed that everything is connected. This connection means that anytime the earth is disturbed, a human-related and/or fossil item may be uncovered, so there is no real distinction between archaeological and paleontological resources. Currently, the Oglala Sioux Tribe has a nationally recognized THPO, program funding and personnel, consultants, a Tribal Historic Preservation Plan, and a MOA with the NPS assuming certain functions previously conducted by the State Historic Preservation Office. The THPO is working collaboratively with several other Tribal and Federal entities as well as educational institutions to address ongoing needs for protecting and preserving cultural/historic properties and paleontological resources. There are plans in place to make Oglala Lakota College, through its Department of Math, Science & Technology, the official repository and archival warehouse for Oglala Sioux Tribal paleontological resources.

KEYWORDS—Tribal, Oglala, Resource Management

*Presenting author

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ORAL PRESENTATION

SITE CONDITION ASSESSMENTS OF FOSSILS IN THE NATIONAL CAPITAL REGION

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ABSTRACT—Using paleontological resource inventory and geologic resource evaluation reports, site condition assessments were completed at three parks in the National Capital Region: Manassas National Battlefield Park, Fort Washington Park, and the Chesapeake and Ohio Canal National Historical Park. At Manassas National Battlefield Park, fossil-bearing outcrops are well-constrained in unpublished maps by Dr. Robert Weems (USGS) and other researchers. At Fort Washington Park, fieldwork revealed multiple exposures of the shell-rich Aquia Formation in steep ravines. The discovery of accelerated erosion in one ravine causing destruction of fossil casts and molds led to a successful NPS Geologic Resource Division technical assistance request. Subsequent training workshops raised awareness among regional staff, and prepared interpreters to tell the story of Fort Washington's ancient history. At the Chesapeake and Ohio Canal National Historical Park, fossils Cambrian to Devonian in age (540 to 460 million years old) were described at five sites within the Valley and Ridge Province. Site condition assessments revealed the differences between carbonate rock sites in the Great Valley and shale exposures in the western part of the park. Limestone and dolomite outcrops were in good condition, with stable rock faces, few fossils visible and little evidence of visitor impacts on the sites. In contrast, Devonian-age shale exposures along the Western Maryland Railroad grade present resource concerns due to accelerated erosion rates, increased fossil visibility, and possible impacts on fossils by park visitors. A year-long paleontological inventory of C & O Canal National Historic Park will expand on this work in 2011. This six-month Geoscientist-in-the-Park internship raised awareness about fossils—a resource for which eastern parks are not traditionally known.

KEYWORDS—Manassas National Battlefield Park, Fort Washington Park, Chesapeake and Ohio Canal National Historical Park, Paleontological resources, Site condition assessments

ORAL PRESENTATION

LEAFY THERMOMETERS AND RAIN GAUGES: USING FOSSIL LEAVES TO TEACH ABOUT EOCENE CLIMATE IN THE CLASSROOM

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ABSTRACT—The National Park Service encourages incorporating the history and science of our parks into the classroom. This affords an opportunity for middle and high school teachers, particularly in the sciences, to offer concrete, relevant examples from iconic American landscapes to engage students and aid them in mastering abstract principles. Fossil Butte National Monument uses an inquiry-based, integrated learning approach in the activity *Leafy Thermometers and Rain Gauges*. Using a suite of 37 fossil leaf photographs from the Green River Formation, students conduct leaf margin analysis (LMA) and leaf area analysis (LAA) to produce estimates of mean annual temperature (MAT) and mean annual precipitation (MAP) for the Early Eocene in a classroom setting. In essence, students do climate science. Students test the robustness of the model by collecting local leaves and comparing the result of LMA and LAA with an observational weather database.

Beyond the basic methodology and testing, a comparison of temperature and precipitation estimates from fossil leaves with observational climate records for southwestern Wyoming allows students to make general statements about how climate has changed since the Early Eocene and brainstorm potential causes. Further, contrasting a graph of the temperature trend for SW Wyoming based on two data points (52 million years ago and today) with other graphs of temperature change over various time intervals facilitates a discussion of how and why climate has changed and whether or not the evidence presented rejects a hypothesis of human-induced climate change.

KEYWORDS—Climate change; Interpretation; Eocene; Leaf Margin Analysis; Leaf Area Analysis

*Presenting author

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ORAL PRESENTATION

A PALEONTOLOGICAL RESOURCE INVENTORY OF BUREAU OF LAND MANAGEMENT WILDERNESS LANDS IN WASHINGTON COUNTY, UTAH

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ABSTRACT—The Washington County Wilderness Bill, which is part of the Omnibus Public Lands Bill signed into law in 2009, designates 129,300 acres of public land administered by the Bureau of Land Management (BLM) as wilderness. As part of the planning process, the BLM funded the Utah Geological Survey (UGS) to conduct a paleontological inventory of wilderness areas, providing an opportunity for input into critical land-use and management decisions. This marks the first time that paleontological resources have been included in an initial natural resource inventory for a new public wilderness area.

To create potential fossil yield classification (PFYC) maps for the wilderness areas, we used data from UGS 1:24,000 and 1:100,000-scale geological maps of the region to prioritize paleontological data collection in the field. Based on the location of important fossil-bearing strata—the Chinle, Moenave, and Kayenta formations and, to a lesser degree, the Navajo Sandstone and Carmel formations—and their proximity to developed areas, the BLM selected the Cottonwood Canyon, Red Mountain, and Canaan Mountain wilderness areas for field inventory.

Field work began in the fall of 2010 at Red Mountain and Cottonwood Canyon. Numerous sites with tracks attributed to *Grallator*, *Eubrontes*, and *Brasilichnium* were discovered in the Navajo Sandstone along with several tracksites in the Kayenta Formation. We will continue our field survey during the spring of 2011, concentrating on Canaan Mountain, which has the highest potential for significant body fossils.

KEYWORDS—Fossil Resource Management, BLM wilderness, PFYC maps, Washington County, Navajo Formation

ORAL PRESENTATION

DEVELOPING A POTENTIAL FOSSIL YIELD CLASSIFICATION MAP FOR GLEN CANYON NATIONAL RECREATION AREA

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ABSTRACT—Utah Geological Survey (UGS) has been using GIS to integrate existing digital geologic maps with the UGS Paleontological Locality Database to generate Potential Fossil Yield Classification (PFYC) 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.

The Bureau of Land Management has defined 6 levels of sensitivity for map units for the purpose of developing paleontological sensitivity maps, which the UGS has adopted. This sensitivity scale starts at five for the most sensitive map units and decreases to zero for map units that do not preserve fossil resources. This scale is: (5) Significant fossils are known and widespread; (4) Significant fossils are present; (3) Common fossils may be abundant, but significant fossils are rare (This category includes most Paleozoic formations and Pleistocene deposits.); (2) Significant fossils are rare; (1) Fossils are unlikely to occur; (0) Map units represent water and human-made features.

Distribution of fossil resources is typically first assessed by a thorough literature review, followed by fieldwork. Paleontological resources correlate with the distribution of geological units, so paleontological sensitivity maps may be constructed based on literature reviews and field data.

The PFYC map produced for the Glen Canyon National Recreation Area (GLCA) was based on geological maps published and under development by the UGS for the GLCA at 1:100,000 scale or greater. Only a general sense of the distribution of significant fossil resources can be made at the scale figured here (Fig. 1), as the size of the polygons defined in the GIS data are often smaller than the pixel size. However, the 1/125,000 scale map exhibited in this poster provides a tool that we hope will prove useful for National Park Service resource managers at GLCA. Future geological mapping at 1/24,000 scale would provide a basis for significantly better management tools.

KEYWORDS—Potential Fossil Yield Classification, Mapping, Glen Canyon

*Presenting author

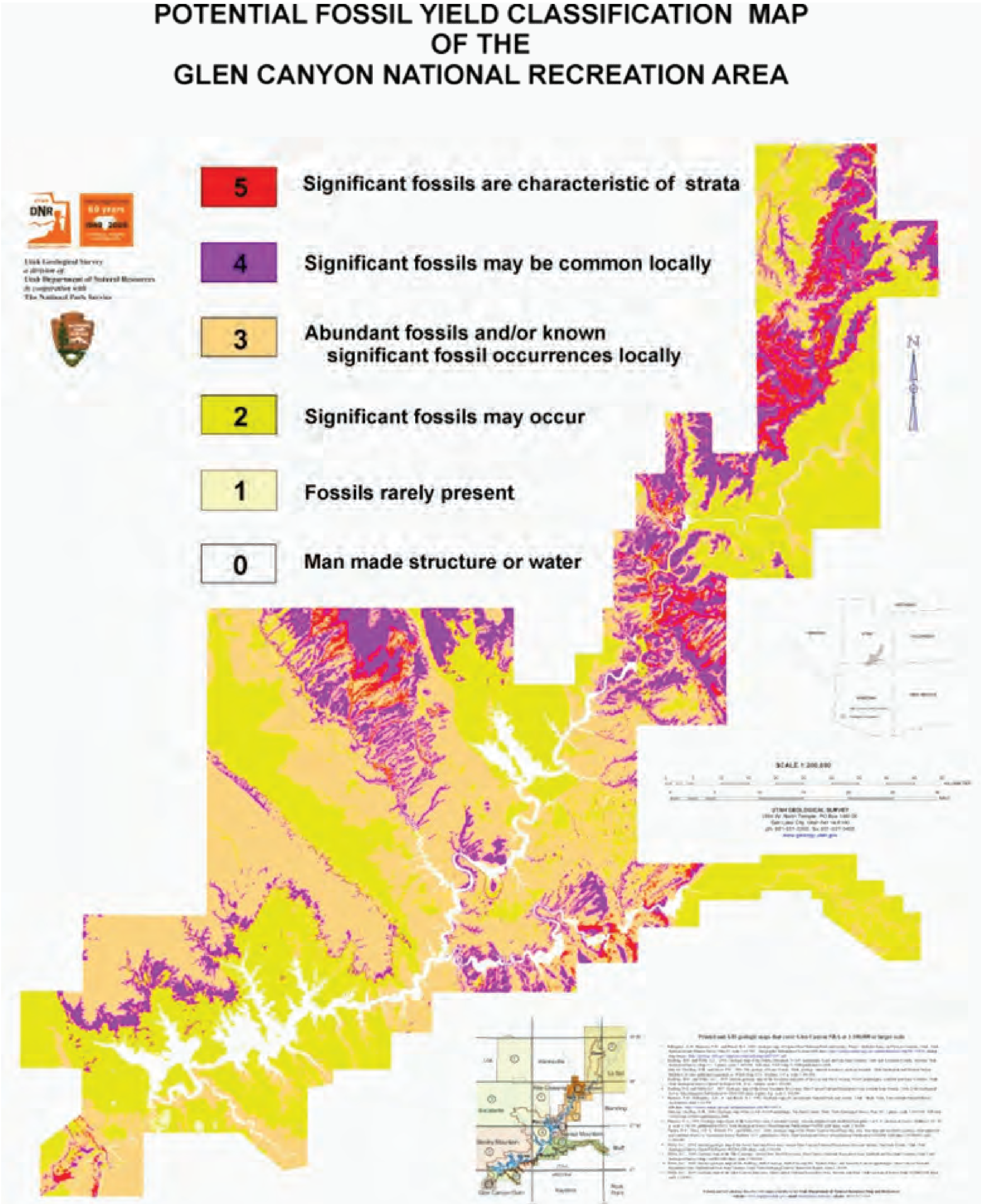

FIGURE 1. Potential Fossil Yield Classification (PFYC) for GLCA based on data collected during the course of this investigation.

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ORAL PRESENTATION

UPDATE ON THE STATUS OF THE SVP STANDARD GUIDELINES FOR THE ASSESSMENT AND MITIGATION OF ADVERSE IMPACTS TO PALEONTOLOGICAL RESOURCES

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ABSTRACT—In 1995, the Society of Vertebrate Paleontology (SVP) published "Standard Guidelines" for the "Assessment and Mitigation of Adverse Impacts on Nonrenewable Paleontologic Resources." In the 15 years following their introduction, these guidelines functioned well, becoming *the* standard against which the adequacy of paleontological resource impact assessments and mitigation programs were judged. Many federal and state regulatory agencies either formally or informally adopted the SVP's Standard Guidelines for the mitigation of construction-related adverse impacts on paleontological resources. The SVP's guidelines outlined acceptable professional practices in the conduct of paleontological resource impact assessments and surveys, monitoring and mitigation programs, data and fossil recovery, sampling procedures, and specimen preparation, identification, analysis, and curation. The SVP's Standard Guidelines were approved by a consensus of professional vertebrate paleontologists and most practicing professional paleontologists involved in mitigation adhered closely to the SVP's assessment, mitigation, and monitoring recommendations.

Although the 1995 SVP Standard Guidelines were highly successful in standardizing procedures for protecting paleontological resources, in 2009 several paleontologists suggested to the SVP Executive Committee that the guidelines should be reviewed to determine their effectiveness and adequacy—a particularly timely suggestion, since legislation requiring federal agencies to rewrite resource regulations pertaining to the preservation of paleontological resources was also coming into effect. The SVP Executive Committee reconvened the Conformable Impact Mitigation Committee (which wrote the 1995 edition of the Standard Guidelines) under the new name "Ad hoc Committee on SVP Impact Mitigation Guidelines Revision" and appointed six new members to join six members of the original committee, with Bob Reynolds and Lanny Fisk as co-chairs. The co-chairs and committee members were selected for their experience with mitigation of construction-related impacts on paleontological resources. Members include paleontologists active in the private sector, paleontologists employed by federal and state public agencies, and academicians involved with mitigation on a part-time basis. Committee members engaged in lively and fruitful discussions as they strived for mutual understanding and consensus.

From the beginning, all agreed that the professional paleontological community must be proactive in establishing "best practice" guidelines for the protection of paleontological resources. Committee members agreed that the profession must step forward with standard guidelines so that individual agencies would not be tempted to establish separate and perhaps inconsistent guidelines without professional input. Likewise, the committee agreed that the SVP's Standard Guidelines should be acceptable to the community of professional paleontologists so that they would not be tempted to develop their own individual guidelines independent of the SVP. There was universal agreement that the SVP Standard Guidelines should clearly and unequivocally state what the community of professional paleontologists would like to see as standard procedures for assessing potential impacts to fossils and mitigating these impacts. Overall, the committee's goal was to develop revised guidelines that would gain wider acceptance, approval, and application and thus result in greater protection of paleontological resources.

The Ad Hoc Committee on SVP Mitigation Guidelines submitted its final draft of the revised guidelines, retitled Standard Procedures for the Assessment and Mitigation of Adverse Impacts to Paleontological Resources, to the SVP Executive Committee for review in March 2010. While still emphasizing vertebrate fossils, the revised guidelines provide broader application to other paleontological resources so as to be consistent with the 2009 Paleontological Resources Preservation Act (PRPA, 16 U.S.C. 470aaa) and new regulations currently being developed by the departments of Interior and Agriculture. The 2010 edition of the SVP standard guidelines also amends rock unit classification categories (1) high, (2) low, or (3) undetermined to add a fourth--(4) no potential for containing significant paleontological resources, meant to apply to high-grade metamorphic rocks (such as gneisses and schists) and plutonic igneous rocks (such as granites and diorites). Another proposed revision addresses standardization of verbs such as "will be," "should be," and "may be" to help clarify exactly what actions the community of professional paleontologists consider important and necessary versus those that are optional or only recommended.

KEYWORDS—Society of Vertebrate Paleontology, SVP Standard Guidelines, Paleontological Mitigation, Paleontological Resource Impact Assessment, Paleontological Protection

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POSTER SESSION

MILESTONES IN U.S. GOVERNMENT PALEONTOLOGY

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ABSTRACT—As it acquired various territories, the young and expanding United States needed to know what mineral, cultural, and natural resources existed on its western lands. A Congressional survey of the Territories was followed by detailed mapping and analysis by the US Geological Survey (USGS) and eventually evolved into the bureaucracy of federal land management agencies that we still have today. Each step of the way, the laws and policies of the ever-expanding nation were informed by exploration and scientific inquiry.

Following the "Bone Wars" of 1891 and the exclusion of fossils from the Antiquity Act of 1906, policy regarding paleontological resources has lagged behind that regulating nearly every other natural or cultural resource on America's public lands. This timeline, which traces the history of paleontological exploration and policy, illustrates the complex and often nuanced relationship between historical events, notable personalities, and legislative actions.

KEYWORDS—Policy, USGS, Antiquity Act

ORAL PRESENTATION
Article, p. 43–50

PALEONTOLOGY AND PUBLIC DIPLOMACY

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ABSTRACT—Questions of global climate change and other currently relevant social and political issues require applications of paleontological research that are far more complex than which dinosaur fossil is largest or how many new fossil species may be identified in one year. Management of public lands, both for current development and for the enjoyment of future generations, requires that people making decisions have the best information that is based on scientific principles and expertise. An inability to reach the general public with meaningful and relevant scientific results has led to a lack of appreciation for the importance of paleontological research. A lack of diplomatic skills may also have hindered paleontological managers from garnering the bureaucratic support necessary to develop paleontology into a fully functioning independent program within the United States Government.

With advances in scientific methodology, including increased collaboration between related sciences, understanding paleontology is more important than ever. The science of paleontology offers a unique "deep-time" perspective that can enrich understanding of many current scientific questions on topics ranging from nuclear proliferation to global climate change. With the recent implementation of the Paleontological Resources Preservation Act, government paleontologists have a unique opportunity to create and mold concepts of policy and diplomacy that will affect the way paleontological resources will be viewed and managed well into the future.

KEYWORDS—Paleontology, Policy, Land Management

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ORAL PRESENTATION

A HISTORY OF FEDERAL PALEONTOLOGISTS

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ABSTRACT—Starting with O. C. Marsh and continuing through the present, the United States government has continuously employed paleontologists. The earliest paleontologists were contracted to conduct surveys of the Territories. The federal government began directly funding paleontological exploration, research, and curation in 1878, when the U.S. Geological Survey was created and directed to deposit collections with the Smithsonian. The National Park Service did not establish a full-time paleontologist position until 1953, however, and the Bureau of Land Management and the U. S. Forest Service did not do so until 1980 and 1992, respectively. To date, the Bureau of Reclamation, Fish & Wildlife Service, U. S. Department of Defense, and U. S. Department of Energy—all federal agencies that manage lands containing significant paleontological resources—have never hired a paleontologist.

Today there are approximately 38 paleontologists assigned to paleontology positions in the federal government; nearly the same number of geologists, archaeologists, and museum curators have job responsibilities that require advanced knowledge of the field. While this is the largest number of paleontologists to be employed at any time in U.S. history, it is still too few to compel the U.S. Government's Office of Personnel Management to establish a career series in paleontology. Over the past 30 years there has been a shift in paleontological careers in the federal government from basic exploration and research to management and development of paleontological programs, providing infrastructure for greater participation by non-governmental paleontologists.

KEYWORDS—Paleontology, Policy, Federal Land Management

ORAL PRESENTATION

TRILOBITES FROM THE UPPER CADIZ FORMATION (MIDDLE CAMBRIAN; DELEMARAN) OF THE SOUTHERN MARBLE MOUNTAINS OF CALIFORNIA

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ABSTRACT—*Glossopleura* (*G. walcotti* and *G. boccar*?) and *"Anoria" lodensis* dominate a sample of about 200 trilobite specimens from the top of the middle Cambrian Cadiz Formation in the Marble Mountains of California. Fauna also includes indeterminate kochaspids (possibly including *Amecephalus* sp.), *Kochina vestita*, *Mexicella mexicana*, *Mexicaspis stenopyge*, and *Caborcella* sp. The sampled fauna is from the *Glossopleura* biozone (Delamaran; Series 3) and is from approximately 5–10 meters below the Bonanza King Formation. The degree of articulation at the site is extremely low; the sample is dominated by cranidia and librigenae. Corynexochida accounts for nearly 75% of the specimens collected; small specimens are less common but still present and well preserved. A revised faunal list for the site is presented along with a discussion of previous summaries, of which there are very few for the Cadiz Formation. The site exhibits taphonomic characteristics quite different from similar-age deposits in the Spence Shale and Bright Angel Shale.

KEYWORDS—Trilobites, Cambrian, Cadiz Formation

ORAL PRESENTATION

UTAH'S PALEONTOLOGICAL LOCALITY DATABASE SYSTEM

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ABSTRACT—In 1977, a revision of the Utah State Antiquities Act added "paleontology" to the wording of the law, created the office of the Utah State Paleontologist, and provided a legal basis for the protection and management paleontological resources on state lands. Since then, the office of the State Paleontologist, now at the Utah Geological Survey (UGS), has worked to develop programs, policies, and strategies to protect and manage Utah's fossils. Efforts to preserve and protect paleontological resources on all lands in Utah have relied upon partnerships and cooperative agreements with state and federal land management agencies, private landowners, paleontological consultants, and researchers working in the state of Utah. One of the major resource management projects has been to develop and maintain the Utah Paleontological Locality Database System. The original database, begun over 30 years ago as a compilation of paleontological localities from the published literature, has developed through the years into an integrated statewide database system. It is currently maintained in a Microsoft Access Database linked to an ArcGIS map project that displays fossil locality data in relation to other data layers, including topographic, geologic, and land-ownership data. Since 2002, the UGS has had a cooperative agreement with the Utah State Office of the Bureau of Land Management for the management of paleontological locality data. Effective data management is key to the successful management of paleontological resources. Data collection standards, data security, and availability of accurate GIS data are some of the data management issues that will be discussed.

KEYWORDS—Utah State Antiquities Act, Utah Geological Survey, Paleontological Locality, Database System

ABSTRACT

UPDATE ON MINERAL WELLS FOSSIL PARK–A PROJECT BY THE CITY OF MINERAL WELLS, TEXAS WITH ASSISTANCE FROM THE DALLAS PALEONTOLOGICAL SOCIETY

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ABSTRACT—Development of Mineral Wells Fossil Park (MWFP, www.mineralwellsfossilpark.com)—a free, city-owned park located 90 minutes west of downtown Dallas and 45 minutes west of downtown Fort Worth—continues to progress. After the City of Mineral Wells' City Council and Park Board approved its establishment, the Dallas Paleontological Society (DPS, www.dallaspaleo.org) raised and donated over $7000, numerous individuals and organizations contributed toward its opening, and the City agreed to match these funds. A gate, school bus parking lot, primitive toilet, informational sign, fencing, and chain handrail were installed and MWFP officially opened on 8 May 2010 with a ribbon cutting witnessed by more than 400 visitors (see Figures).

The site is now an outdoor hands-on science museum where visitors can touch and collect common Pennsylvanian Age marine fossils in situ, creating excitement and positive feelings about paleontology.

Information about the new park is being disseminated in a variety of forms: newspapers in Dallas, Fort Worth, Denton, and Austin have published articles; Texas Highways magazine will release an article about Mineral Wells mentioning Mineral Wells Fossil Park in May; Channel 4 in Dallas will be doing a video article; printed flyers from the Mineral Wells Chamber of Commerce are making their way to local museums; and a facebook page dedicated to Mineral Wells Fossil Park already numbers 574 members. Although highway signage for the park is not yet resolved, it should be forthcoming.

KEYWORDS—Mineral Wells, Fossil Park, Pennsylvanian Age, Dallas Paleontological Society

FIGURES. Mineral Wells Fossil Park, Texas, Grand Opening, November 2010. Example of fossils found at the park (image at right).

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ORAL PRESENTATION

FUN WITH TRACKS AND BONES: COOPERATIVE MANAGEMENT OF PARK PALEONTOLOGICAL RESOURCES BY COLORADO NATIONAL MONUMENT AND THE MUSEUM OF WESTERN COLORADO

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ABSTRACT—In the decade following George Callison's paleontological survey of Colorado National Monument in western Colorado in 1977, little paleontological work was done in this National Park Service unit. After Foster (1998) listed several sauropod tracksites in the Morrison Formation of the Monument, the Museum of Western Colorado began working with the monument in 2001 to document new paleontological sites and monitor those previously found. Work by museum crews, and by Ryan King and Josh Smith, documented a number of dinosaur track sites in the canyons of the monument, both in place and in fall blocks of Wingate Sandstone. Most of these tracks consist of *Grallator* specimens 6–17 cm in length (King et al., 2004) and occur as both natural casts and impressions. At least seven of the sites occur in Ute Canyon. A second, monument-wide survey by Kelli Trujillo and others in 2004 documented more sites and relocated many of Callison's sites. Most significant among the new finds was the tooth plate of a lungfish from the lower Morrison Formation (Imhof and Trujillo, 2005). In 2005, Fruita resident Marilyn Sokolosky showed museum crews a track site in the lower Morrison Formation that contained the second known occurrence of turtle tracks from the Late Jurassic of North America (Lockley and Foster, 2006). Not far from this site, and at the same stratigraphic level, was a second locality with tracks of a theropod and an ornithopod, the latter assigned to *Dinehichnus* (Lockley and Foster, 2006). Part of the slab with turtle tracks was collected in September 2010. Around the same time, Jim Roberson, a monument maintenance employee, found a small theropod or ornithopod track in the lower Morrison near Artists Point. John Foster and ReBecca Hunt-Foster found a new type of track, possibly belonging to small reptiles, in the lower Morrison in the same area.

The partnership between Colorado National Monument and the Museum of Western Colorado strengthened in 2010 with collaboration for the first ever National Fossil Day. National Fossil Day, hosted by the National Park Service and the American Geological Institute, is a celebration organized to promote public awareness and stewardship of paleontological resources and to foster a greater appreciation of the scientific and educational value of fossils. On October 12, 2010, Colorado National Monument and the Museum of Western Colorado provided a paleontology-focused field trip for more than 230 fourth grade students. During this National Fossil Day celebration, students visited both the museum and the monument: at the museum, students learned how fossils form, about geologic time and the geology of our area, and about fossils we find locally; at the monument, students took a ranger-guided hike in relevant geologic strata. Field trip content not only highlighted local fossil discoveries but also aligned with Colorado state science standards. Junior Paleontologist activity books were distributed to the three local, participating schools prior to the field trip date; students completed educational fossil activities and were awarded their Junior Paleontologist badges during the field trip. The fourth graders were the first public to view the "unveiling" of newly recovered fossilized turtle tracks displayed at the monument (later moved to the museum). Colorado National Monument hosted a public fossil "unveiling" on October 13, 2010, highlighting the recent discoveries, new exhibits, and honoring George Callison, John Foster and Bill Hood for their contributions to paleontological and geological research in the monument.

The partnership between Colorado National Monument and the Museum of Western Colorado has grown over the years, resulting in numerous educational opportunities, cooperative exhibits, and increased scientific research. This great working relationship benefits not only the residents of western Colorado, but all visitors to both venues.

KEYWORDS— Colorado National Monument, Museum of Western Colorado, National Fossil Day, Wingate Sandstone, Morrison Formation, Fossil Tracks

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ORAL PRESENTATION

ANCIENT CHANGES, MODERN MESSAGE: UTILIZING PALEOECOSYSTEMS OF THE CENOZOIC FOSSIL PARKS TO INTERPRET PAST AND PRESENT CLIMATE CHANGE

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ABSTRACT—At a fossil park, visitors are surrounded by a modern ecosystem different from the one experienced by its ancient inhabitants, making fossil parks ideal locations for interpreting past and present climate change. Oregon State University and the National Park Service are in the process of developing a training manual for interpreters at six Cenozoic fossil parks, designed to help interpreters connect visitors to the fossil evidence of changing landscapes, climates, and life preserved in the parks as well as clues about how change will affect our future. The manual focuses on the dramatic shift that occurred over the past 65 million years as the Earth transitioned from the greenhouse world experienced by the dinosaurs to a planet so cold that ice sheets advanced and retreated during the ice ages, with each park telling a different chapter of that story. Using the horse family as an illustration, the manual discusses how animals and plants migrated to more favorable conditions, adapted to the changes, or did not survive when the ancient ecosystems changed outside of an organism's "comfort zone." As modern climate continues to change, all living things—including humans—will face those same challenges. The manual also includes background information and suggestions for interpreting paleontology while answering three common visitor questions: "How old is it?" "What is a fossil?" and "Were all of those fossils found here?!" Although designed for use at the Cenozoic fossil parks, the interpretive suggestions can be tailored to any fossil site.

KEYWORDS— Climate Change, Cenozoic Era, Interpretation, Education, Paleoecosystem

POSTER PRESENTATION
Article, p. 51–60

ESTABLISHING A PALEONTOLOGICAL MONITORING TEST SITE AT GLEN CANYON NATIONAL RECREATION AREA

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ABSTRACT—Several factors were taken into consideration while establishing a paleontological monitoring test site at Glen Canyon National Recreation Area. Strata in the Recreation Area preserve a significant fossil record that includes many world class paleontological sites (Santucci and Kirkland, 2010), most notably a wealth of Lower Jurassic dinosaur tracksites preserved in the Glen Canyon Group along the margins of Lake Powell (Lockley et al., 1992, 1998). Santucci et al. (2009a) summarized the factors affecting in situ paleontological resources and strategies for monitoring their effects. There is little documentation of the long-term effect of these factors on fossil resources, but it is generally not an extremely rapid process unless the fossil is in an area of active erosion such as the bank of a river or the coast of a large body of water, or if the fossil in located in soft sediment. Vandalism and theft by humans pose a major threat to in situ fossil resources.

It is important to consider the costs associated with developing a monitoring plan. The most sophisticated methodologies may be cost-prohibitive and require trained scientists to carry out. Once a paleontological site has been properly documented, a plan can be developed to provide a means for low-cost, long-term monitoring. If significant changes are documented during subsequent visits, a follow-up inspection may be made by specialists (Milner et al., 2006; Santucci et al., 2009a, Spears et al. 2009).

KEYWORDS—Paleontological Monitoring, Glen Canyon National Recreation Area, Dinosaur Tracksite

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ORAL PRESENTATION

PLANNING, EXCAVATING, AND RECLAIMING A DINOSAUR EXCAVATION USING MECHANIZED EQUIPMENT IN THE 21st CENTURY

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ABSTRACT—While investigating a pipeline corridor with Uinta Paleontological Consultants, Inc. in 2002, Bureau of Land Management (BLM) geologist Roland Heath discovered ornithopod dinosaur bones weathering out of the Lower Cretaceous Cedar Mountain Formation a few tens of meters east of the pipeline corridor northwest of Dinosaur National Monument (DNM). The site, now known as the Reef Ornithopod, was referred to Scott Madsen, then preparator-geologist at DNM, who secured permits from the BLM and began a test excavation on the site in 2004. Several unguals, phalangies, and caudal vertebrae were recovered and curated into the DNM collections.

Policy changes at DNM precluded further work on the site by DNM personnel, and the site was turned over to the Utah Geological Survey (UGS). Permits were secured and more extensive excavations resumed in the spring of 2007 with the Utah Museum of Natural History as the newly designated repository. These excavations resulted in the exposure of a more associated skeleton with many more phalangies, vertebrae, and ribs, portions of the forelimbs, teeth, and possible skull material in a large block of rock, with more of the skeleton extending into the ground.

The site is situated on a steep slope and the enclosing strata dip steeply into the hill, requiring an extensive high wall to be excavated in the rock to expose even a small portion on the bone-bearing layer. This phase of the excavation required about three days of back-breaking pick, shovel, and electric jack hammer work for each day of work on the bone-bearing interval (estimated at about 0.5 meter thick). Upon reaching a large natural parting surface cutting across the specimen, we made a plaster jacket over the block then flipped the jacketed block (which weighed several hundred kilograms) off the parting with railroad pry-bars without splitting any bones. Because the pipeline crew was scheduled to reach the area in a few weeks, we decided to request permission from the BLM to take advantage of the pipeline company's offer to use their equipment to lift the jacketed portion of skeleton off the site and to remove overburden upslope so that the rest of the skeleton could be excavated. The plaster jacket and quarry were buried until we could return and excavate the remainder of the skeleton.

The National Environmental Policy Act required a new evaluation of the site and the environmental consequences of utilizing mechanized equipment to excavate the remainder of the skeleton. The Utah State Paleontologist quickly put together a formal excavation plan (Fig. 1) and submitted it to the BLM, but the opportunity to have free use of mechanized equipment had passed. A permit was issued in the spring of 2009, but funds were unavailable to support field work or to hire equipment to assist in the excavation for the 2009 field season. Over the winter of 2009–2010, a connection was made with Ames Construction through the interest their engineer, Don Brummel, and his family have in dinosaur paleontology. Ames Construction was generous enough to provide equipment, transportation, and operators to assist in the excavation in May 2010.

The UGS crew arrived a few days early to uncover the jacket, ready the quarry, and become familiar with the route into the site approved by the Vernal BLM office. The plaster jacket had corroded badly over the two winters it lay buried in the field and had to be completely rejacketed. By the time Don Brummel arrived with his crew, we had harnessed the jacket up so that it was ready to be lifted out of the quarry, transported down to the road, and put on a truck for transport to the UGS preparation lab in Salt Lake City. Meanwhile, Ames Construction excavated the overburden from above and around the remainder of the skeleton, leaving the remaining dinosaur bones in a small hill within a large hole.

Over the next week the UGS crew worked to delineate, map, and jacket the remainder of the skeleton so that we would be ready when Ames Construction returned to Vernal to assist in lifting the remainder of the dinosaur out of the excavation and transporting it to the road. Had we not completely excavated the dinosaur in the area they exposed for us, any additional bones would have to be left in the ground, as it would have been impractical to dig the pit any deeper in the tough rock enclosing them. Fortunately, we were able to excavate all of the skeletal remains and encase them in a jacketed block (which also weighed hundreds of kilograms). The Vernal Field House of Natural History offered to help prepare this block. We decided if enough fossil material was available to construct a mounted skeleton, we would seek to get a mount for Vernal as well as the Utah Museum of Natural History. While there is much work to go on that block, preliminary preparation has exposed at least one jaw with teeth.

Ames Construction was completely responsible for the reclamation of the excavation, which would easily have taken more than a week if our crew had attempted it with hand tools. They filled the excavation pit, contoured the slope, and smoothed out the rough area to ensure good drainage of the site. Additionally, they raked out the access route and dropped some large rocks across the gap in the ridge that they had used to access the site from the road to discourage use by off-road vehicles. Six months after reclamation, there is barely a sign that this excavation took place.

Preparation of the fossils themselves is still in the early stages, but we have skull material so it is likely that we have collected taxonomically-significant material. Our initial guess, based on stratigraphic position, was that the dinosaur might represent the first specimen of *Tenontosaurus* to be collected in Utah, but the morphology of the jaw suggests it may be something else, perhaps something new. A publication on our geological observations of the stratigraphic section exposed crossing the site and on the implications of a new radiometric date we obtained from the overlying Dakota Formation is currently in review.

Despite the trials and tribulations involved in this excavation, it still stands out as a true success story for the kind of research and minimal environmental impacts that may result from interagency cooperation and a bit of patience on all sides.

*Presenting author

KEYWORDS—Site Steward, Volunteer, Resource Management

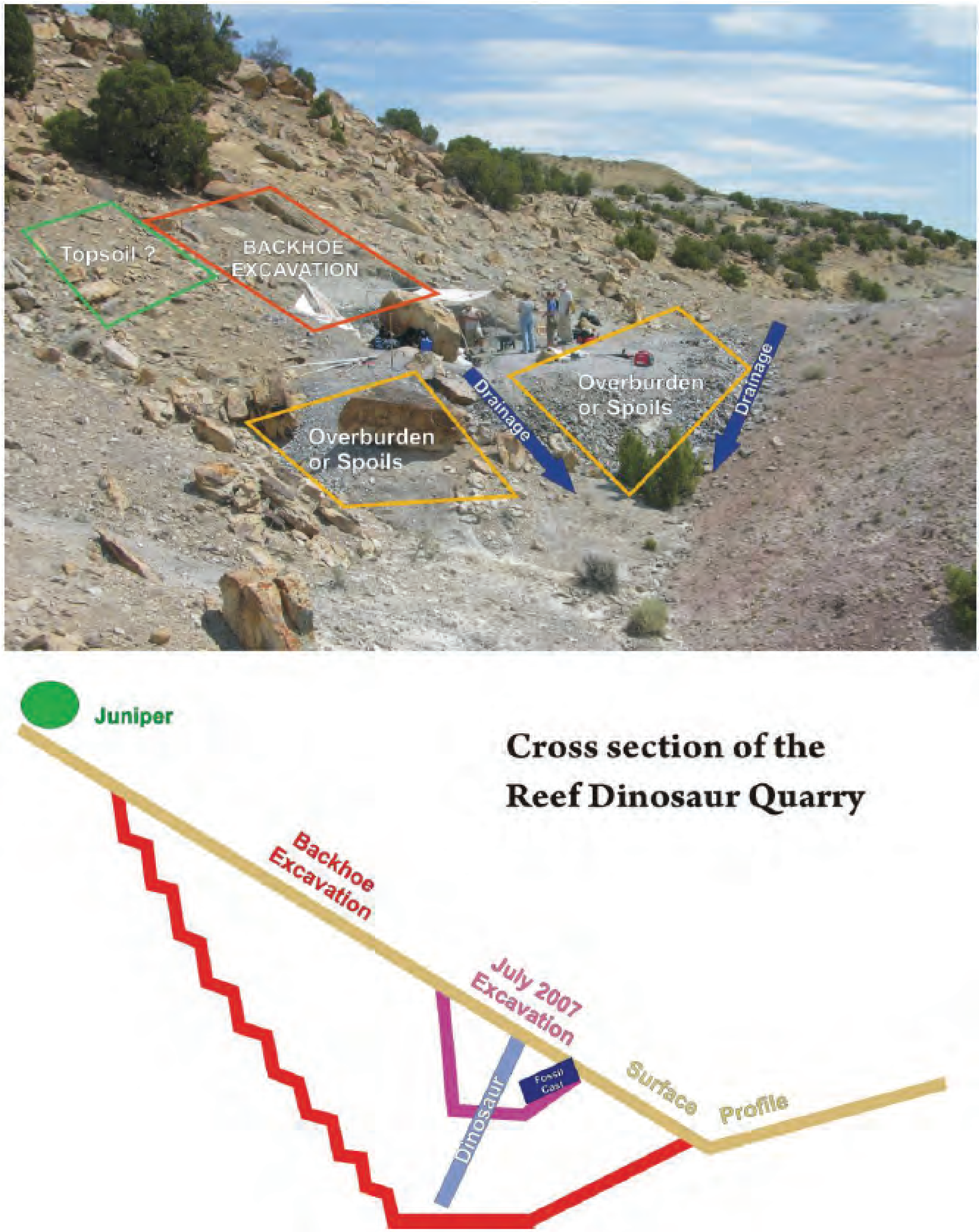

FIGURE 1. Initial excavation plan for the Reef Ornithopod.

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ORAL PRESENTATION

THE EFFECTIVENESS OF PRE-SURVEY AERIAL PHOTOGRAPHY AND GEOLOGIC MAP REVIEWS: A CASE STUDY BASED ON FOSSIL DISTRIBUTION WITHIN THE UINTA FORMATION, UINTAH COUNTY, UTAH

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ABSTRACT—Prior to conducting field surveys, mitigation paleontologists commonly examine topographic, fossil locality, and geologic maps, as well as aerial photography in order to delineate areas with the highest paleontological potential. This practice has become especially prevalent in recent years with ready access to high resolution aerial imagery via free software such as Google Earth and data sets such as the USGS Seamless Data Warehouse. These methods are especially useful to mitigation paleontologists when analyzing large geographic areas as part of the permitting process for surface disturbing projects on public lands. Many such projects have time, cost, and/or access constraints which make such analyses beneficial. Subsequent to this initial desktop review the overall sensitivity of a project area is generally considered to be adequately assessed, and the information is used to determine a field survey strategy. At this point it is typically assumed that areas with the greatest amount of exposed sedimentary bedrock have the highest paleontological sensitivity (greatest potential to yield scientifically significant surface fossils). Using a large data set comprised of approximately 5,000 fossil occurrences recorded during a block paleontological survey of the Uinta Formation in the vicinity of Leland Bench, Uintah County, Utah, we explore the effectiveness of pre-field survey desktop analyses to predict actual surface fossil distribution. Using aerial photography of six square miles within the original block survey, we calculated the amount of terrain consisting of a) well exposed bedrock; b) weathered and partially vegetated bedrock; and c) bedrock completely covered by vegetated surficial sedimentary deposits, then inferred differential paleontological sensitivity. We compared the resulting sensitivity map with the fossil occurrence data from the field survey to determine the reliability of the predictive model.

KEYWORDS—Uinta Formation, Uintan, Geologic Mapping, Paleontological Resource Management, Aerial Photography

ORAL PRESENTATION

INVENTORY AND UPDATING THE WHITE RIVER GROUP COLLECTIONS FOR THE MOVE TO THE JAMES E. MARTIN PALEONTOLOGICAL RESEARCH LABORATORY

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ABSTRACT—The collections at the Museum of Geology at South Dakota School of Mines and Technology (SDSM), started in 1885, currently numbers more than 500,000 specimens. A large number of these specimens were recovered from federally-managed lands in the extensive White River Badlands of South Dakota and Nebraska (Oligocene through Miocene); SDSM acts as a repository partner for federal land management agencies. Fossils have been used for research, teaching, and training.

When construction of the new James E. Martin Paleontological Research Laboratory began in 2009, SDSM undertook a complete review and inventory of these fossils and their associated data for the first time in many years. The extent and complexity of the White River Badlands fossil holdings and their associated data have made this a particularly important project. The principal goal of this project was to move the fossils into the best possible biostratigraphic sequence in order to facilitate future retrieval and research. Secondarily, the project will separate the White River Badlands collection into three administrative sub-collections: those associated with Badlands National Park (North Unit), those associated with Badlands National Park and the Pine Ridge Reservation (South Unit), and the remaining White River Badlands fossils from all other public and private lands. This project will be ongoing through 2011 and will result in much finer-grained and accurate data for all specimens as well as better management of fossil collections with multiple stakeholders.

KEYWORDS—South Dakota School of Mines and Technology, White River Badlands, Paleontological Research Laboratory, Museum Collections

*Presenting author

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ORAL PRESENTATION

THE IMPACT OF VOLUNTEER PALEONTOLOGICAL MONITORING AND SURVEYING IN CARIBOU-TARGHEE NATIONAL FOREST ON THE CRETACEOUS PALEONTOLOGY OF SOUTHEASTERN IDAHO

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ABSTRACT—In 2001, volunteers began monitoring and surveying paleontological resources in mid-Cretaceous strata found within the boundaries of the Caribou-Targhee National Forest near the Wyoming border of southern Idaho. Fieldwork focused in the Caribou Basin and Fall Creek areas of Bonneville County, and the Tincup Canyon area of Caribou County and was conducted on a volunteer basis by the primary author (LK), an undergraduate student at Idaho State University at the time, under the supervision of the Caribou-Targhee National Forest Regional Paleontologist at the time, the secondary author (SR), through a formal voluntary agreement. The purpose of this paleontological reconnaissance was the monitoring of known fossil localities, collection of additional specimens from these localities, and the search for new paleontological localities; it also resulted in numerous undergraduate research projects, published abstracts and a paper, a MS thesis, and ongoing research opportunities.

Findings from this work include a freshwater vertebrate fauna from the Aptian-Albian Draney Limestone of the Gannett Group, exposed in Tincup Canyon. The Draney Limestone represents a series of one or more large lakes that straddled the Idaho/Wyoming border in the mid-Cretaceous. The Draney fauna is known from two localities, Pine Bar and Cretaceous Park. The Pine Bar locality has produced the most varied fauna, consisting of rare teeth from the shark *Hybodus*, abundant crushing teeth from the fish cf. *Lepidotes*, numerous unidentified fish bones and ganoid scales, a poorly preserved large dinosaur trackway, as well as plastron and carapace fragments from the turtle cf. *Glyptops*. Invertebrates include numerous ostracods, freshwater gastropods, and unionid bivalves, while flora are represented by unidentified wood petrifactions and angiosperm leaf fragments. The Cretaceous Park locality is less varied, with plastron and carapace fragments from the turtles cf. *Glyptops* and cf. *Naomichelys* and crocodylian teeth. Invertebrates here consist of abundant ostracods and rare gastropods.

Work in the Cenomanian Wayan Formation, as exposed in Tincup Canyon, Caribou Basin, and the Fall Creek area, has facilitated understanding of what is now Idaho's best represented Mesozoic terrestrial fauna. Deposition of the Wayan Formation occurred in a narrow inland alluvial strip with the Paris and Meade Thrust highlands of the early Sevier Orogeny to the west and the Mowry Seaway to the east. This area was subject to a monsoonal climate represented by numerous well developed paleosol horizons with calcareous nodules. Discoveries include numerous partial skeletons of Idaho's first well represented dinosaur, the small fossorial ornithopod *Oryctodromeus*. Taphonomic evidence for these specimens supports fossorial behavior and social grouping as demonstrated for the holotype and paratype specimens from the Blackleaf Formation of southwestern Montana. Other specimens include associated vertebrae and pedal elements from an indeterminate small iguanodontian, a dromaeosaurid theropod tooth, abundant eggshell of the family Elongatoolithidae (possibly representing nesting sites of indeterminate large theropods), a partial large crocodylian skull that exhibits similarities to the later Cretaceous form *Deinosuchus*, crushing fish teeth and ganoid scales similar to *Lepidotes*, and unidentified turtle carapace and plastron fragments. Moderately well-represented flora is known from one locality and consists of foliage from the ferns *Gleichenia* and *Anemia*, as well as foliage and cones from conifers, partial angiosperm leaves, and wood petrifactions.

Notably, all of these discoveries result from work done by volunteers through 2008. Because supervised volunteer locality monitoring and prospecting were conducted on a relatively cost-free basis and afforded opportunities for Caribou-Targhee National Forest and other federal land management agencies with the same strata to gain a greater understanding of fragile paleontological resources, this represents an advantageous model of paleontological conservation on federal lands. Significant specimens, which have since been utilized in numerous research projects, were collected under supervision of the Regional Paleontologist and were reposited in federally accredited repositories. In addition, this opportunity of volunteerism represents an advantageous way to harness amateur and student enthusiasm, providing a springboard for student research and related projects and valuable hands-on and field experience learning opportunities.

KEYWORDS—Idaho, Cretaceous, Wayan, Draney, Caribou-Targhee

*Presenting author

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ORAL PRESENTATION

EDUCATING FUTURE PALEONTOLOGICAL RESOURCE MANAGERS AT OGLALA LAKOTA COLLEGE (OGLALA SIOUX TRIBE), PINE RIDGE RESERVATION, SOUTH DAKOTA

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ABSTRACT—Since the decision to return the South Unit of Badlands National Park to the Oglala Sioux Tribe in late 2010, there has been a growing interest within Oglala Sioux Tribe (OST) governmental agencies to employ academically trained Lakota people in the field of cultural and paleontological resource management. On the Pine Ridge Reservation, fossils, artifacts, and human remains are collectively considered to be *cultural resources*, in that they are all remains of the interconnected once-living that are recovered by excavating the earth. Oglala Lakota College (OLC) has responded to this need by obtaining external funding to support undergraduate and graduate student curricula in cultural (paleontological) resource management and by establishing data and specimen repositories to support the OST Tribal Historical Preservation Office's (THPO's) efforts. Our undergraduate curriculum, which is still being developed, consists of a Cultural Resources Emphasis in our B.S. in Natural Science. The OLC Department of Humanities contributes coursework in archeology to this degree program. Our graduate curriculum is also in progress, and consists of an M.S. in Cultural Resource Management granted by St. Cloud State University. This curriculum consists of coursework and research conducted principally at OLC, and presently accommodates a cohort of four graduate students. The OLC data and specimen repositories were originally intended to house biological collections. However, ongoing plans to repatriate fossils and artifacts from the South Dakota School of Mines & Technology, the Smithsonian Institution, Augustana College, and the South Dakota Archeological Center, along with fossils and artifacts recovered during highway salvage operations, has required that we expand the mission of our repository. The repository is under construction with completion projected for late 2011 or early 2012. In addition, discussions are underway to house the OST THPO at the OLC Department of Math, Science, & Technology. The curriculum development and repository described herein are supported by National Science Foundation Tribal Colleges and Universities Program and Academic Research Infrastructure grants to C. Jason Tinant and Hannan E. LaGarry (CoPIs).

KEYWORDS—Paleontological Resources, Tribal, Oglala, Education, Management

ORAL PRESENTATION

GIS MAPPING OF FOSSIL LOCALITIES USED AS A MANAGEMENT TOOL

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ABSTRACT—The Farmington, New Mexico Field Office (FFO) of the Bureau of Land Management manages the 44,897 acre Bisti/De-Na-Zin Wilderness. The last systematic inventory of paleontological resources in the Bisti was conducted in 1977; the FFO has used Geographic Information Systems (GIS) to generate a map using that data. We have also incorporated locality data collected over the last 20 years by the New Mexico Museum of Natural History and Science (NMMNHS) and the State Museum of Pennsylvania through reconnaissance, surface collection, and excavation. The map's spatial data will help to highlight areas where fossils were recorded or collected sorted by year, by project, by collector, or by fossil type.

A complete paleontological resources inventory of the Bisti will begin in July of 2011 through an assistance agreement with the NMMNHS. This multi-year project will review all previously-known fossil localities in the Wilderness (published and unpublished), including a re-inventory of the 1977 sites. Use of the map will help identify survey priorities by pinpointing areas where the most pressing needs for inventory exist. New localities discovered during the course of the survey will be added to the GIS data base map.

This map provides an effective visual inventory and a valuable paleontological resource management tool for the FFO. In the future, similar GIS maps can be developed for the FFO's nine paleontological Specially Designated Areas. The BLM can use these maps to protect fossil resources, coordinate volunteer efforts, prioritize field work, develop monitoring strategies, locate new research areas, and reconstruct paleoenvironments. They can also be used for partnerships, public outreach, and educational purposes.

KEYWORDS—Bisti/De-Na-Zin, Inventory, GIS, Survey, Strategy

*Presenting author

ORAL PRESENTATION

BUILDING A NEW PALEONTOLOGY SITE STEWARD PROGRAM

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ABSTRACT—Ideally, paleontological resource management would include a smorgasbord of surface reconnaissance, monitoring of recorded fossil localities, patrolling areas of heavy public use in fossil-rich areas, monitoring permitted field projects, assisting with research projects, in-house endeavors, outreach, and monitoring erosion at known sites. The BLM Farmington Field Office (FFO) manages 1.8 million acres, of which 120,299 acres fall into paleontological Specially-Designated Areas. The FFO manages 85% of the acreage in New Mexico's paleontological specially-designated areas. In addition, the remaining 1.6 million acres in the FFO are classified as 5 (Very High/highly fossiliferous and/or at risk) on the Potential Fossil Yield Classification scale. Management of this vast resource falls on one half-time paleontology specialist.

Following on the heels of a highly successful Archeology Site Steward Program, management will fill the gap with well-trained volunteer manpower. Volunteers will provide the BLM with additional "boots on the ground" to exponentially increase observation and recordation. The program offers concerned citizens opportunities to participate proactively in the stewardship of paleontological resources. The FFO will draw on its own thriving Archeology Site Steward Program and the St. George Field Office's dual-resource Site Steward Training Manual and modify them to fit local needs.

Trained volunteer manpower will help the FFO manage our vulnerable and scientifically important paleontological resources. These volunteers will also increase public awareness of the significance and value of paleontology while promoting an understanding of local geology and federal paleontology laws.

KEYWORDS—Site Steward, Volunteer, Resource Management

POSTER PRESENTATION
Article, p. 61–68

THE KEYA PAHA FAULT AND RELATED STRUCTURES: THEIR SIGNIFICANCE TO THE GEOLOGY OF SOUTH DAKOTA

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ABSTRACT—A major geological structural feature, the Keya Paha Fault, occurs in south-central South Dakota and appears to extend northwestward across South Dakota. The fault is subparallel to the well-documented White Clay Fault, occurring farther west in South Dakota, and to other lineaments occurring between the two faults. Ponca Creek and even the portion of the Missouri River subparallel the direction of the Keya Paha Fault to the east. The trends of all these structural features suggest a northwesterly directed structural fabric across western South Dakota. The Keya Paha Fault is demarked by the absolute straight trend of the Keya Paha River across Tripp and Todd counties, offset of Tertiary fossiliferous beds in the Badlands, and perhaps the trend of the Northern Black Hills Tertiary Intrusive Province. Additional subparallel lineaments occurring along the South Dakota-Nebraska border may also eventually prove to be of fault origin in South Dakota. Recent investigations along the Missouri River have indicated smaller scale faults and clastic dikes. These too are often trending northwesterly and have been found with glacial debris within the fault gauge, suggesting relatively recent movement. Overall, this northwesterly trending structural fabric has great impact upon the distribution of natural resources in South Dakota, including, among others, water, petroleum, minerals, and fossils

KEYWORDS—Keya Paha Fault, South Dakota, Lineaments, Structural Geology

*Presenting author

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ORAL PRESENTATION

TAKING MEASURE OF TECHNOLOGY: WHERE WE HAVE BEEN AND WHERE WE ARE GOING WITH 3D IMAGE CAPTURE AND CLOSE-RANGE PHOTOGRAMMETRY

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ABSTRACT—In 1997, dinosaur footprints preserved in the limestone bed of a dry wash in the Bighorn Basin of Wyoming were observed and reported to the Worland Field Office of the Bureau of Land Management (BLM). This discovery started a chain of events that has led to the Red Gulch Dinosaur Tracksite (RGDT) becoming one of the most thoroughly documented fossil footprint sites in the world. Early in the history of the RGDT project, it was decide to use the best science to capture the scientific value of the site prior to developing and interpreting it for the public. Thus began BLM's use of close-range photogrammetry for the documentation of vertebrate fossil sites.

Photogrammetry is the art, science, and technology of obtaining reliable measurements from photographs. The basic requirement for photogrammetry is an overlapping pair of photographs taken to mimic the perspective centers of human stereoscopic vision. During the early days of 3D photodocumentation at RGDT, the process was very labor intensive and could require as much as a week to get a final dataset for a single footprint. As technology advanced, stereoscopic photographs, captured at a variety of heights from a number of different platforms at the RGDT, provided a wealth of 3D data for interpretation and analyses. Not only did these efforts increase the knowledge of the unique, paleontological resources at the site, they also provided a visual and quantifiable baseline that is being used to evaluate and better understand changes that occur to the track surface.

In the years since its beginnings at RGDT, close-range photogrammetry has been used to document and interpret fossil footprints sites throughout the western United States. Following the model established at RGDT, the camera and in some cases the photographer have taken to the air, using blimps, helicopters, and ladders to obtain the needed photographic perspectives of the subject. Individual tracks, trackways, and even entire track surfaces have been documented using close-range photogrammetry on lands managed by BLM, U.S. Forest Service, National Park Service, and Bureau of Reclamation in Wyoming, Utah, Colorado, Nebraska, Oklahoma, New Mexico, Arizona, California, and Alaska.

Today, advances in digital cameras, computer architecture, and multi-view matching software make it possible to take photos and produce a final dataset in a matter of minutes. In addition, the technique is much more portable, allowing the capture of stereoscopic photos to be conducted by field personnel. This makes close-range photogrammetry (CRP) an effective method for capturing important data about a wide variety of resources. Often the use of photogrammetry can be more efficient, less labor-intensive, and more cost-effective than other types of field 3D data collection.

Recent advancements in software now provide low- and no-cost solutions for successfully processing stereoscopic photographs that have been taken with 60 to 75 % overlap. This will significantly increase the use of CRP for resource documentation by allowing the field photographer to receive almost immediate feedback on the success of image capture. With the introduction of low/no cost software the processing of close-range photogrammetric images is no longer confined to a few locations, thus reducing the limitations on generating, using, and sharing 3D date of ichnological features.

KEYWORDS—Resource Inventory, Resource Monitoring, Close-Range Photogrammetry, Ichnology, Vertebrate Paleontology

*Presenting author

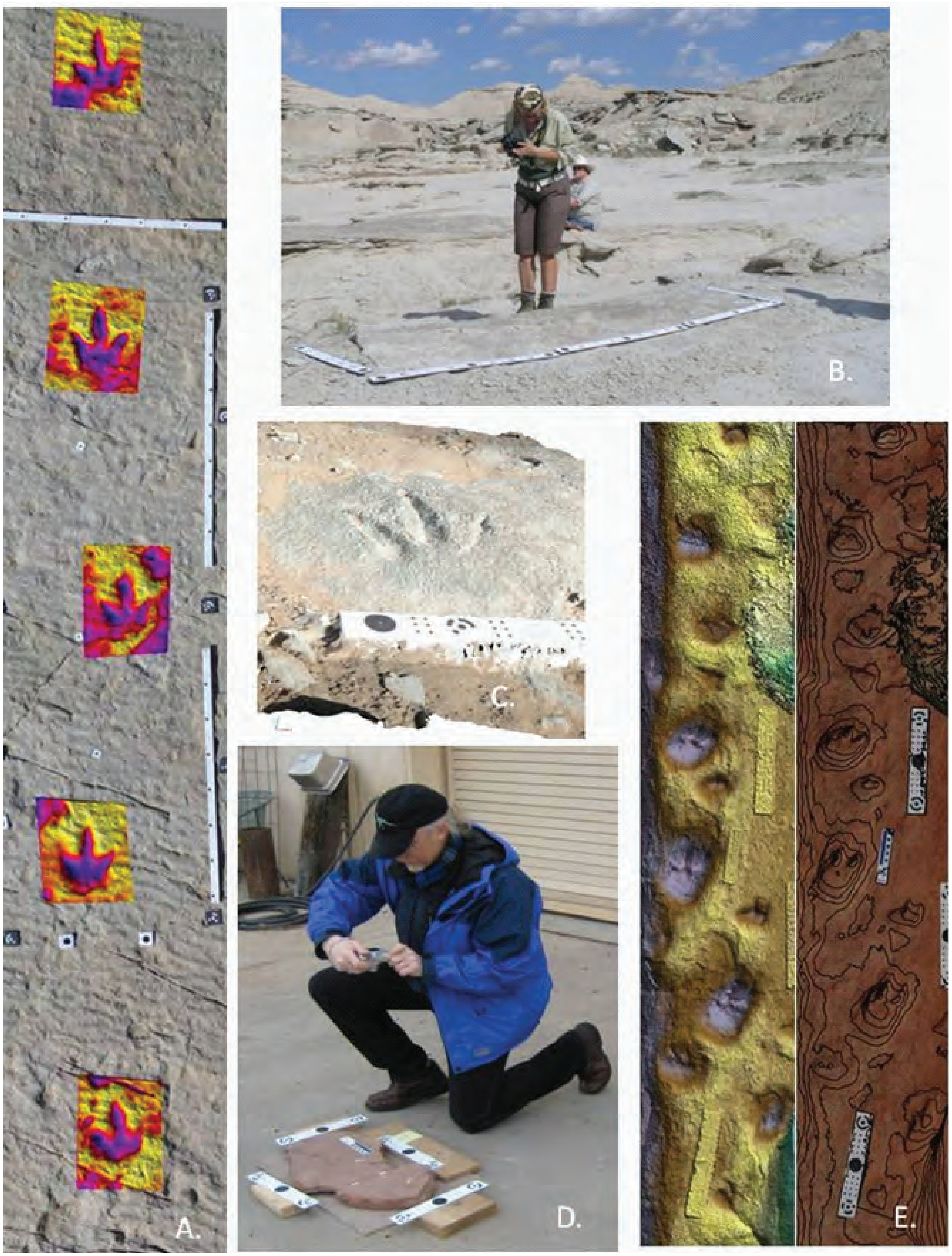

FIGURE 1. **A**, Orthoimage of the “Crosstown” theropod trackway from the Red Gulch Dinosaur Tracksite, Wyoming; tracks are depicted with color contours. **B**, Close-range photogrammetric capture of a track surface at Toadstool Geologic Park, Oglala National Grasslands, Nebraska. **C**, Mill Canyon Road, Utah, track rotated to 3D perspective, **D**, Photography of museum specimen from the Prehistoric Trackways National Monument, New Mexico. **E**, *Navahopus* trackway shown in color surface model and 2 mm contours, Paria Canyon-Vermilion Cliffs Wilderness, Utah.

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POSTER PRESENTATION

THREE-DIMENSIONAL FOSSIL FOOTPRINT TRACKING: VERTEBRATE ICHNOLOGY IN THE NATIONAL LANDSCAPE CONSERVATION SYSTEM

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ABSTRACT—The Western United States contains 27 million acres set aside as National Landscape Conservation System (NLCS) lands administered by the Bureau of Land Management (BLM). The Omnibus Public Lands Management Act established the NLCS as a formal system of BLM-administered public lands and also enacted Paleontological Resources Preservation legislation. There are more than 886 federally-recognized areas within the NLCS, including National Monuments, National Conservation Areas, Wilderness Areas, Wilderness Study Areas, and other areas of special designation. NLCS lands contain significant paleontological resources. Federal agencies now have a mandate to preserve these resources on public lands and manage them using scientific principles and expertise. Over the past decade, the BLM has adopted a more active approach in the management of paleontological resources by coordinating and promoting external research partnerships, as well as by using cutting-edge Geographic Information Systems, Global Positioning Systems, close-range photogrammetry (CRP), 3-D visualization, and other technological methods. During this time, CRP has experienced rapid technological evolution. Economic high-resolution digital SLR cameras, increasing capabilities of computers, and advancements in the analytical software have simultaneously decreased the costs and increased the usability of CRP. Both ground-based photography and low-level aerial imagery have been used in ichnological studies within the NLCS. These cutting-edge studies documented Permian through Middle Jurassic fossil footprints located in Prehistoric Trackways National Monument, New Mexico, Vermilion Cliffs National Monument and Paria Canyon-Vermilion Cliffs Wilderness, Arizona and Utah, and Grand Staircase Escalante National Monument, Utah.

KEYWORDS— Resource Inventory, Resource Monitoring, Close-Range Photogrammetry, Dinosaur Tracks

POSTER PRESENTATION

BURGESS SHALE FOSSIL MANAGEMENT THROUGH PROTECTION, PRESENTATION AND SCIENCE: YOHO NATIONAL PARK, BRITISH COLUMBIA

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ABSTRACT—As one of the most significant fossil localities in the world, designated a World Heritage Site by UNESCO in 1981, the Burgess Shale is important for understanding early animal evolution during the Middle Cambrian Period. As the steward of this internationally significant resource, Parks Canada strives to protect the fossil sites and collections, provide visitors with experiences that promote awareness and understanding of the importance of Burgess Shale, and support ongoing scientific research. In particular, Yoho National Park is undertaking a suite of initiatives directed at effectively managing and promoting the in-situ and off-site Burgess Shale resources. This poster presents the park's current management plans related to the protection of the resources within the context of the following themes: planning, area signage and fencing, site monitoring, enforcement, access and research. The poster also presents achievements related to the provision of visitor opportunities in the area of interpretation, guiding and off-site presentation through the use of wireless webcams. Parks Canada strives to enhance its management of the Burgess Shale resources by continuing to observe and adapt the strategies used by others who have similar responsibilities for the care of fossil resources elsewhere.

KEYWORDS—Burgess Shale, Resource Management, Protection

*Presenting author

ORAL PRESENTATION

CREATIVE STRATEGIES IN CONSERVATION: DOCUMENTING THE ESTABLISHMENT AND HISTORY OF FLORISSANT FOSSIL BEDS NATIONAL MONUMENT

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ABSTRACT—We are using firsthand accounts to complete a book on the controversial establishment and important history of Florissant Fossil Beds National Monument. The Monument was created from private lands in 1969. Before then, real estate subdivision threatened to destroy the fossil resources while establishing legislation was stalled in Congress. Scientists and citizen groups organized to form the Defenders of Florissant in an effort to stop the planned development. The Defenders were represented by the lawyer who founded environmental law, and the Florissant case became well-recognized for its innovative strategies applying the Public Trust Doctrine to an environmental legal issue. The effort was successful in obtaining an injunction from the federal courts, which stopped the development long enough for Congress to act. Once established, the new monument took many years to achieve its congressionally-defined priorities in paleontology. Our emphasis in the book demonstrates the influence of this significant fossil site on early stages of the environmental movement and the establishment of environmental law. We also address the accomplishments and impediments made by the National Park Service in focusing on its defined purpose for a paleontology park and providing public recognition for the lawyers and others who made history at Florissant. The book has stimulated new recognition by NPS for important players in the movement, and it provides an important contribution to the administrative history and paleontological significance of the Monument.

KEYWORDS—Florissant Fossil Beds National Monument, Environmental Law, Estella Leopold

ORAL PRESENTATION

FULL DISCLOSURE OF PALEONTOLOGICAL LOCALITY DATA: AN INTEGRAL COMPONENT OF CREDIBLE SCIENCE

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ABSTRACT—Collection and reporting of primary data are fundamental components of the scientific method. Observational data form the basis for analysis, synthesis of results, and formulation of conclusions. The process of credible peer review requires that primary data be openly accessible in publication for reviewers and readers to critically analyze the study's merits. Because geology and paleontology are inherently three-dimensional, spatial data for stratigraphic and geographic coordinates are critical for documenting and interpreting fossiliferous assemblages, geologic formations, paleoecological context, and taphonomic bias. Publication of these data typically requires presentation in tables, maps, and figures. Unlike archaeology, where spatial data occur within a limited internal framework that can be documented without revealing geographic location, fossils occur in a geologic context over large spatial areas. Withholding primary data, including precise locality data, significantly compromises the integrity of the science of paleontology; failure to report these data constitutes a breach of research integrity, including an inability to repeat the study, which is foundational to the scientific method. Furthermore, the data management plan of the National Science Foundation newly requires primary data be made available to the public; preventing open availability of locality data dooms the field of paleontology to fall behind other fields that are making great strides in understanding the influence of abiotic and biotic variables on the biogeography and evolution of organisms. By restricting access to these invaluable specimen metadata, we lose the ability to study broad-scale spatial patterns of the past and generate predictive models for the future.

KEYWORDS—Paleoecological Context, Geologic Context, Scientific Data, Fossil Locality

*Presenting author

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ORAL PRESENTATION

ROCKS, REGULATIONS AND REPOSITORIES: THE THREE "Rs" OF A SUCCESSFUL CURRICULUM FOR PALEONTOLOGISTS IN A PRPA WORLD

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ABSTRACT—With passage of the Paleontological Resources Preservation Act (PRPA), the need for resource management paleontologists is just as imperative as that for researchers and educators. The South Dakota School of Mines offers programs which emphasize "hands on" aspects of paleontology, particularly field and collections work. The challenge remains to strike a balance between training paleontologists with diverse skills desired in a PRPA world and maintaining the rigor of a curriculum which prepares students to be effective researchers.

Our undergraduate curriculum stresses "geology first" and employability. The standard suite of geology courses is complemented by extensive training in Geographic Information Systems (GIS). Geology and paleontology field camps are required. Mandatory senior thesis projects instill research skills and promote professional interaction outside the classroom. Additional courses on fossil preparation, collections and resource management enhance the baccalaureate course load.

The Master's program emphasizes a traditional, geological approach to paleontology. Comparative Osteology familiarizes students with skeletons of various groups enhancing bone identification skills. Vertebrate Paleontology is an in-depth treatment of the fossil record of vertebrates. Biostratigraphy places fossils in spatial and temporal context and develops familiarity with stratigraphic units. Advanced field training is coupled with courses in fossil preparation, curation, and resource management.

Additions to this type of curriculum may better prepare students for jobs in government or private firms. Courses such as business management, business and research ethics, and American civics may result in better functionality in a non-academic environment. Increased cooperation among academic, government, and private entities is essential for continued development of effective paleontology curricula.

KEYWORDS—Paleontology, Education, Curriculum, Resource Management

*Presenting author

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ORAL PRESENTATION

PRELIMINARY REPORT OF THE FIRST RECORDED LATE PLEISTOCENE MAMMAL TRACKS FROM SOUTHEAST IDAHO AND MANAGEMENT IMPLICATIONS

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ABSTRACT—Late Pleistocene mammal tracks were recently discovered in southeast Idaho on both US Bureau of Reclamation (BOR) and US Forest Service (USFS) administered lands. While tracks from earlier time periods have been reported in Idaho, this is the first report of Pleistocene tracks. A USFS employee (lead author) discovered these tracks during the inventory and salvage of fossils from the Palisades Reservoir area. This individual also discovered tracks at American Falls Reservoir (AFR) while working under a voluntary agreement with the BOR. Because the tracks are located in popular recreation and high erosion areas, impacts will destroy these tracks if management plans are not developed and implemented. The location of these tracks presents both concerns and opportunities for federal agencies to manage and/or protect these important non-renewable resources by developing cooperative agreements with other agencies/individuals.

Tracks are known from a few localities on USFS lands in the Palisades Reservoir area, near the Idaho-Wyoming state line. Stratigraphy of the track-containing loess deposits is complex, and correlation between track localities generally cannot be established. The tracks appear to represent the following taxa (detailed studies forthcoming): proboscidean, camelid, horse, bison/musk ox, and possibly other ungulates. Known skeletal fossil remains from these deposits include mammoth, mastodon, camel/llama, horse, bison, musk ox, big horn sheep, mountain goat, and other megafauna. As many as 10 different track horizons may be present at the most prolific track locality. Individual track-ways have not yet been recognized because of limited outcrop exposure and trampling.

Three additional track localities have been found at AFR on BOR lands near Pocatello, Idaho. Two of these localities are below the high water line and one just above it. The known late Pleistocene fauna from the American Falls Reservoir area is extensive and well-documented, but this is the first report of tracks.

A small locality that preserves numerous horse tracks in a calcareous, fine-grained sandstone was found at AFR in 2009. Little could be done at this locality in 2009 because the tracks were under water when found and were not exposed again until fall 2010. Two short trackways, with a few actual tracks and numerous under-tracks, are present. Wave action and recreational activities have contributed to the destruction of these tracks. A cooperative agreement between the BOR and the Idaho Museum of Natural History (IMNH) to document and salvage these tracks was started in October, 2010.

Probable proboscidean tracks were found in an unconsolidated silty clay layer at AFR in 2010. Repeated wind and wave erosion are removing most of the delicate surface track details and structures. The surface appears to be somewhat trampled, yet a few individual trackways appear to be recognizable. Many traces here may only be under-tracks.

The third track area at AFR, also discovered in 2010, lies just above the high water line at the base of a cliff of unconsolidated sand, silt and clay. The proboscidean tracks here were initially recognized in cross-section in the cliff face in a silty clay layer. In fall 2010, some of the overburden was removed, revealing numerous near-pristine tracks which appear to continue into the cliff. The preservation quality of these tracks was aided by burial by a fine-grained sand with little apparent erosion prior to burial. Two relatively large felid tracks—a very rare occurrence anywhere—are associated with these proboscidean tracks.

Over the past 25 years, the BOR has performed erosion control work at AFR to help prevent heavy erosion of the shoreline and surrounding cliffs. This program involves back-sloping the top of the cliff and using geotextile fabric, earthen barriers, and large boulders in a process called rip-rapping to prevent erosion and loss of land surface, reduce sediment input into the reservoir, and reduce safety hazards associated with the cliffs. This track locality is in an area scheduled for rip-rapping in July, 2011.

Due to the paleontological significance of the cliff track locality, the BOR has agreed to modify erosion control activities in the immediate area and is working with experts to develop a management plan to document and conserve these tracks. An initial on-site evaluation was made in October, 2010 to begin the preliminary discussion of possible erosion control modifications. A team of researchers is being assembled and will be brought on-site in 2011 to document and conserve the tracks and make recommendations for a management plan for this and the other track localities.

KEYWORDS— Pleistocene, Fossil Tracks, Idaho, Proboscidean, Felid

*Presenting author

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ORAL PRESENTATION

NEW FOSSILS FROM OLD FOSSIL BEDS: PALEONTOLOGICAL RESOURCE MONITORING AT JOHN DAY FOSSIL BEDS NATIONAL MONUMENT

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ABSTRACT—The John Day River Basin in east central Oregon is well known for its rich fossil resources, which have been studied since the late 19th century. Today, John Day Fossil Beds National Monument includes three separate units with fossil beds ranging from 5 to 50 million years old, which preserve vertebrate, invertebrate, and plant fossils. Cyclic prospecting by park paleontologists helps locate and preserve these paleontological resources. Despite a history of almost 150 years of research in the region, ongoing work regularly uncovers new species and occurrences. Recent finds include the earliest known record of a modern beaver in North America (at least 7 million years ago), the only known skull and jaws of an Oligocene pocket mouse, specimens of an unusual lagomorph, and the park's first postcranial bone from the large sabertooth *Pogonodon*. These finds improve our understanding of the region's history and changes in the structure of ecosystems over the past 50 million years.

KEYWORDS—John Day Fossil Beds National Monument, Oligocene, Paleontological Resource Monitoring

ORAL PRESENTATION

DOCUMENTATION OF PALEONTOLOGICAL RESOURCES THROUGHOUT THE NATIONAL PARK SYSTEM

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ABSTRACT—Baseline paleontological resource data is essential to support decision-making associated with the management, protection, preservation, and interpretation of National Park Service (NPS) fossils. This principle is supported by the Paleontological Resources Preservation Act which was signed into federal law in March 2009. Section 6302 of the legislation requires five federal land managing agencies, including the NPS, to develop plans for inventory, monitoring, and the scientific and educational use of paleontological resources. The NPS established a strategy for the compilation of baseline paleontological resource data for each of the agency's 394 administrative units. The strategy adopted the system of 32 Inventory and Monitoring Networks established under the agency's Natural Resource Challenge and set out to develop paleontological resource summaries for each network. The first network-based paleontological resource inventory was initiated for the sixteen parks of the Northern Colorado Plateau Network in 2002 and completed in early 2011. Written summaries for each network park include information on the scope, significance, distributions, research, museum collections, resource management issues and other information associated with the park's fossils, as well as a comprehensive bibliography of relevant geology and paleontology references and a series of recommendations for future work, research, management or other actions which would promote the preservation of the park's non-renewable fossils. This effort has documented fossils in situ, within the park museum collections, and/or within a cultural resource context in at least 230 units of the NPS. These network reports are not a substitute for field work, but aimed to provide a foundation for future field-based resource management and interpretation.

KEYWORDS—National Park Service, Paleontological Resources, Inventory and Monitoring Networks

*Presenting author

ORAL PRESENTATION

NATIONAL FOSSIL DAY: CELEBRATING THE SCIENTIFIC AND EDUCATIONAL VALUES OF FOSSILS

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ABSTRACT—The inaugural National Fossil Day was celebrated on October 13, 2010 as a means to recognize and promote the scientific and educational values of fossils. More than 130 institutions, organizations, government agencies and other groups joined together to form the National Fossil Day partnership. Hundreds of fossil related events, activities and educational programs were hosted throughout the country. Some of the impetus behind the establishment of National Fossil Day is derived from the Omnibus Public Lands Act of 2009, specifically from within the Paleontological Resources Preservation Act. Section 6303 of the legislation mandates five federal land managing agencies, including the National Park Service (NPS), to establish a program to increase public awareness about the significance of paleontological resources.

The date for National Fossil Day was selected to coincide with Earth Science Week. Thousands of classrooms, representing millions of school children, participate in Earth Science Week activities. In order to build upon the successful educational outreach achieved by the American Geological Institute during Earth Science Week, a cooperative agreement was established between this organization and the NPS. As the word spread about the plans for a national celebration for fossils, the dimensions of National Fossil Day expanded and took shape. Scientists, educators and park rangers found a common cause to contribute to and work toward. A logo, song, video and website helped to give birth to the identity of this new national event.

On the morning of National Fossil Day, a special letter addressed from the White House and signed by President Barack Obama was delivered to those participating in the opening ceremony on the National Mall in Washington, D.C. Throughout the day, large numbers of children from across the country were sworn in as Junior Paleontologists, the winners of the National Fossil Day art contest were announced, the Trail of Time exhibit at Grand Canyon National Park was dedicated, and a new generation of young people was inspired by fossils and paleontology.

KEYWORDS—National Fossil Day, National Park Service

ORAL PRESENTATION

PALEONTOLOGICAL RESOURCE MONITORING OF IN SITU VERTEBRATE TRACKSITES AT GLEN CANYON NATIONAL RECREATION AREA, UTAH

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ABSTRACT—The stability of in situ paleontological resources is a function of the natural processes, environmental conditions, and anthropogenic factors present at the fossil locality. Once destructive forces begin to act upon fossils in situ, the scientific and educational values of these non-renewable resources are usually diminished. In 2009, a paleontological resource monitoring strategy was developed to outline five methodologies, referred to as vital signs, for evaluating the condition and stability of fossils maintained in a geologic context. Glen Canyon National Recreation Area was established as a prototype paleontological resource monitoring park to field test the monitoring strategy. A team of paleontologists from the National Park Service, Utah Geological Survey and the St. George Dinosaur Tracksite collaborated to identify paleontological localities which would be suitable for long-term monitoring. Two vertebrate track localities, including the "Slick George Dinosaur Tracksite" and the "Megatrack Block Locality," both within the Early Jurassic Navajo Sandstone, were initially identified, assessed, mapped, and photodocumented. Both localities contain an important vertebrate ichnofauna and exhibit varying degrees of deterioration related to natural and human related factors. Monitoring recommendations were developed for each locality to promote tracksite conversation.

KEYWORDS—Paleontological Resource Monitoring, Glen Canyon, Vertebrate Tracksite

*Presenting author

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ORAL PRESENTATION

AN EVALUATION OF SIXTEEN YEARS OF PALEONTOLOGICAL VISITOR SITE REPORTS IN BADLANDS NATIONAL PARK, SOUTH DAKOTA

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ABSTRACT—Badlands National Park contains some of the best paleontological exposures of the Eocene–Oligocene White River Group. In 1994, park staff developed a noninvasive method for park visitors to report fossil exposures. A one-page (front and back) Paleontological Visitor Site Report (VSR) includes guides for indicating physical appearance of the fossil, a description of the surrounding bedrock and terrain, and a general location of the exposure, all of which are subsequently reinvestigated in the field by a trained paleontologist. After reinvestigation of each VSR, park staff enter data on the biological, taphonomic, and geologic condition of the fossil exposure into a spreadsheet database. While VSRs have regularly been filled and investigated since 1994, no cumulative evaluation of the database had occurred prior to 2010. In the summer of 2010, we studied sixteen years of VSRs in the database (n=900, 1995–2010) for patterns among the 17 data categories (i.e. taxa represented, host formation). The cumulative VSRs account for 443 fossils representing 46 different taxa. The most commonly reported fossils and host rocks represent the most common taxa and formations in the park, and taphonomic condition of the fossils (fragmentation or modern weathering) did not bias whether an exposure was reported. This suggests that this process of reporting can provide an approximate census of the fossil fauna in areas of high visitation.

KEYWORDS—Badlands National Park, Paleontological Resource Monitoring, Visitor Site Report

ORAL PRESENTATION

PALEOECOLOGICAL AND PALEOENVIRONMENTAL IMPLICATIONS OF MICROFOSSIL SPECIMENS UTILIZING GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

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ABSTRACT—Since 1979, the Pioneer Trails Regional Museum in Bowman, North Dakota has been collecting and protecting fossils through the effort of a volunteer work force. They have accurately collected and re-collected annually from a number of sites including 46 microfaunal sites from the Late Cretaceous Hell Creek Formation of southwestern North Dakota. When these collections were made, the details of the ongoing collection of macrofauna, pollens and other plant material, microfauna, sedimentary specimens and associated information was only recorded in hard copy—not digitized or converted to any database. This limited the museum's ability to correlate the information in any way other than manually. Now, the ability to link information tables to points on a map using Geographical Information Systems (GIS) has introduced a new future for paper-based data collections. GIS, with its ability to generate detailed maps with links to associated data, allows for more complex and in-depth scientific analyses, such as reconstruction of paleoenvironmental and paleoecological conditions in this critical transition zone. This study analyzes the implications for data available to date, but there is still much room for growth, as more data can be added to the maps using the GIS ability to add layers of data. Layers can include anything from pollen to sedimentary information and can accommodate information from many more microsites.

KEYWORDS—Microfauna, Late Cretaceous, Geographical Information Systems, Paleoecology

*Presenting author

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ORAL PRESENTATION

THE SDSMT MUSEUM OF GEOLOGY'S JAMES E. MARTIN PALEONTOLOGY RESEARCH LABORATORY: A REGIONAL REPOSITORY FOR FEDERAL, TRIBAL, AND STATE COLLECTIONS

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ABSTRACT—The exhibit, collection, and preparation capacity of the Museum of Geology at South Dakota School of Mines and Technology has been an important part of the school's geology and paleontology programs since 1885. In 2010, the collections and laboratories moved to a new building—the James E. Martin Paleontology Research Laboratory (PRL),—thanks to funding provided by the South Dakota Board of Regents and private donors. This facility will enable a comprehensive program of preparation, research and education under one roof, uniting all the collections, Federal, tribal and state repository holdings, and associated data. The building will also showcase the Museum's extensive field, laboratory and classroom work, including visible preparation areas. The monumental task of moving over 500,000 fossils, minerals, and associated holdings has resulted in greater accessibility and organization, creating opportunities to build stronger research and programmatic relationships between the Museum and its stakeholders as well as regional students, educational programs, and communities. The PRL was designed to meet all requirements for environmental conditions and monitoring, security, and access specified in the Federal curation checklists and standards. The result is a major regional repository that will ensure the best use of paleontological resources for research, education, professional training, and public programs, benefiting all stakeholders.

KEYWORDS—South Dakota School of Mines and Technology, Resource Repository, Paleontological Research

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POSTER PRESENTATION

PALEONTOLOGIC SITE STEWARDSHIP ON FEDERAL LAND IN NEVADA: A MODEL FOR PROMOTING CITIZEN SCIENCE

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ABSTRACT—In 2008, the Bureau of Land Management awarded the San Bernardino County Museum (SBCM) a Federal Assistance Agreement entitled "Upper Las Vegas Wash Conservation Transfer Area (CTA)—Treatment, Protection, and Interpretation of Heritage Paleontologic Resources through Public Involvement." The CTA comprises about 5,000 acres, including sediments that indicate changing levels of ground water discharge through the last two glacial maxima, and protects about 500 fossil sites, including one of the most significant late Pleistocene vertebrate assemblages in the American southwest. The grant directs the collection and curation of late Pleistocene (Rancholabrean) taxa from the Las Vegas Formation, geologic mapping, and research.

Objectives of the agreement include creation of a site stewardship program to engage the local community in the management of fossil resources within the CTA, allowing for hands-on involvement whereby stewards actively participate in citizen science. Training includes a three-day classroom/field workshop to orient future stewards on the geology and paleontology of the region, an introduction to GPS and maps, and a primer on Federal laws protecting fossil resources, including the 2009 Paleontologic Resources Preservation Act. Stewards conduct an initial walk-through of assigned parcels, then excavate fossils under direct supervision in a previously-disturbed quarry, doubly illustrating the need to protect the resources. Stewards are expected to return to prospect their parcel on a quarterly basis. Additionally, the SBCM produced exhibit content and fossils for interpretive kiosks.

KEYWORDS—Las Vegas, Vertebrate Fossils, Pleistocene, Site Stewardship, Citizen Science

*Presenting author

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POSTER PRESENTATION

THE TULE SPRINGS LOCAL FAUNA: LATE PLEISTOCENE VERTEBRATES FROM THE UPPER LAS VEGAS WASH, CLARK COUNTY, NEVADA

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ABSTRACT—The Tule Springs site in the upper Las Vegas Wash north of Las Vegas, Nevada was the focus of archaeological scrutiny from the 1930s through the early 1960s. Forty years later, the San Bernardino County Museum has discovered hundreds of new fossils throughout the upper Las Vegas Wash, greatly extending the geographic and temporal footprint of earlier investigations. The upper Las Vegas Wash encompasses the largest open-site Rancholabrean vertebrate fossil assemblage in the Mojave Desert / southern Great Basin, warranting designation as a local fauna named for the original Tule Springs site.

Mammuthus columbi and *Camelops hesternus* dominate the large mammal assemblage, with three distinct species of *Equus* and two species of *Bison* also present. Newly-recognized faunal components include *Rana* sp., *Anniella* sp., *Masticophis* sp., cf. *Arizona* sp., *Marmota flaviventris*, *Neotoma* sp. cf., *N. lepida*, *Reithrodontomys* sp., cf. *Onychomys* sp., *Lynx rufus*, an indeterminate large bovid, and the first definitive fossils of *Bison antiquus*. The latter fossils constitute the youngest reliably-dated *Bison* remains known from the Mojave Desert.

The depositional setting is a series of fine-grained ground water discharge deposits of the informally designated Las Vegas Formation. Seven stratigraphically-ascending units (A through G) are recognized. Units B, D, and E were known to be fossiliferous from earlier studies; recent efforts confirm unit C is also sparsely fossiliferous. The deposits span as much as the last 200 ka, encompassing a sedimentary and faunal record of multiple glacial-interglacial climatic shifts including the end-Pleistocene transition.

KEYWORDS—Las Vegas, Pleistocene, Rancholabrean, Mojave Desert, Great Basin

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POSTER PRESENTATION

NEW FOSSIL RECORDS FROM BLANCAN (PLIO–PLEISTOCENE) DEPOSITS, GRAHAM COUNTY, ARIZONA

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ABSTRACT—The Safford Field Office of the Bureau of Land Management (BLM) manages vertebrate fossil sites of Blancan (Plio–Pleistocene) age, from near the beginning of the Ice Age. These contain mammals such as glyptodonts and capybaras that record the beginning of the Great American Faunal Interchange. Numerous other mammals have been found, as have birds and reptiles, especially tortoises. Over 50 species have been recorded, representing one of the best Blancan-aged mammal assemblages in North America.

The Safford Field Office works in partnership with the Arizona Museum of Natural History in Mesa, their affiliate the Southwest Paleontological Society (SPS), the International Wildlife Museum in Tucson, Western Arizona College in Yuma, and the University of Arizona in Tucson to inventory, collect, and curate the fossils. Particularly productive areas are periodically monitored by the BLM and SPS.

More than 1,000 fossils have been collected since the project started in 1998. Previously unreported taxa collected from these beds include beaver, tapir, deer, duck, swan, goose, box turtle, and a mud turtle. Some material collected may be the basis for new taxa. We have also come across several trackways in the Safford Valley, including those of camel, llama, mastodont, and the three-toed horse *Nannippus*. Fossils from this inventory are on display at the Arizona Museum of Natural History and the Graham County Historical Society in Thatcher, Arizona. Others have been sent to specialists around the country for study.

KEYWORDS—Plio–Pleistocene, Mammal Fossils, Bureau of Land Management, Southwest Paleontological Society

*Presenting author

ORAL PRESENTATION
Article, p. 69–74

MANAGEMENT OF PALEONTOLOGY RESOURCES IN LANCE CREEK FOSSIL AREA

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ABSTRACT—Huge numbers of fossils were collected and excavated from the Lance Creek Fossil Area beginning in the 1880s and are now scattered to museums and other institutions all over the globe. The National Park Service recognized the significance of these fossil discoveries by designating the area a National Natural Landmark (NNL) in 1973. The area designated was approximately 16 sections and consisted of a mixture of public lands, split estate, and private lands and minerals. The Bureau of Land Management (BLM) Newcastle Field Office Resource Management Plan (RMP) developed in the 1990s initially proposed designating the BLM lands within the NNL as an Area of Critical Environmental Concern (ACEC). During RMP scoping many private landowners became aware for the first time that their ranches were inside an NNL. Public outcry led to de-designating the NNL in 2006. An ACEC designation was also dropped from the BLM RMP signed in 2000, partly due to lack of survey data identifying exactly where fossils were located. The large amount of split estate and private lands and the scattered locations of BLM lands make it difficult to manage paleontology resources on the public lands. Large numbers of fossils are still collected from the Lance Creek Fossil Area reputedly from private lands. However, following a widely publicized fossil theft trial in 1995, fossils documented as removed from Federal lands were returned to the BLM.

KEYWORDS—Lance Creek Fossil Area, National Natural Landmark

ORAL PRESENTATION

HIGHWAY CONSTRUCTION AND FOSSIL RESOURCES: ROAD TO DESTRUCTION OR PATH TO PRESERVATION? NEBRASKA'S HIGHWAY PALEONTOLOGY PROGRAM

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ABSTRACT—In Nebraska, there is a possibility that fossils will be uncovered whenever highway construction disrupts the land surface. The Nebraska Department of Roads (NDOR) and University of Nebraska State Museum (UNSM) work together to prevent the destruction of these irreplaceable scientific resources. In 1960, Nebraska created the nation's first full-time program devoted to fossil recovery on road construction projects. Backed by state and federal legislation, the Highway Paleontology Program has collected approximately 200,000 fossil vertebrate specimens, including 20 holotypes, from more than 150 localities in the past five decades.

UNSM works closely with contractors and NDOR personnel in all phases of construction to preserve the state's rich prehistoric past without causing delays. Early notification of pending projects allows for field surveys and test excavations prior to construction. Pre-construction meetings and on-site training inform the contractor and NDOR staff of potentially fossiliferous areas and what to look for while excavating. If fossil remains are discovered during construction, contractors continue working but shift their grading operations to avoid paleontologically sensitive areas. After construction is completed, NDOR will provide equipment to re-open localities for additional study. This successful inter-agency partnership enhances our scientific knowledge by preserving specimens which otherwise would be destroyed during construction.

KEYWORDS—Fossil Mitigation, Paleontology, Highway Construction, Nebraska Highway Paleontology Program, Fossils

*Presenting author

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Article, p. 75–82

ANCHISAURUS FROM SPRINGFIELD ARMORY

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ABSTRACT—The term "dinosaur" was only 13 years old in 1855 when blasting operations at the Water Shops of Springfield Armory in Massachusetts uncovered the partial fossil skeleton of an extinct reptile. Paleontological discoveries were not new to the area; the Connecticut River Valley, which includes the Armory, was an early hotbed of vertebrate paleontology thanks to the combination of Late Triassic–Early Jurassic-age footprints and interested naturalists. The Armory specimen, now the holotype of *Anchisaurus polyzelus*, has passed through several generic names and been classified with theropods, prosauropods, and sauropods. Views on its paleobiology have changed from an active carnivore, to an herbivore, to an omnivore. Along the way, it has been discussed in print by numerous well-known figures in paleontology.

The holotype of *A. polyzelus* is one of a handful of tetrapod body fossils from the Hartford Basin. As part of the history of Springfield Armory National Historic Site, it is also one of many historically and scientifically significant fossil specimens associated with National Park Service areas.

KEYWORDS—*Anchisaurus*, Springfield Armory National Historic Site, Portland Formation, Hartford Basin, History of Paleontology

ORAL PRESENTATION

INTERPRETING PLEISTOCENE ENVIRONMENTS AT THE FLORISSANT FOSSIL BEDS NATIONAL MONUMENT, COLORADO

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ABSTRACT—The Florissant fossil beds are one of the most taxonomically diverse fossil sites in the world. The lacustrine shales of the Eocene Florissant Formation have yielded at least 1,700 described species of plants, insects, and spiders. The fossil beds also preserve a fossil record in Quaternary sediments. Fragmentary material of a mandible and molar of a Columbian mammoth has been recovered near the Visitor Center in Pleistocene gravels. The tooth has been radiocarbon dated at 49,830 ± 3290, a date that exceeds the reliable range for radiocarbon dating. Associated in these sediments are pollen and spores that enable reconstruction of Pleistocene terrestrial plant communities contemporaneous with the mammoth.

Interpretation of Florissant's Quaternary fossil record has been designed with hands-on activities. These include activities to reconstruct the dimensions of the mammoth, to demonstrate how mammoth species are determined by making simple dental measurements, and to use actual fossil pollen and spores for reconstructing the Pleistocene environment. These activities emphasize how to conduct a paleontological excavation, how environments and climates change over time, how pollen and spores are collected and processed, and how Florissant's Pleistocene environment is reconstructed using proxy data such as pollen and spores.

Florissant's Pleistocene fossil record engages visitors in the process of `scientific discovery. Visitors are connected to the process of science and learn observational skills, learn about the scientific method, and experience discovery as they use pollen to reconstruct ancient environments. These interpretive activities also clearly demonstrate the importance of interdisciplinary studies in reconstructing paleoenvironments.

KEYWORDS—Florissant Fossil Beds, Columbian Mammoth, Pleistocene, Pollen, Spores

*Presenting author

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POSTER PRESENTATION

THE REDESCRIPTION AND EXCAVATION OF WILBUR KNIGHT'S 1895 *MEGALNEUSAURUS REX* SITE: MAPPING AN INCOMPLETE HISTORY

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ABSTRACT—Rediscovery of the collection site of the large Jurassic pliosaur *Megalneusaurus rex* on Federal land was made possible by the use of Wilbur Knight's letters and geological description of the area. Rediscovery of the site is significant in that little is known about this largest member of the Sundance marine reptile fauna. This information was used to verify that *Megalneusaurus rex* was collected from the upper Redwater Shale Member of the Sundance Formation and that the original excavation was incomplete.

Examination and mapping revealed new fossil material as well as artifacts from the 1895 excavation. Newly-collected fossil material included another articulated flipper, portions of vertebrae, pectoral and/or pelvic material, epipodials, ribs and large amounts of gut contents. Mapping of the site, based on known limb dimensions and the proportions of the vertebrae, ribs and gut material as well as potential skull material, has allowed for some speculation of the taphonomy of the pliosaur and an outline and parameters of the original excavation.

Scattered piles of bone and spoil mounds indicate past disturbance. Artifacts such as a broken knife blade, a button and a nail were recovered from the site. The nail is significant as it was recovered above the uncollected flipper bones, suggesting the site was marked for potential return to the excavation in 1895. Remains of a metal 'Hercules Blasting Powder' canister and an intact whiskey bottle were also collected from near the site; both artifacts were comfortably dated to the late 1890s and early 1900s.

Portions of ichthyosaur material including vertebrae and ribs found in the pit suggest that some of the material Wilbur Knight collected may have included bulk collection from the general area. However, a second site collected in the Southern Bighorn Basin revealed ichthyosaur material mixed with large pliosaur bones.

Uranium pits were noted in the locality, and whereas the history of theses pits are not known, they were most likely excavated post 1900. The surface disturbance of these pits may have camouflaged the excavation site allowing for its rediscovery. Likewise, an intact central spoil pile may have existed, but could have been reworked by transport with heavy equipment in the course of the industrial uranium excavation.

KEYWORDS—Wilbur Knight, Pliosaur, Paleontological Excavation

POSTER PRESENTATION

PALEONTOLOGICAL INVENTORY OF BIG BEND NATIONAL PARK

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ABSTRACT—Big Bend National Park (BIBE) encompasses more than 800,000 acres in southwestern Texas on the border with Mexico. We have recently completed an inventory of the park's fossil resources.

BIBE contains a very diverse, largely uninterrupted, Late Mesozoic–Tertiary geologic interval (spanning 135 million years) containing a wide variety of fossil plants, invertebrates, and vertebrates. BIBE ranks as one of the most paleontologically diverse parks in the National Park Service (NPS) system, with over 1100 reported fossil taxa.

Numerous sites in BIBE have important scientific value. These include type localities for unique specimens (holotypes) known only from the park and fossil sites which have produced spectacular and important specimens. Furthermore, several particularly charismatic specimens from the park have become famous world-wide (e.g., the giant pterosaur *Quetzalcoatlus*, the giant crocodile *Deinosuchus*, and the dinosaur *Alamosaurus*).

BIBE harbors deposits from a unique, southern paleobiogeographic province separated from other more intensely-studied paleontological localities to the north. The park's location, ensemble of formations, and associated fossils are crucial to the understanding of Cretaceous floral and faunal relationships on a continental scale. Many current and hotly debated theories involving paleofaunal endemism, biostratigraphy, paleoclimate, and taxonomy relating to Cretaceous North America would be incomplete (or impossible) without including the strata and fossils of BIBE. The park also preserves deposits from the extinction episode at the end of the Cretaceous Period, making it one of very few public lands and perhaps the only NPS unit where K–P boundary strata can be studied.

KEYWORDS—Paleontological Inventory, Big Bend National Park, Cretaceous Period

*Presenting author

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ORAL PRESENTATION

THE HANKSVILLE-BURPEE QUARRY: COOPERATIVE MANAGEMENT OF AN IMPORTANT PALEONTOLOGICAL BONEBED

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ABSTRACT—One of the largest new dinosaur bonebeds found in the last decade, the Hanksville-Burpee Quarry (Fig. 1) is a sauropod-dominated, latest Jurassic quarry on lands administered by the Bureau of Land Management (BLM) in Southern Utah. The quarry is stratigraphically placed within the Brushy Basin Member of the Morrison Formation and was previously known to local fossil collectors for producing petrified wood and bone "scrap." In 2007, BLM geologist Francis "Buzz" Rakow showed this prolific locality to field crews from the Burpee Museum of Natural History. Burpee initially identified more than six well-preserved, partially articulated dinosaurs (Fig. 2) at the locality. Since excavations began under BLM permit in 2008, several thousand pounds of dinosaur material have been collected, including the following taxa: *Camarasaurus, Diplodocus, Barosaurus,* and a partial undetermined theropod. The extent of the locality has been explored and as excavations continue the quarry is being mapped. It appears the site is massive, with the bone-bearing layer extending approximately half a kilometer.

During this excavation process, Burpee Museum has partnered closely with other institutions including the BLM and Western Illinois University (WIU). The size and scope of the quarry provides the resources to conduct introductory college field courses in geology and paleontology. WIU has conducted annual field courses at the Hanksville-Burpee Quarry since 2008, allowing in-the-field, hands-on opportunities for undergraduate and graduate students. WIU will continue to bring students to the quarry for future field work. Additionally, Western Illinois University is working closely with Burpee to research the locality in an effort to reconstruct the paleoenvironment, compare this quarry to other large bonebeds, and to identify research grants.

Aside from formal excavation and research, Burpee has utilized the quarry for ongoing public education (Fig. 3). During select weeks over the last two summers, education staff from Burpee Museum have conducted programmatic tours for the general public. These tours have introduced more than 1100 people to general principles of geology, paleontology and the importance of fossil resources. Burpee Museum staff and the BLM have worked closely with the town of Hanksville to help protect and preserve this locality. Local businesses post information regarding quarry tours and contact information for the BLM, and the BLM provides educational information about the quarry to a broader audience through its web pages that are updated as the quarry continues to develop.

These many opportunities for research, public education, and collaboration are not without challenges. The infusion of large quantities of vertebrate fossil material to Burpee's permanent collection has created challenges for timely fossil preparation. To address some of these issues, Burpee Museum has recently finished a capital campaign which allowed the construction of a larger and more modern fossil viewing lab that, when properly staffed, will be a living exhibit and educational program. To meet the demands accompanied by new fossil material, additional space within the permanent collections was created. Finally, a full-time Chief Preparator has been hired to train and supervise grant-funded fossil preparators and volunteers. However, in order to maintain a steady rate of fossil preparation and to provide the "living exhibit" part of the process, additional funds will be sought and stronger volunteer programs developed. As these challenges are addressed, the Hanksville-Burpee Quarry will continue to be utilized as an active quarry where students learn the principles of geology and paleontology; where field paleontologists collect quality specimens for eventual preparation, research and exhibition; and the public can see "in progress" field paleontology in order to foster a better understanding of paleontological resources on their public lands.

KEYWORDS—Burpee, Hanksville, Jurassic, Morrison, Sauropod

*Presenting author

FIGURE 1. Hanksville Burpee Quarry 2007

FIGURE 2. Articulated diplodocid caudal vertebra

FIGURE 3. Scott Williams talking to students from Hanksville Elementary School

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POSTER PRESENTATION

GEOLOGY OF THE WASATCH AND GREEN RIVER FORMATIONS (EARLY EOCENE) AND MAMMALIAN PALEONTOLOGY OF THE WASATCH FORMATION, NORTHWESTERN GREATER GREEN RIVER BASIN: FIELD WORK UPDATE

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ABSTRACT—Erathem-Vanir Geological Consultants (EVG) have conducted geological and paleontological studies on Early Eocene strata in the Pinedale, Wyoming area since 1995. This work includes pre-field searches, field surveys, and Bureau of Land Management (BLM)-driven mitigation and monitoring. In 2011, EVG will continue this work with detailed geologic and paleontologic-sensitivity mapping west of the Jonah Field. Our revised west to east geologic cross section of Early Eocene rocks along Wyoming 351 includes from oldest to youngest (Tw= Wasatch Formation, Tg = Green River Formation): (1) LaBarge Member (Tw); (2) Scheggs Bed of the Tipton Shale (Tg); (3) Farson Sandstone (Tg); (4) Alkali Creek Member (Tw); (5) Wilkins Peak Member (Tg); (5) an as yet unnamed member of the Tw; and (6) Laney Member (Tg). Stratigraphic relations are complicated by a plethora of named units and the presence of an unconformity at the base of the Laney Member, attributed to desiccation of Lake Gosiute, subsequent erosion during and following deposition of the Wilkins Peak Member, and re-expansion of the lake during deposition of the Laney Member.

The Green River and Wasatch formations produce fossils of scientific importance and are ranked as having a Probable Fossil Yield Class of 3 and above. Fossil vertebrate material is common in all the members of the Wasatch Formation. Based on our definition of paleontological significance, the Wasatch Formation includes approximately 100 fossil localities yielding about 40 mammalian taxa.

KEYWORDS—Wasatch Formation, Green River Formation, Fossil Vertebrate, LaBarge Member, Alkali Creek Member

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ARTICLE

PALEONTOLOGICAL RESOURCE MANAGEMENT AND THE OGLALA SIOUX TRIBE'S TRIBAL HISTORIC PRESERVATION OFFICE

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ABSTRACT—The Oglala Sioux Tribe has historically delegated responsibility for cultural/historic preservation and paleontological resource management to various Tribal agencies through Tribal Council Resolutions and Ordinances based on the need of each specific situation. In April 2008, a Tribal Council Ordinance established a Tribal Historic Preservation Office (THPO). This office was directed to: 1) develop a Tribal Historic Preservation Plan and Program, 2) obtain National Park Service (NPS) Historic Preservation Program approval for official status as a nationally recognized THPO, as provided by the National Historic Preservation Act, 3) negotiate a Memorandum of Agreement (MOA) with the NPS to acquire funding necessary to implement the Program, 4) assist in developing a paleontological resource management plan, and 5) create an Advisory Council to serve as an elder advisory group for all cultural and historical management. Since its inception, the Advisory Council has been called upon to address paleontological resource management issues on the Pine Ridge Reservation. Based on traditional teachings, it is believed that everything is connected. This connection means that anytime the earth is disturbed, a human-related and/or fossil item may be uncovered, so there is no real distinction between archaeological and paleontological resources. Currently, the Oglala Sioux Tribe has a nationally recognized THPO, program funding and personnel, consultants, a Tribal Historic Preservation Plan, and a MOA with the NPS assuming certain functions previously conducted by the State Historic Preservation Office. The THPO is working collaboratively with several other Tribal and Federal entities as well as educational institutions to address ongoing needs for protecting and preserving cultural/historic properties and paleontological resources. There are plans in place to make Oglala Lakota College, through its Department of Math, Science & Technology, the official repository and archival warehouse for Oglala Sioux Tribal paleontological resources.

KEYWORDS—Tribal, Oglala, Resource Management

INTRODUCTION

The Pine Ridge Reservation of southwestern South Dakota is the home of the Oglala Lakota people (Oglala Sioux Tribe) and the second largest reservation in the United States with over 3.4 million acres and approximately 28,000 residents. The greater Reservation boundary includes all of Shannon and Bennett counties and the southern half of Jackson County, encompassing an area about the size of the state of Connecticut. The reservation includes various fossiliferous rock formations of late Mesozoic and Cenozoic age, including the Cretaceous Pierre Shale, the Paleogene White River Group, the Paleogene–Neogene Arikaree Group, the Neogene Ogallala Group, and many unconsolidated Quaternary units. In addition to an abundant fossil record, the region's Pleistocene and Holocene sediments record at least 14,600 years of human history. On the Pine Ridge Reservation, people consider both fossils and artifacts to be *cultural resources*, in that both are records of past life and part of an unbroken cycle of existence. Also, both are recovered by excavating in the Earth, and have been the subject of a long history of dispossession of relics from Native lands (Bradley 2010). The cultural resources of the Pine Ridge Reservation are managed by the Oglala Sioux Tribe's Tribal Historical Preservation Office. This paper will briefly describe the role and function of this office so that the paleontological and archeological scientific and resource management communities can be effective partners in research and management in the years ahead.

OGLALA SIOUX TRIBE TRIBAL HISTORICAL PRESERVATION OFFICE—ORDINANCES

The Oglala Sioux Tribe (OST) has historically held responsibilities related to historic preservation and cultural resource management through various Resolutions under the Tribal Fifth Member's Office. Because this Office is politically appointed, it often changes with the changing Tribal Administrations every two years. To provide more consistency and continuity, in April 2008 the Tribal Council created a Tribal Historic Preservation Office (THPO) through Tribal Council Ordinance No. 08-09, making this office a Tribal program under the existing P.L. 93-638 contract for Natural Resources Regulatory Agency.

The THPO was successful in obtaining acceptance for the "*Oglala Sioux Tribe—Tribal Historic Preservation Plan*" (the Plan) from the National Park Service (NPS) Historic Preservation Program on May 27, 2009. As approved by the Tribal Council and National Park Service (NPS), this Plan addresses responsibilities of protecting and preserving cultural/historic properties and any environmental impacts within the Treaty, ancestral, and aboriginal territories.

Later in 2009, the Tribal Council passed Ordinance No. 09-29, approving the "*Memorandum of Agreement with the National Park Service*" for the Tribe to assume and administer certain functions previously conducted by the State Historic Preservation Office in accordance with the National Historic Preservation Act (NHPA) based on the language provided in the Plan.

In May 2010, the Tribal Council enacted Ordinance No. 10-13, approving the "…*Tribal Preservation of Paleontological, Archaeological, Cultural and Historic Resources Code, to be codified at Law and Order Code Chapter 49*." It was of utmost importance to create this Ordinance; the Oglala Sioux Tribal Council deemed it necessary to effectively manage, regulate, and protect its paleontological, archaeological, cultural and historic resources. The Code was written to incorporate a Lakota philosophy expressing the special relationship between the people and the land, which includes paleontological resources. The Code also provides a process to maintain the balance of this relationship while preserving and protecting the resources that provide our people and future generations with portions of our history and our past.

FUNDING

With the authorization to establish the Oglala Sioux Tribal Historic Preservation Office (THPO) through Ordinances No. 08-09 and No. 09-29 and the Memorandum of Agreement (MOA) with the NPS, the OST entered into an Annual Funding Agreement through the NPS Historic Preservation Fund to fulfill its duties as a THPO. The THPO still seeks additional funding to supplement the National Park Service funding received to sustain its minimal staff, though. Former Tribal President Theresa Two Bulls was successful in obtaining additional funding in 2010 through her Aid to Tribal Government funding from the Bureau of Indian Affairs—Pine Ridge Agency (BIA PRA). Currently we are asking that returning Tribal President John Yellowbird-Steele continue with a similar funding level and even assist the THPO with a request for additional funding from other federal agencies such as the BIA PRA. The THPO also collaborates with other Tribal entities such as Oglala Lakota College (OLC), which is working to further enhance a repository for archaeological and paleontological collections from projects on the Pine Ridge Reservation.

Ordinance No. 10-13 provides a mechanism for the THPO to create a budget to administer its duties through permit revenues collected and/or through civil forfeiture/penalties.

STAFFING AND OFFICES

By Tribal Presidential re-appointment on December 14, 2010, Mr. Wilmer Mesteth was named the new Tribal Historic Preservation Officer (THP Officer) following the previous appointment of Mr. Michael Catches Enemy in 2009. This appointment was understood as being strictly on a volunteer basis, as Mr. Mesteth was and currently still is an instructor for OLC. Prior to the appointment, Mr. Mesteth was nominated to serve on the THPO Advisory Council, as provided in the Plan and Ordinance 08-09.

At the request of the current THP Officer Mr. Mesteth, administrative and historical assistance was required of Mr. Catches Enemy as the returning Natural Resources Director. Project Review Officer Ms. Roberta Joyce Whiting is the only full-time position at this time. Mr. Mesteth also requested technical assistance and repository guidance from the Co-Chair of the Math & Science Department at Oglala Lakota College, Dr. Hannan LaGarry. The THPO anticipates Tribal Administration financial support in order to fulfill duties listed in the Plan and agreed upon in the MOA with the NPS.

TRIBAL HISTORIC PRESERVATION ADVISORY COUNCIL

Through Ordinance 08-09, the Oglala Sioux Tribal Council authorized a three (3) member Tribal Historic Preservation Advisory Council (THPAC) to be appointed with legal authority to act and perform as the lead preservation program that will advise and make scheduled reports to the Oglala Sioux Tribal President and the Tribal Council. A THPAC consisting of Mr. Tom Bad Heart Bull from Oglala District, Mr. Francis "Chubbs" Thunder Hawk from Porcupine District, and Mr. Garvard Good Plume, Jr. from Wakpamni District is currently in place.

Training

The THPO will provide relevant training and certification to other Tribal programs, following receipt of this same training by THPO staff, on topics such as the National Environmental Policy Act (NEPA), the Native American Graves Protection and Repatriation Act (NAGPRA), the National Historic Preservation Act (NHPA), and the Archaeological Resources Protection Act (ARPA) in order to remain in compliance with both Tribal and federal regulations and laws regarding ground-disturbing activities that are considered a federal undertaking. Federal undertakings have a tie to federal funding and are subject to the National Historic Preservation Act.

CONFIDENTIALITY

All THPO staff, consultants, monitors, contractual agents, and other associated individuals will adhere to strict confidentiality and will be expected to encourage other entities to help protect the integrity of cultural resources.

EDUCATION AND OUTREACH

Because education outreach can help residents of the Pine Ridge Reservation understand on-going issues concerning cultural resource protection and preservation, it will be an essential component of the THPO. The THPO continues to disseminate information on cultural resource protection and preservation, codes compliance, and historic sites through brochures, news-letters, posters, calendars, presentations, at career fairs, District/ Community meetings, schools, OST Programs, businesses, and other entities as requested.

REPOSITORY NEEDS

The Math and Science Department at Oglala Lakota College has secured funding to establish and maintain a specimen repository. The funding enables the purchase of cabinets and supplies; labor required for maintenance of the repository will be provided by OLC researchers and interns as part of their regular grant-funded duties. Additional funding will likely be required in four years' time. Dr. Hannan LaGarry is Curator, and Alessandra Higa is Collections Manager. Fulfilling the function of a THPO repository to maintain document archives, LaVera Rose, OLC Archivist, has agreed to work with the Math and Science Department to establish and maintain a records repository.

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ARTICLE

PALEONTOLOGY AND PUBLIC DIPLOMACY

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ABSTRACT—Questions of global climate change and other currently relevant social and political issues require applications of paleontological research that are far more complex than which dinosaur fossil is largest or how many new fossil species may be identified in one year. Management of public lands, both for current development and for the enjoyment of future generations, requires that people making decisions have the best information that is based on scientific principles and expertise. An inability to reach the general public with meaningful and relevant scientific results has led to a lack of appreciation for the importance of paleontological research. A lack of diplomatic skills may also have hindered paleontological managers from garnering the bureaucratic support necessary to develop paleontology into a fully functioning independent program within the United States Government.

With advances in scientific methodology, including increased collaboration between related sciences, understanding paleontology is more important than ever. The science of paleontology offers a unique "deep-time" perspective that can enrich understanding of many current scientific questions on topics ranging from nuclear proliferation to global climate change. With the recent implementation of the Paleontological Resources Preservation Act, government paleontologists have a unique opportunity to create and mold concepts of policy and diplomacy that will affect the way paleontological resources will be viewed and managed well into the future.

KEYWORDS—Paleontology, Policy, Land Management

INTRODUCTION

Questions of global climate change and other currently relevant social and political issues require applications of paleontological research that are far more complex than which dinosaur fossil is largest or how many new fossil species may be identified in one year. Management of public lands, both for current development and for the enjoyment of future generations, requires that people making decisions have the best information that is based on scientific principles and expertise. An inability to reach the general public with meaningful and relevant scientific results has led to a lack of appreciation for the importance of paleontological research. A lack of diplomatic skills may also have hindered paleontological managers from garnering the bureaucratic support necessary to develop paleontology into a fully functioning independent program within the United States Government.

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THE ANTIQUITIES ACT OF 1906

The Antiquities Act of 1906 was one of the most influential pieces of public land management legislation in the history of the United States. In addition to calling for the preservation and protection of antiquities, it served as the authority for permitting the excavation of paleontological resources. The act also grants the President of the United States executive authority to assign particular parcels of public land national monument status and direct how they be managed.

Many areas of special paleontological significance have been designated National Monuments through the Antiquities Act. These monuments are administered by four separate land management agencies: the National Park Service (NPS), the Bureau of Land Management (BLM), the US Fish and Wildlife Service (USFW), and the US Forest Service (USFS). While administration of national monuments by four agencies may cause some confusion, it actually makes a great deal of sense. It is analogous to the administration of wilderness areas by the same agencies, as designated by the Wilderness Act of 1964. The BLM manages National Monuments as part of the National Landscape Conservation System, which has a mandate to "conserve and protect nationally significant landscapes that have outstanding cultural, ecological, and scientific values for the benefit of current and future generations" (P.L. 110-011, Title II, Subtitle A, Sec. 2002). This mandate is similar to that of the NPS, which is "to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS Organic Act, 1916) (Fig. 1).

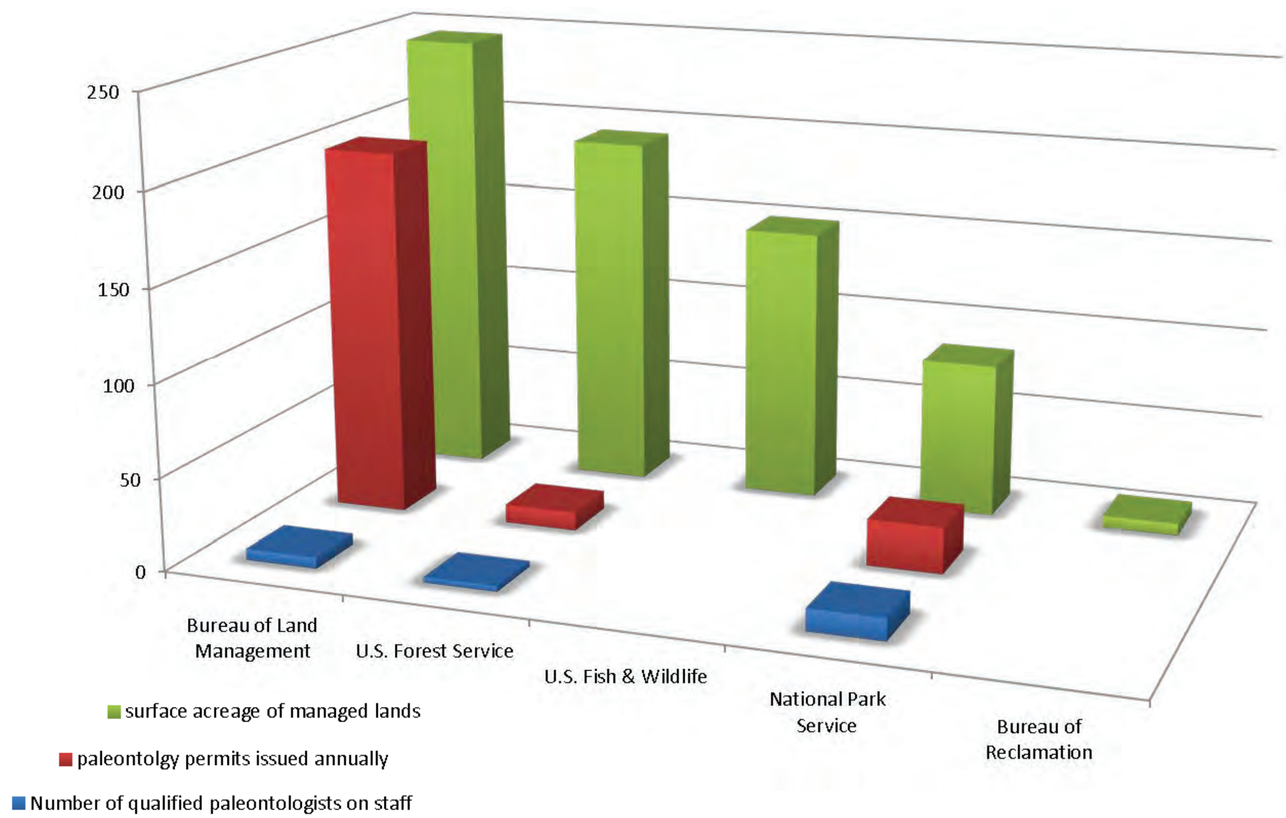


FIGURE 1. Where are we managing paleontological resources?

The most important point, better appreciated by researchers than by public land managers or politicians, is that wildlife, both extinct and extant, doesn't appreciate boundary fences, plat lines, or section markers. The great Western Interior Seaway of the Cretaceous Period, full of marine lizards and shelled ammonites and bordered by horned dinosaurs and cycad plants, engulfed what is now public, private, and Tribal lands. In many ways, the variable styles of management of public lands is less important for what the land was and more important for what land will be many generations from now.

SURVEYS OF THE TERRITORIES

The legacy of managing paleontological resources on America's public lands started well before the Antiquities Act of 1906. The mid-1800s saw settlers moving West in enormous numbers, which drove the U.S. Government to take inventory of the western lands at an accelerated rate. Wildlife, minerals, water, and the ethnology of native peoples needed to be cataloged and, in the case of natural resources, claimed and exploited at an incredible rate. One small facet of these early surveys included locating, recording, and collecting fossils.

The first description of a fossil from the west was published in 1847 by an amateur paleontologist, Dr. Hiram Prout from St. Louis. Most fossils were sent East for description. Joseph Leidy at the Philadelphia Academy of Sciences received one of the earliest of these shipments. He recognized new species of fossil mammals from the White River Badlands of what is now South Dakota and, in 1853, published the earliest monograph with descriptions of new species of extinct animals from the new American West (Owen, 1853). This was the beginning of paleontological resource management on America's public lands.

THE COPE - MARSH FEUD

"What practical use has the Government for Paleontology?"
—Representative Herbert, 1892

What is probably the most important chapter in the history of managing paleontological resources on America's public lands dates to 1890, when a professional rivalry reached national headlines. First Edward Drinker Cope then Othniel C. Marsh launched a series of accusations, threats, and insults at one another from the headlines of the New York Harold, one of the nation's largest newspapers at the time. Neither paleontologist gained an advantage through these repeated volleys; eventually both found their careers mortally damaged. The feud did, though, invite a critical view into the workings of paleontological resource management and congressional scrutiny into the administrative leadership of John Wesley Powell, who was the head of the U.S. Geological Survey and the only funding source for a fledgling federal paleontology program. Both the public and Congress were made aware of shortfalls in institutional paleontological management, specifically the lack of both professional and public access to federally owned museum collections in the care of O.C. Marsh. People started to ask why Marsh, Cope, and other paleontologists did not allow public access to publicly-owned paleontological collections. Collateral damage to their friends and peers was severe; many former collaborators chose to distance themselves not only from Cope and Marsh, but from the science of paleontology in general.

Paleontology became the pariah of federal science at a time when Congress was looking to significantly reduce the federal budget. Two years later, a member of the House of Representatives noted, "[w]e are expending today on science twenty times more than any government in the world." He went on to state, "[i]f there is on this earth an abstract science, it is paleontology. What practical use has the Government for Paleontology?" (Op. Cit. Jaffe, 2000, p.338). In 1892, the politically-weakened USGS suffered a massive budget reduction. The first cut was made to Marsh's paleontology program. Powell wired to Marsh: "Appropriation cut-off. Please send your resignation at once."

It was left to the peers of Cope and Marsh to regain what credibility the science of paleontology could muster. Henry Fairfield Osborne, then curator of mammals at the American Museum of Natural History and professor of paleontology at Columbia University, was able to lobby for the inclusion of invertebrate paleontology in subsequent USGS surveys because of its importance to correlating geologic strata, but was forced to concede that vertebrate paleontology was less important (Jaffe, 2000). After Powell left the Geological Survey in 1894, Charles Doolittle Walcott took over. Walcott, an invertebrate paleontologist himself, continued to include invertebrate paleontology in subsequent surveys (including important Cambrian localities in western Utah), but vertebrate paleontology was all but extinct in the parlance of public land management. Walcott became the secretary of the Smithsonian in 1907 and went on to discover important Cambrian localities in the Burgess Shale in British Columbia (Yochelson, 1998).

Marsh had run the first and only federally-funded paleontology program and, through Powell, had directed federal paleontological policy. He was the first paleocrat. In spite of the introduction of the Antiquities Act in 1906, after Congress pulled the plug in 1892, paleontology as a program and a science would not receive a clear federal mandate for another 117 years.

THE PALEONTOLOGICAL RESOURCES PRESERVATION ACT

On March 30, 2009, the Paleontological Resources Preservation Act (PRPA) was signed into law by President Barack Obama. The PRPA, which directs land management agencies to "manage and protect paleontological resources on Federal land using scientific principles and expertise," is the most important paleontological legislation ever enacted in the United States. The act (formally 16 U.S.C. 470aaa) provides the unified authority that agencies need to in order to manage paleontological resources, issue permits, promote recreational collecting, develop educational programs, and, when necessary, issue citations and prosecute criminal theft (Foss, 2009). It is the primary permitting authority for the collection and study of paleontological resources on public lands. The permitting process must be comprehensive enough to incorporate various types of authorized use, including research, survey, collecting, excavation, and consulting. Streamlined procedures must also be met with a common ethical standard that applies to all permittees.

PERMITTING

Permittees—Paleontological resource use permittees are responsible for all of the paleontological research that occurs on public lands. With mandates such as the Presidential Memorandum of March 9, 2009—Scientific Integrity; Presidential Memorandum of April 16, 2010—America's Great Outdoors; DOI Secretary's Order 3289—Addressing the Impacts of Climate Change on America's Water, Land, and Other Natural and Cultural Resources; and DOI Secretary's Order 3305—Scientific Integrity Policy, it is critical that land management agencies generate relevant scientific insights into both the land management and the social issues of the day. Paleontological research on public lands has not only resulted in a record number of new dinosaur species over the past year, but has also brought us important revelations about the history of ecosystem diversity and climate change on Earth over the past 500 million years.

Collecting paleontological resources—Significant paleontological resources belong to the American people. All collecting must be on behalf of and for the benefit of the American people. Therefore, in order to collect significant paleontological resources, permittees need a permit that guarantees the following conditions:

1. The collection will benefit the American people and the act of collecting will not hinder the preservation of other equally important resources.
2. Paleontological resources (fossils and associated data) will be preserved for the public in an approved repository where they will be available for study.
3. The permittee will work with the public land manager to ensure that all rules are followed and that the terms and conditions of the partnership are met.

Public lands are not a private research laboratory. In return for access to this public laboratory, the permittee owes something back to the American people. This is explained in the obligations of a permit holder, discussed below.

OBTAINING A PERMIT

All permits require a partnership with the issuing agency. Obstacles to obtaining a permit are normally due to difficulty in forming a partnership. The scope of work for a research or salvage project should take the form of a partnership. In other words, "what's in it for the agency?," "what's in it for the resource?," and "what's in it for the American people?" Why should a land management agency take the time to consider a proposed project that does not offer a return on the investment of time and money by the American people? Scientific results are a valuable asset that should be shared with the Agency.

Consider the responsibilities, mandates, authorities, and priorities of the agency. Are they compatible with those of the permittee? Often they are, and the permit will be processed. If they help perform the function of the agency for the agency, there may even be funding available to promote the project.

The land management agency, the researcher, and the museum need each other. If university researchers cannot justify the relevance of their research, they receive fewer grants and overall less support for their research. Similarly, if museums cannot justify the relevance of their collections, they will find less funding available to support the construction of storage space or even for the continued maintenance of expensive collections. It is the same in the federal government. If land management agencies cannot justify the expensive of paleontology, the program will be cut and it will be harder for researchers and museums to find partners in government to sponsor their research.

OBLIGATIONS OF PERMIT HOLDERS

Development of scientific knowledge is what drives the permitting process. Federal land management agencies are mandated to use scientific principles and expertise when making management decisions that affect paleontological resources. However, agencies as a whole do not have enough technical experts or resources to do all of the basic research that is required in order to answer all of the research questions that arise on public lands. Furthermore, most research questions require an interdisciplinary approach, time-intensive protocols, and, often, expensive equipment. Thus, although America's public lands serve as one of the world's greatest laboratories, scientific investigation, which is central to the management of these areas, must be carried out by professional researchers. Individual government scientists usually serve as only a small part of a larger collaborative scientific effort.

A permit is not a ticket to ride, rather it is a contract. Paleontological resource use permittees should be viewed as collaborators who partner with government agencies to conduct research in order to develop the scientific expertise that is required to make informed land management decisions. In return, permittees are given access to resources that may be limited to a small locality or that may extend to many land units administered by multiple agencies across many states. The breadth of access to public lands for scientific research is dependent on the permittee's scope of work or the nature of the scientific question they wish to pursue.

As a partner, the permittee has responsibilities. In return for access to America's greatest research laboratory, the permittee is responsible for being a good steward of the resource, reporting research results, allowing others to access resources, placing all collected specimens and associated data into a publicly-accessible and approved repository, and acknowledging all of their partners. "Being a good steward" means following all rules and regulations that apply to everyone else who uses and enjoys public lands; it also means agreeing to and following all terms and conditions of the permit. "Reporting research results" means providing the agency with follow-up summaries of what has been learned or synthesized, including providing copies of published papers; failing to share results denies the agency the ability to access important research results when making management decisions. "Allowing others to access resources" means recognizing that a permittee should have a reasonable amount of time to prepare, catalog, and report on their discoveries, and also that scientific research requires the ability for subsequent researchers to examine the same resources in order to test for reproducible results. "Placing all collected specimens and associated data into a publicly-accessible and approved repository" means ensuring that all discoveries are available for future research and educational outreach. "Acknowledgement of partners" means acknowledging the land management agency or owner of the land in any published report that discusses specimens or information that was collected from those lands. Agencies expend a lot of professional and logistic support to researchers and the American public owns the specimens and land from which they were collected; both deserve adequate recognition.

There is no bounty or finder's fee for discovering an important fossil. Land management agencies do not keep a store of cash on hand to reward people for spotting an elk, a bear, or even a rare bird. The same is true for fossils. Amateur paleontologists make an enormous contribution toward the science of paleontology by discovering rare or unusual fossils, but just like spotting a rare bird, the contribution is not fully appreciated until it is evaluated in context. The publicly-owned resource includes both the land and any collections made on it. Whether a fossil or an idea, individuals occasionally develop a personal connection to a discovery, but it should be recognized that the real value of a discovery is in its contribution toward scientific knowledge and the real reward is in presenting it back to the people who actually own it—the American public.

Will the Government fund this work? The permittee's proposed scope of work is important because it allows public land managers to assess the magnitude of work that will be done and the potential benefits in terms of scientific information that may be revealed. If the scope of work is either vague or inconsistent with an agency's mission, the permit request may be denied. On the other hand, if the scope of work promises to further the agency's mission greatly, the government may be able to help fund the work in the form of a grant or other logistical support.

Scientific research is not recreation. Recreational use, including collecting, is an important component of using public lands; casual collection of some paleontological resources is allowed without a permit. A permit, on the other hand, is a partnership between the agency and the researcher and therefore does not apply to recreational collecting. Scientific research performed under the guise of casual collecting or recreation denies the land management agency access to research results and other information that would otherwise be very important to its science-based decision making. It also denies the American public legitimate access to specimens and research that belong to them.

HOW SHOULD RESEARCH RESULTS BE PUBLICIZE TO THE GENERAL PUBLIC?

Imagine this scenario: You give your neighbor permission to collect some pretty rocks in the garden behind your house. On a Saturday morning two years later you wake up to a couple dozen people sifting through your garden looking for more pretty rocks. An hour after that you receive a phone call from the local newspaper asking how you feel about the new type of rock that was discovered on your property. I am betting that you are just a little bit annoyed.

Most peer reviewed journals have editorial procedures that follow established ethical guidelines for reporting on scientific discoveries and insights. It remains the responsibility of the researcher to ensure that all of the information has been collected legally, all images and artwork are legally owned, all citations are accurate, and that all contributors (including the land management agency and land owners) are properly acknowledged. Furthermore, any press release that highlights research (including new fossil species) from specific areas of land must be done in conjunction with the appropriate land owner or land management agency. The primary reason for this is that press releases and public announcements heighten public interest in an area and the land owner or land management agency needs to be prepared for this increase in interest. In addition, the publication of research from public lands will enhance a land manager's ability to promote resources in their care and potentially fund more work in the future. Finally, land management agencies have dedicated pubic affairs offices that are able to coordinate press releases and promote research results in ways that most researchers and smaller institutions are unable to match. Remember, permittees and land owners are partners.

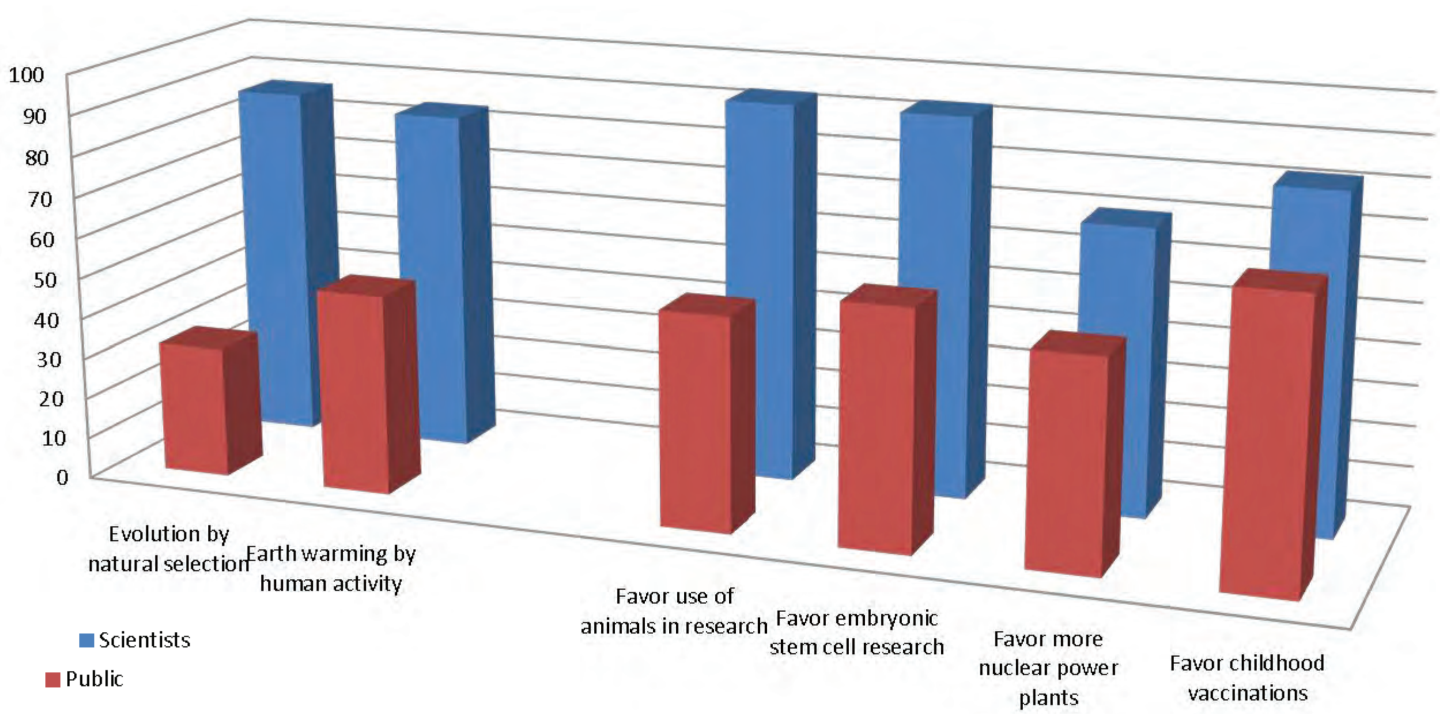
HOW DOES THE PUBLIC VIEW SCIENCE?

There is a positive correlation between the qualifications of a teacher and the subject retention of the students. However, in 1995 a full one third of all K–12 students in the United States were taught science and mathematics by teachers that had not majored or minored in the subject they were teaching. The numbers improved by 2000, but the problem persisted (Klemballa, 2005).

It has also been reported that 85% of scientists believe that one of the greatest difficulties in conducting and reporting their research is directly related to the public's ignorance of science (Pew, 2009). Despite scientists' perceptions, nearly the same percentage of the public (84%) believe that science has a positive effect on society (Pew, 2009). In fact, next to members of the military and teachers, scientists are regarded as the greatest contributors to society's well-being (Pew 2009). The fact is that scientists perceive issues in the world slightly different than the public as a whole.

When it comes to scientific or medical issues, scientists are more than twice as likely as the public to accept scientific explanations for evolution and climate change. Scientists are also nearly twice as likely to favor research on animals, embryonic stem cell research, nuclear power, and childhood vaccinations (Pew, 2009) (Fig. 2). Although most scientists claim to be nonpolitical, as a group they tend toward similar political ideolo-

FIGURE 2. Does the public connect with science? Current issues in science. Information from Pew, 2009



gies and vote similarly (Pew, 2009). In a poll asking why they chose to go into science, 87% of scientists answered that it was to "solve intellectually challenging problems," whereas only 3% answered that is was for "financial reward" (Pew, 2009).

Paleontology is a science that continues to capture the intellect of all ages and may be one of the best vehicles to make science accessible to the public. Whether it involves getting Americans outdoors or into a library, paleontology offers rewards that at first glance may not be apparent in other sciences. Paleontology, as a profession, must use this opportunity to show that the science goes far beyond the novelty of describing dead organisms and, in fact, elucidates important ideas that are relevant in many levels of social and political discussion.

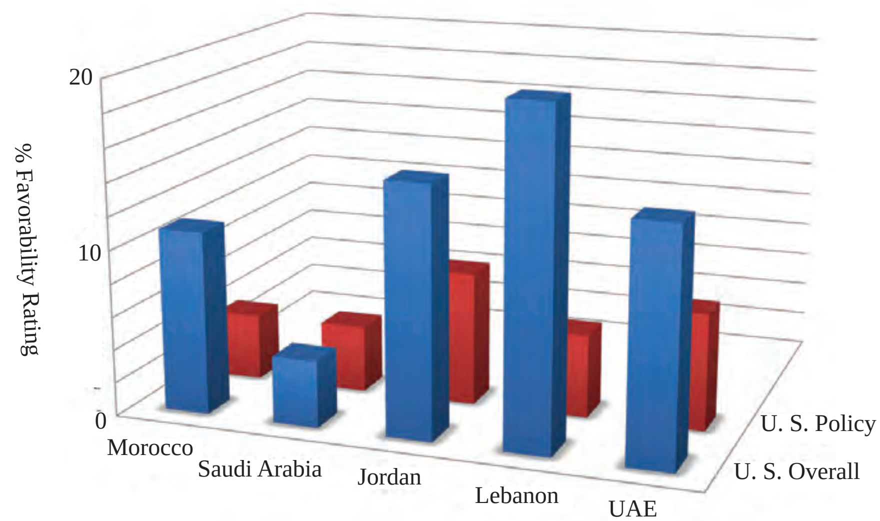


FIGURE 3. Arab attitudes toward the U.S.: They don't like U.S. foreign policy. Information from Zogby, 2004

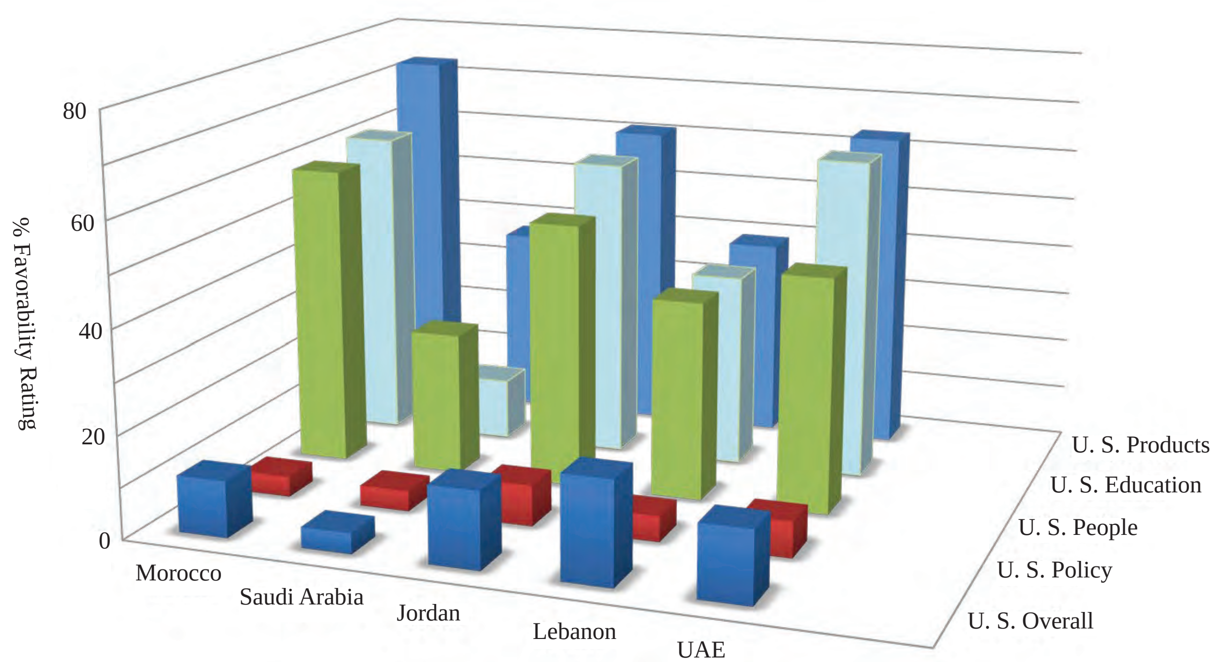


FIGURE 4. Arab attitudes toward the U.S.: They do like U.S. people, education, and products. Information from Zogby, 2004

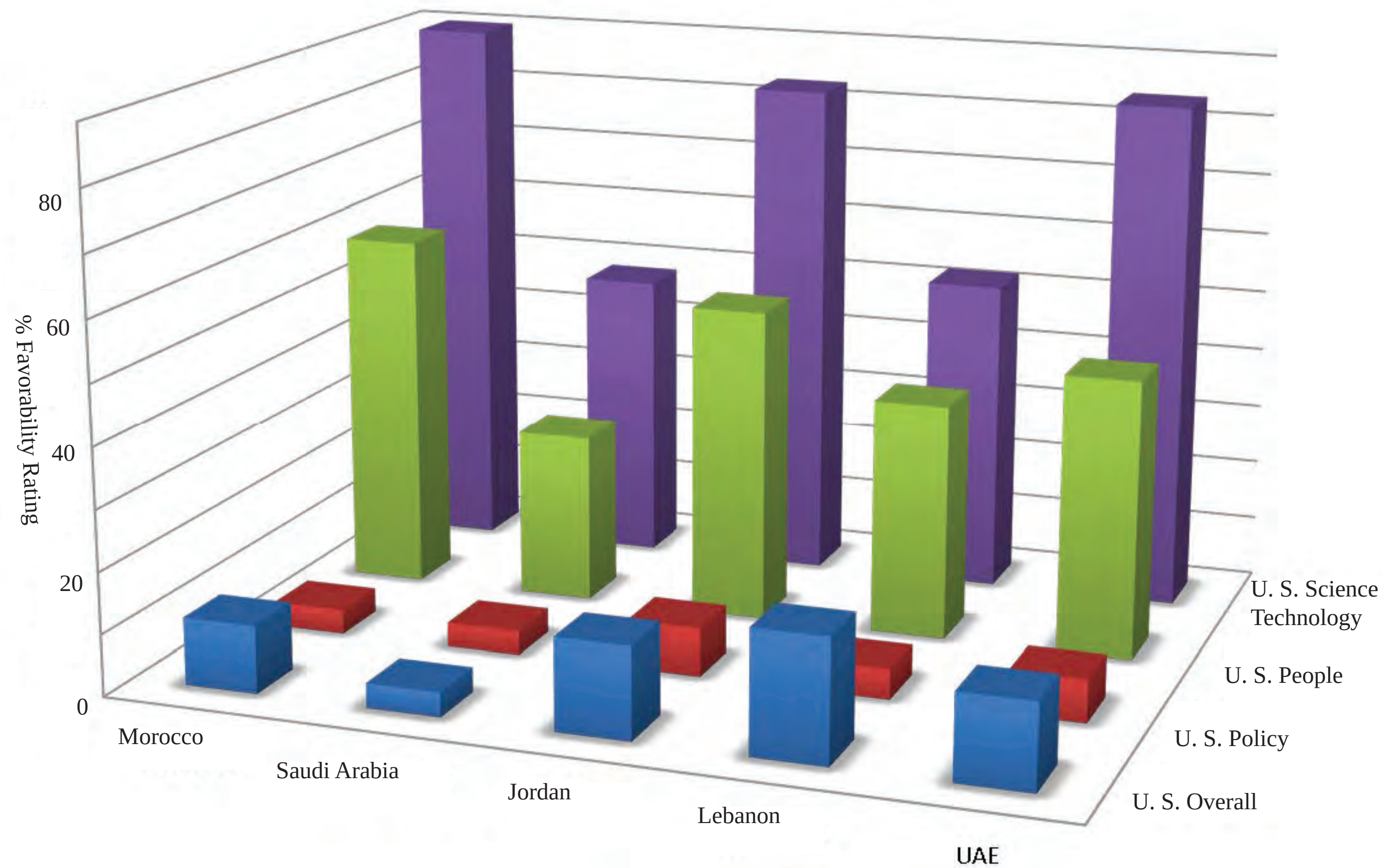


FIGURE 4. Arab attitudes toward the U.S.: They are most positive about U.S. science and technology. Information from Zogby, 2004

PUBLIC DIPLOMACY

It is no secret that the United States has an image problem around the world. The U.S. image is at its worst in the Arab world where overall favorability ratings are normally below 20% and in some cases are as low as 4% (Zogby, 2004). Such low ratings can be attributed to U.S. foreign policy toward these nations; U.S. policies have single digit favorability ratings (Fig. 3). However, these same Arab countries that have such a poor overall view of U.S. foreign policy have a substantially higher view of American people and products; these ratings tend to hover between 50% and 60% (Fig. 4).

What is startling is that the favorability rating toward U.S. science and technology is as high as 80% in many Arab nations (Zogby, 2004) (Fig. 5). This is a number that approaches the level of appreciation that American people foster toward their own science (Rand, 2009). In order to deal with such a severe image problem in foreign countries, the U.S. should promote its strongest asset, which is science.

The Arab example is the most dramatic, but the concept applies to diplomatic relations with all countries. Selling science to the public is a form of diplomacy. The U.S. State Department defines public diplomacy as "government-sponsored programs intended to inform or influence public opinion in other countries" (Rand, 2010). A simpler definition of diplomacy, applied to selling science, would be: programs intended to inform or influence opinion using known facts.

As with poor science and poor science education, there is a danger of mixing falsehoods (intentionally or not) with facts, which changes diplomacy to propaganda—a combination of falsehoods and untruths mixed with facts (Rand, 2010). The Rand (2010) report calls for the U.S. Government to engage in less "public diplomacy" in favor of the marketing model that works so well for U.S. corporations in other countries. The caution toward applying a marketing model to diplomacy is that it is too easy, whether by intention, laziness, or ignorance, to lapse into propaganda, as we observe so often in advertising.

SUBSTANCE VS. STYLE

Science education has substance, but often lacks style. Propaganda, on the other hand, normally has style (mixing of falsehoods and facts), but lacks credibility. The most important asset of good science is its credibility—its ability to maintain integrity even in the face of falsification. Good science allows even its most cherished hypotheses to be falsified; if the process that brought about those hypotheses was followed with integrity, then the process survives even in the face of falsification. That is science! As scientists we must safeguard the integrity of the scientific process while reaching for the style necessary to inform and influence public opinion.

Marketing tactics may be used to sell the science of paleontology, but scientists are bound to the sacred practice of safeguarding the integrity of the scientific process. We may use style to sell the substance, but we must not, through oversimplification or omission of facts, allow falsehoods to enter the message. This will be the most difficult part of integrating the importance of paleontology into a public message.

There is also no reason to apologize for the complexity of natural systems. The challenge is to embrace complexity while translating it into meaningful and relevant messages to our politicians, policymakers, and the general public. If the message is both relevant and delivered with sufficient style, people will listen.

THE PALEOCRAT

The profession of paleontology currently engages highest-caliber researchers, far sighted and progressive museum curators, and fantastically talented fossil preparators who all employ rigorous methodology and the latest techniques. However, paleontologists are currently ill-prepared as program managers or administrators. Until now, few people have chosen to enter the field of paleontology with the specific goal of becoming a manager or bureaucrat. As a group, paleontologists are teachers, researchers, and diggers (Foss, 2009).

The paleocrat is a breed of paleontologist who is versed in business management, public law, and diplomacy, and also maintains the skills of a researcher and teacher. These skills will become increasingly important as the profession of paleontology grows from researching novelties to addressing current social questions in our society.

THE MISSION

Science is our strongest card in the game of diplomacy. The public maintains a favorable view of science in nearly every country in the world and is willing to allow public funds to be spent on scientific inquiry. Failures in direct diplomacy around the world may be mended by playing to the strongest asset we have to offer, which is science. This fact makes it even more important that the scientific method be taught to all students and that it be employed with integrity.

Insights gained from studying paleontology have contributed to public discussions of everything from evolutionary theory to nuclear proliferation. In order to remain relevant, the science of paleontology must continue to provoke public discussion in areas of research that are germane to current issues. In a social and political environment where climate change has become a worldwide issue, the deep time perspective that is offered by the science of paleontology should continue to form a critical component of the discussion.

Every work place has a reason for existing that should be articulated in the form of a mission statement. The relevance of any given task should be measured against that statement. As public servants, the way we spend money should also be appropriate to the mission statement. Adherence to the mission will not only allow us to be more productive and effective as paleontologists, but will also help to guide us away from the political disasters that have befallen the profession of paleontology in the past. As scientists and public servants, this is our mission:

1. Promote science-based decision making in public policy and encourage scientific consideration in all levels of diplomacy.
2. Inform and educate policymakers and the public about important contributions of the science of paleontology toward relevant issues in public discourse.
3. Incorporate the science of paleontology into public outreach and education whenever possible.

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ARTICLE

ESTABLISHING A PALEONTOLOGICAL MONITORING TEST SITE AT GLEN CANYON NATIONAL RECREATION AREA

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ABSTRACT—Several factors were taken into consideration while establishing a paleontological monitoring test site at Glen Canyon National Recreation Area. Strata in the Recreation Area preserve a significant fossil record that includes many world class paleontological sites (Santucci and Kirkland, 2010), most notably a wealth of Lower Jurassic dinosaur tracksites preserved in the Glen Canyon Group along the margins of Lake Powell (Lockley et al., 1992, 1998). Santucci et al. (2009a) summarized the factors affecting in situ paleontological resources and strategies for monitoring their effects. There is little documentation of the long-term effect of these factors on fossil resources, but it is generally not an extremely rapid process unless the fossil is in an area of active erosion such as the bank of a river or the coast of a large body of water, or if the fossil in located in soft sediment. Vandalism and theft by humans pose a major threat to in situ fossil resources.

It is important to consider the costs associated with developing a monitoring plan. The most sophisticated methodologies may be cost-prohibitive and require trained scientists to carry out. Once a paleontological site has been properly documented, a plan can be developed to provide a means for low-cost, long-term monitoring. If significant changes are documented during subsequent visits, a follow-up inspection may be made by specialists (Milner et al., 2006; Santucci et al., 2009a, Spears et al. 2009).

KEYWORDS—Paleontological Monitoring, Glen Canyon National Recreation Area, Dinosaur Tracksite

INTRODUCTION

The National Park Service (NPS) has been developing monitoring programs for the natural resources within our national parks and monuments. The Utah Geological Survey (UGS) was contracted by the NPS to develop a paleontological monitoring test site at Glen Canyon National Recreation Area (GLCA).

Santucci et al. (2009) have summarized the natural and human factors affecting in situ paleontological resources and strategies for monitoring their effects. There is little documentation of the long-term effect of natural processes on fossil resources in the field, but it is generally assumed that fossils do not degrade rapidly under normal conditions unless the fossil is in an area of active erosion (such as the bank of a river or the coast of a large body of water) or if the fossil is located in soft sediment. A major threat to in situ fossil resources is vandalism and theft by humans.

It is important to consider the costs associated with developing a monitoring plan so that they may be carried out within the budget constraints of the NPS unit. The most sophisticated monitoring methodologies may be cost prohibitive and require trained scientists to carry out, thus the most effective monitoring plans are those that NPS staff can undertake with a minimum of specialized training. Once a paleontological site has been properly documented, an efficient plan can be developed that provides a means for low-cost, long-term monitoring. If significant changes are documented during subsequent visits, a follow-up inspection may be made by specialists (Milner et al., 2006; Santucci et al., 2009; Spears et al., 2009).

Strata in GLCA preserve a significant fossil record that includes many world-class paleontological sites (Santucci and Kirkland, 2010). Most notably, the Recreation Area contains a wealth of dinosaur tracksites preserved in the Lower Jurassic Glen Canyon Group along the margins of Lake Powell (Lockley et al., 1992, 1998). This paper summarizes our establishment of a paleontological monitoring test site, such that GLCA staff may appraise the potential costs inherent in developing a park-wide paleontological monitoring plan.

LOCKLEY'S COVE—A SIGNIFICANT PALEONTOLOGICAL SITE COMPLEX

Even in the most famous fossil-bearing strata, such as the Upper Jurassic Morrison Formation, significant vertebrate fossils are not distributed evenly through the outcrop. A Paleontological Site Complex (PSC) is an area of restricted geographic and temporal extent that preserves an abundance of important fossil localities (Kirkland and Foster, 2009). PSCs make up the core of some of America's most famous national parks and monuments, as exemplified by Petrified Forest National Park, Fossil Butte National Monument, Badlands National Park, John Day Fossil Beds National Monument, and Agate Fossil Beds National Monument. As with these PSCs, GLCA's first identified PSC—Lockley's Cove in the Slick Rock area—warrants special attention (Fig. 1).

In seeking a site for which we could develop a model for paleontological monitoring at GLCA, we visited an area preserv-

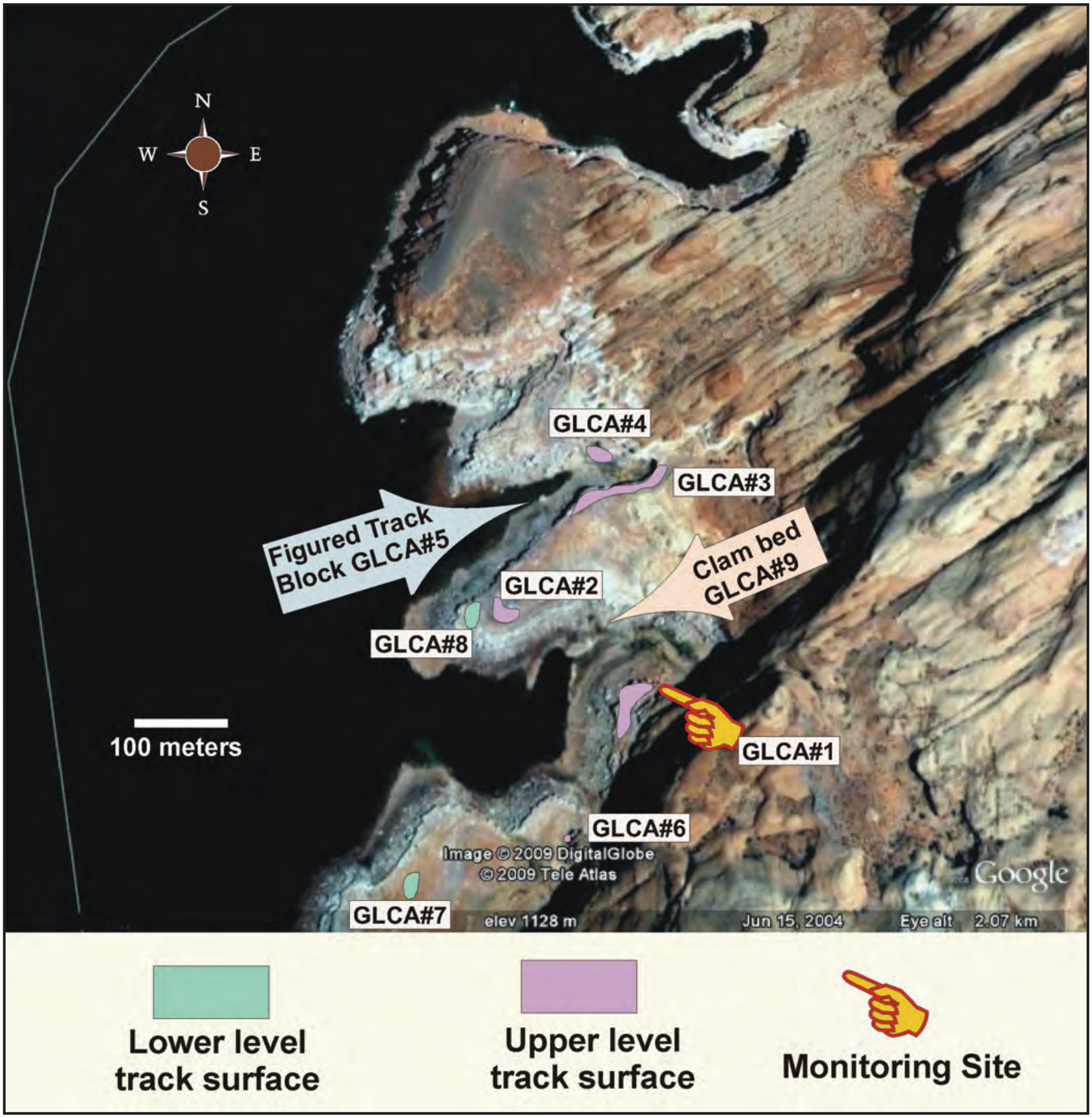

FIGURE 1. Google Earth view of the Lockley's Cove PSC with the distribution of paleontological sites and the primary monitoring site.

ing several dinosaur tracksites at multiple stratigraphic levels, initially researched by a team led by Martin Lockley in 2005 and revisited during a spring 2008 trip. Informally, we have designated this area Lockley's Cove (Fig. 1). The nine recorded fossil sites are preserved in a thick sequence of alternating mudstone, limestone, and sandstone more than 30 m (100 ft) thick, as measured from lake level to the base of the main cliff of cross-bedded Navajo Sandstone (Fig. 2 B). In addition, the area preserves a unique unionid clam bed containing molds of hundreds (potentially thousands) of individual fresh-water bivalves (Phoebes' Clam Bed); this bed was submerged during our visit (Fig. 3). Because there is an obligate parasitic relation between these bivalves and fish—all unionid larvae spend part of their life living in the gill filaments of fish (Good, 1998),—their presence indicates that fish were also present at this location during the Early Jurassic. The site had been originally identified as being in the Kayenta Formation because of the extent of fine-grained rocks and the presence of unionid clams. Using a new

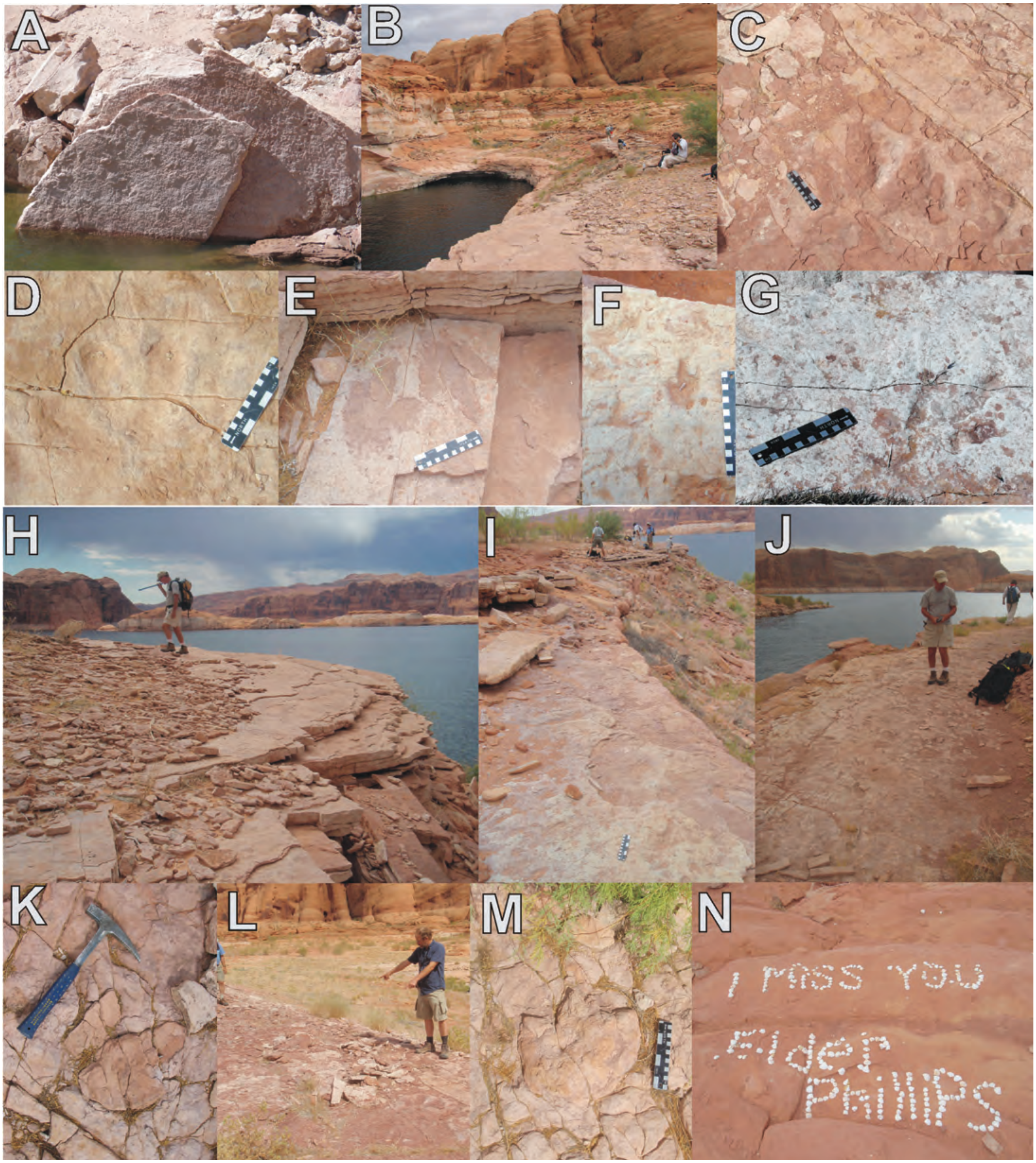

FIGURE 2. Fossil sites and features at Lockley's Cove. **A**, Large fallen track slab GLCA#5 "upper level" identified for salvage in 2008, but completely under water in 2009, figured in Santucci et al. (2009); **B**, Inundated cove northwest of GLCA#3. There would have been no water in this view a year earlier. Note cliff of Navajo Sandstone; **C**, *Eubrontes* track at GLCA#2 "upper level"; **D**, *Anomoepus* tracks at GLCA# 3 "upper level"; **E**, *Anchisauripus* tracks at GLCA#3 "upper level"; **F**, **G**, *Grallator* tracks at GLCA #3; **H**, **I**, Views of GLCA#3 "upper level"; **J**, GLCA#4 "upper level"; **K**, **M**, *Eubrontes* tracks at GLCA#8 " lower level"; **L**, GLCA#8 "lower level"; **N**, Ecologically benign graffiti made by laying out modern *Corbicula* shells.

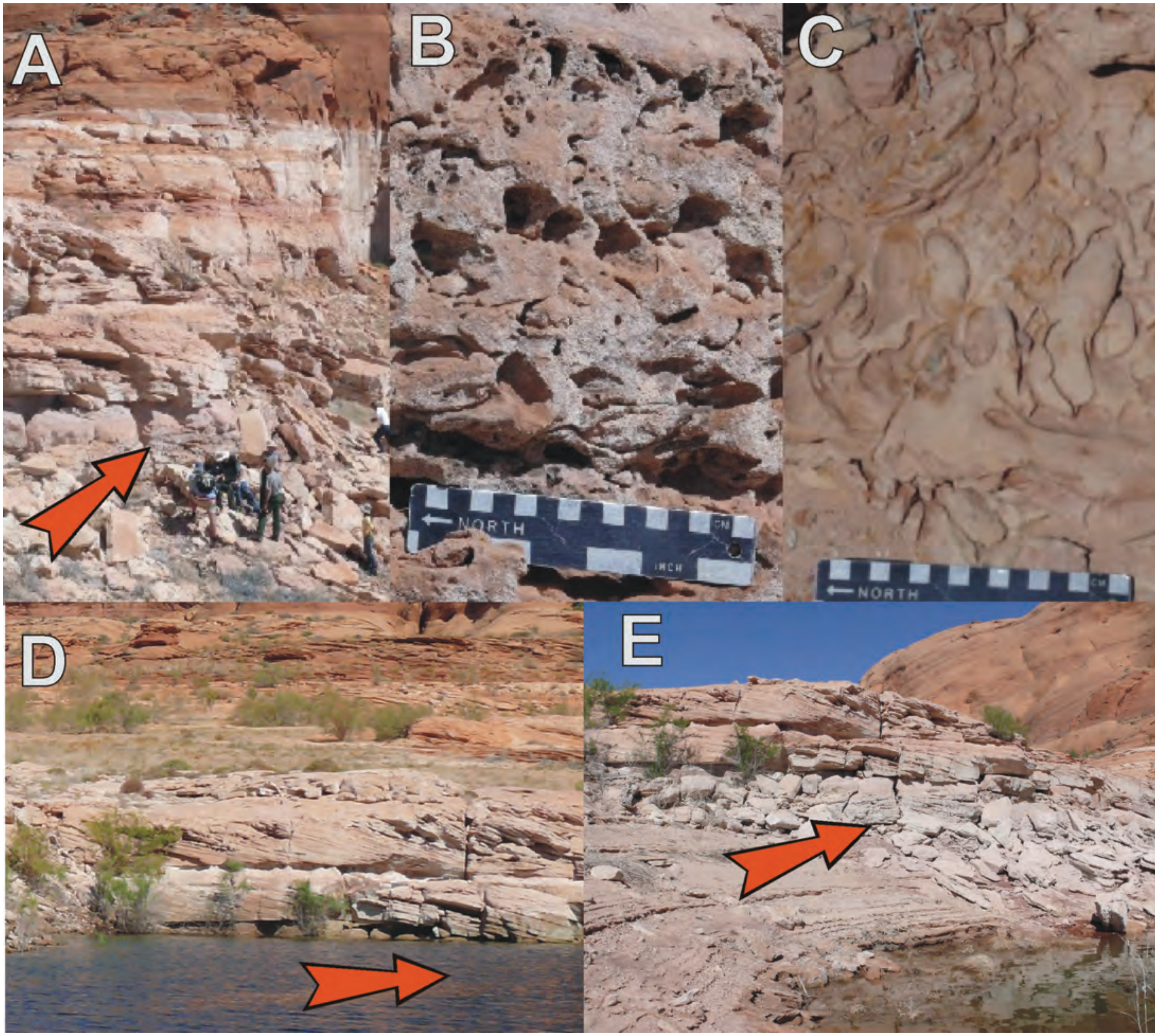

FIGURE 3. Pheobe's Unionid Clam Bed at Lockley's Cove in spring 2008. **A**, GLCA staff inspecting site, upper track level in notch ~ 5 m above, arrow points to in situ clam bed; **B**, unionid molds in cross section; **C**, unionid molds as exposed along bedding plane.

geological map (Doelling and Willis, 2008), we were able to determine that these sites were at least 400 feet above the base of the Navajo Sandstone. Previously, unionid bivalves were unknown in the Navajo of southern Utah, although they had been recognized in the Moab area (Wilkens, 2008). Therefore, unlike the other playa environments preserved within this eolian rock unit at GLCA, which represent times when the Early Jurassic water table impinged on the surface of interdune areas, this site is unique in that it records an environment connected to more permanent water sources near the center of the largest sand sea in Earth's history.

PRIMARY MONITORING SITE

In 2005, George Muller discovered an outstanding tracksite about one kilometer (0.6 mi) up river from Mile Buoy #81 in the Colorado River Arm of Lake Powell. This locality, referred to as the "Dance Floor" by Muller and "Slick George's Dinosaur Tracksite" by Martin Lockley, is down lake from Slick Rock Canyon in an alcove on the east side of the lake. The fossil-producing bed is about 8 meters (26 ft) below the high waterline at an elevation of approximately 3700 ft (Fig. 4).

As documented by Lockley, fossils consist of well-preserved *Anchisauripus*, *Anomoepus*, and *Grallator* tracks, a few of

FIGURE 4. Slick George Dinosaur Tracksite GLCA#1 in the fall of 2009 versus the spring of 2008 during lower lake levels. Position of upper track level indicated by red track symbol and arrow, and approximate position of lower track level indicated by white track symbol and arrow.

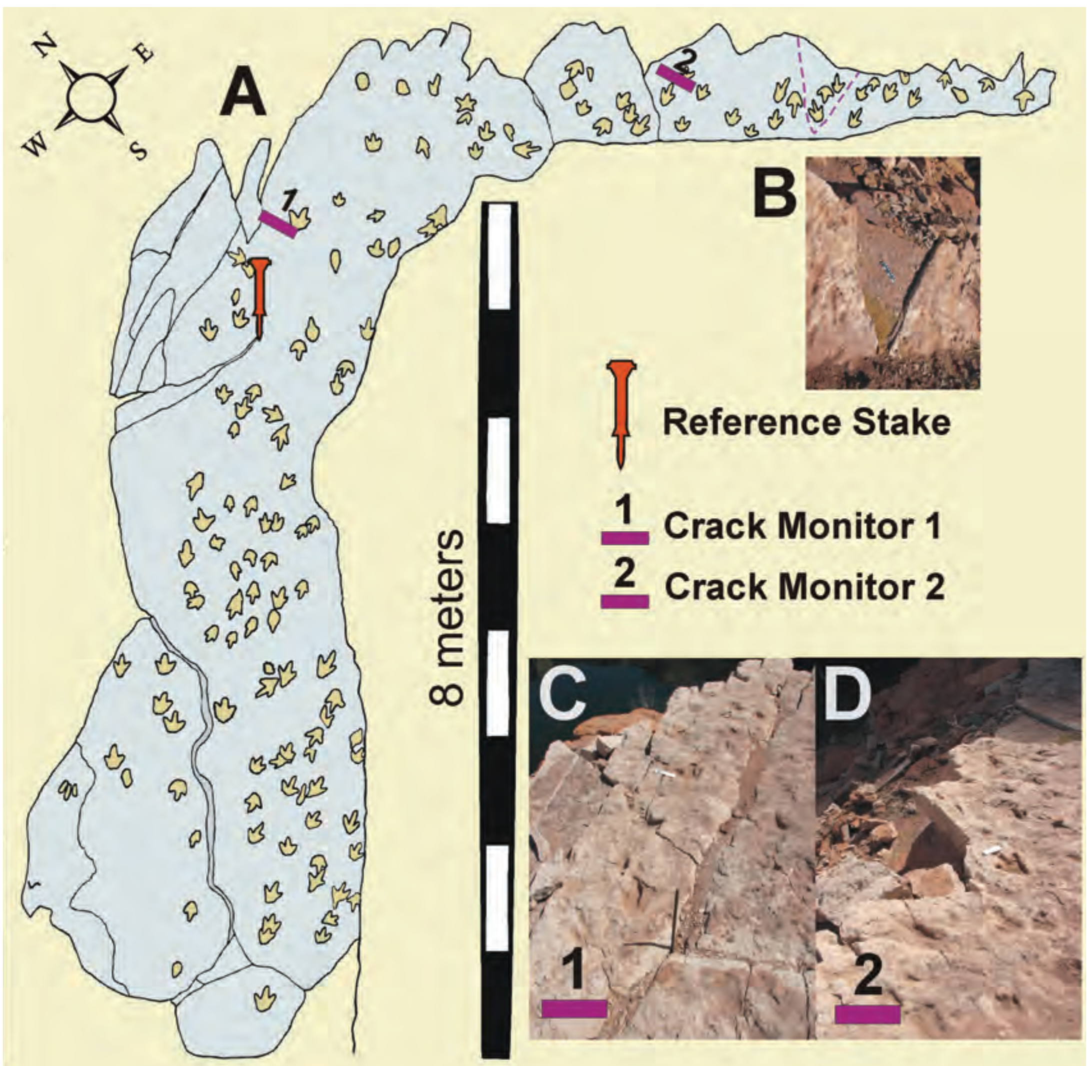

FIGURE 5. Slick George Dinosaur Tracksite, GLCA#1. A) Distribution of tracks at GLCA#1 mapped by Martin Lockley in 2005, showing the position of reference stake and crack monitors, and position of missing track section indicated by dashed line at top of figure; B) 2009 photo showing detail of site of missing track section; C) Surface of site showing position of rebar reference stake and crack monitor 1 looking north; D) Overview of crack monitor 2 looking east.

which appear to be associated trackways made by individuals walking across the surface (Fig. 5). The track-bearing unit, composed of fine-grained quartz sandstone, with rounded grains and carbonate cement, is exposed in several localities around the cove; tracks appear to be fairly abundant in the adjacent areas visited. A specimen of the track layer was sampled for petrographic analysis (Fig. 6). Initial interpretation is that this layer may represent an interdunal playa "oasis" deposit in the Navajo Sandstone, although the associated unionids suggest it may be part of a larger aquatic system. The absence of porosity in these samples is a result of extensive carbonate cementation.

This locality was established as the first Paleontological Resource Monitoring locality for GLCA because its location and wide variety of features make it a good place to implement the methodology of Santucci et al. (2009) for monitoring in situ paleontological resources. The site has the following attributes:

1. It contains significant paleontological resources (Fig. 5).
2. It is accessible from the lake shore (Fig. 1).
3. It is threatened by both natural and human-related factors (Figs. 2, 3).
4. Erosional processes at the site have resulted in a "conveyor belt" retreat of the track-bearing slabs (we documented one track slab that was down dropped from the section). Processes include undercutting of sub-adjacent beds, splitting along joints of track-bearing unit (Figs. 5, 7), and down-drop of boulders from super-adjacent units (documented rock-fall damage from Navajo blocks dropping from above the site).
5. Although the site is located above the current water level for Lake Powell, it is below the high water mark (Fig. 4). Changes to the site can be photo documented using an embedded stake as a reference point, measured directly, or calculated from recorded lake level.
6. There is evidence of human visitors to the site (Fig. 2). One section of rock from the track-bearing unit appears to have been removed intentionally following the initial mapping of the site in 2005 (Fig. 6). (Martin Lockley is not sure if he collected it.)

A reference point for the site was established by the placement of a centrally-located rebar marker (Figs. 5, 7). This marker is the geo-reference point for the site and the photo-point for repeat photo documentation of the site. The location provides views along the two main axes of the track-bearing exposures. The long axis for photo-monitoring is S. 15○ W.; the short axis for photo-monitoring is due east from the stake. GPS coordinate data for the site were obtained by several repeat measurements using a hand-held instrument.

The locality was photo-documented by Scott Madsen at 1:00 p.m. MDT on September 20, 2009. No paleontological resource collections were made from the site, and only the one rock specimen was collected from the track-bearing layer for petrographic analysis (Fig. 6). One slab had previously been removed from the locality (not natural breakage) following the initial mapping in 2005. Martin Lockley is checking his documentation to determine whether he collected any specimens; if he was not responsible, the missing slab may represent an incidence of theft.

A strong joint set is present in the fossil track-bearing unit (Figs. 5, 7). The joints are essentially vertical and strike N. 50○ E., and spaced from 0.25 to 0.5 meter (0.8–1.6 ft) apart. On April 26, 2010, James Kirkland and Scott Madsen met GLCA Aquatic Ecologist Mark Anderson at the Bullfrog Marina and proceeded

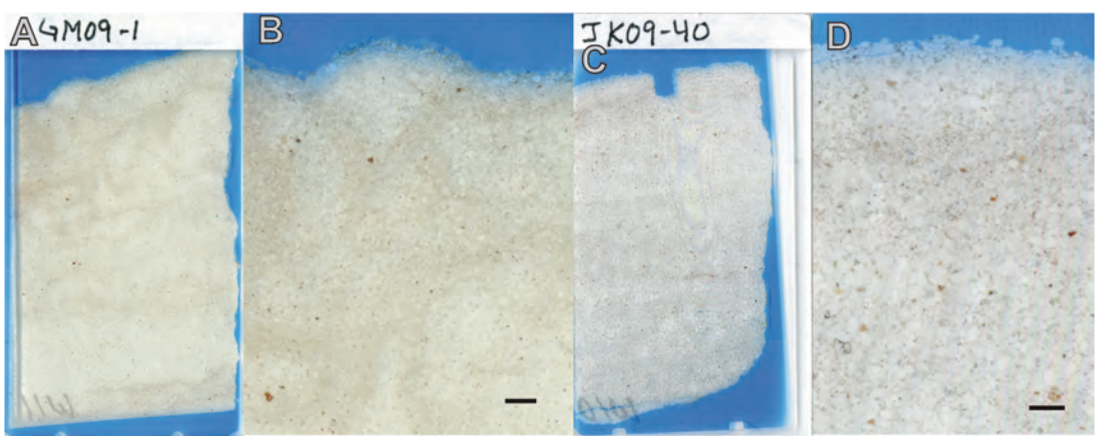

FIGURE 6. Thin sections made from upper track horizon at Lockley's Cove. A) Thin section from Slick George Dinosaur Tracksite GLCA#1; B) Detail of upper surface of track layer GLCA#1, scale bar equals 1 mm, porosity is 0.000%; C) Thin section from Anomoepus Bench GLCA#3; D) Detail of upper surface of track layer GLCA#3, scale equals 1 mm, porosity is 0.028%. All slides are 2.7 cm wide.

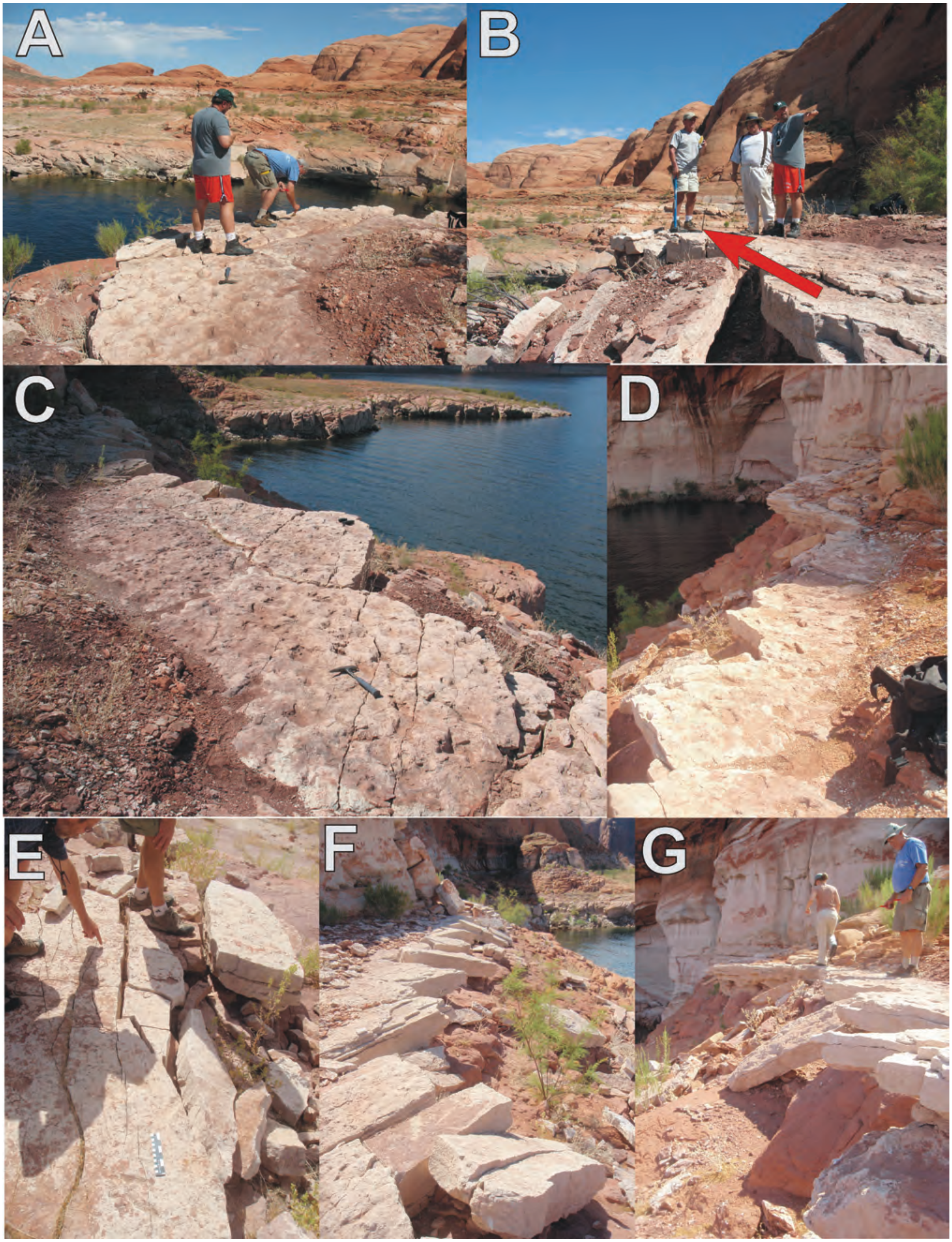

FIGURE 7. Establishing monitoring station at Slick George Dinosaur Tracksite, GLCA#1. **A**, **B**, Establishing rebar reference point, arrow indicates rebar stake; **C**, View from stake looking southwest; **D**, View from stake looking northeast; **E–G**, Sides of site being undercut, splitting along joints, and spalling down slope.

down lake to Lockley's Cove and Monitoring Site GLCA#1 to install crack monitors to measure the expansion of the joints. The team used adhesives to install two crack monitors at both GLCA#3 and GLCA#1 (Figs. 5, 8).

While there, they also took more photographs in order to evaluate any short-term changes that may have occurred in the seven months following the initial establishment of the monitoring site. No appreciable changes were observed (Fig. 9).

In order to put all the fossil sites in the Lockley's Cove area into a temporal context for future researchers, Kirkland measured a stratigraphic section from the water line up through the highest recorded fossil occurrence at GLCA #1. All three fos-

FIGURE 8. Installing crack monitors. **A–E**, Installing crack monitors at GLCA#3. **A**, Mixing epoxy; **B**, Installing crack monitor by *Anomoepus* tracks; **C**, Crack monitor by *Anchisauripus* tracks; **D**, Crack monitor by *Anomoepus* track; **E**, Close-up of crack monitor by *Anomoepus* track showing initial setting of 0,0; **F–H**, Crack monitor 1 at GLCA#1. **F**, Overview looking north; **G**, Another view looking west; **H**, Close-up of crack monitor 1; **I–K**, Crack monitor 2 at GLCA#1 by *Grallator* track. **I**, Overview looking east; **J**, Another view looking northwest; **K**, Close-up of crack monitor 2.

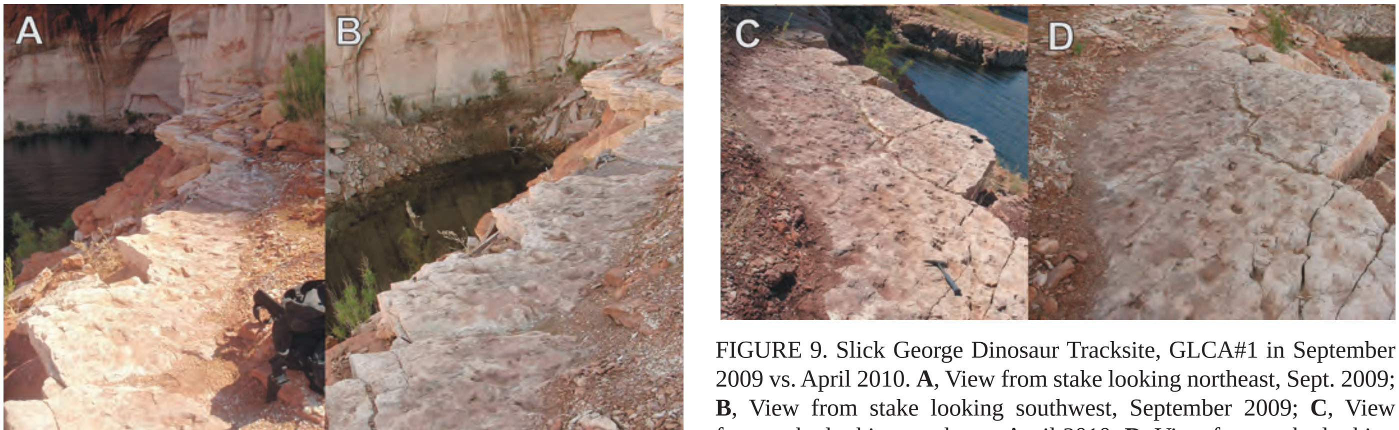

FIGURE 9. Slick George Dinosaur Tracksite, GLCA#1 in September 2009 vs. April 2010. **A**, View from stake looking northeast, Sept. 2009; **B**, View from stake looking southwest, September 2009; **C**, View from stake looking northeast, April 2010; **D**, View from stake looking southwest, April 2010.

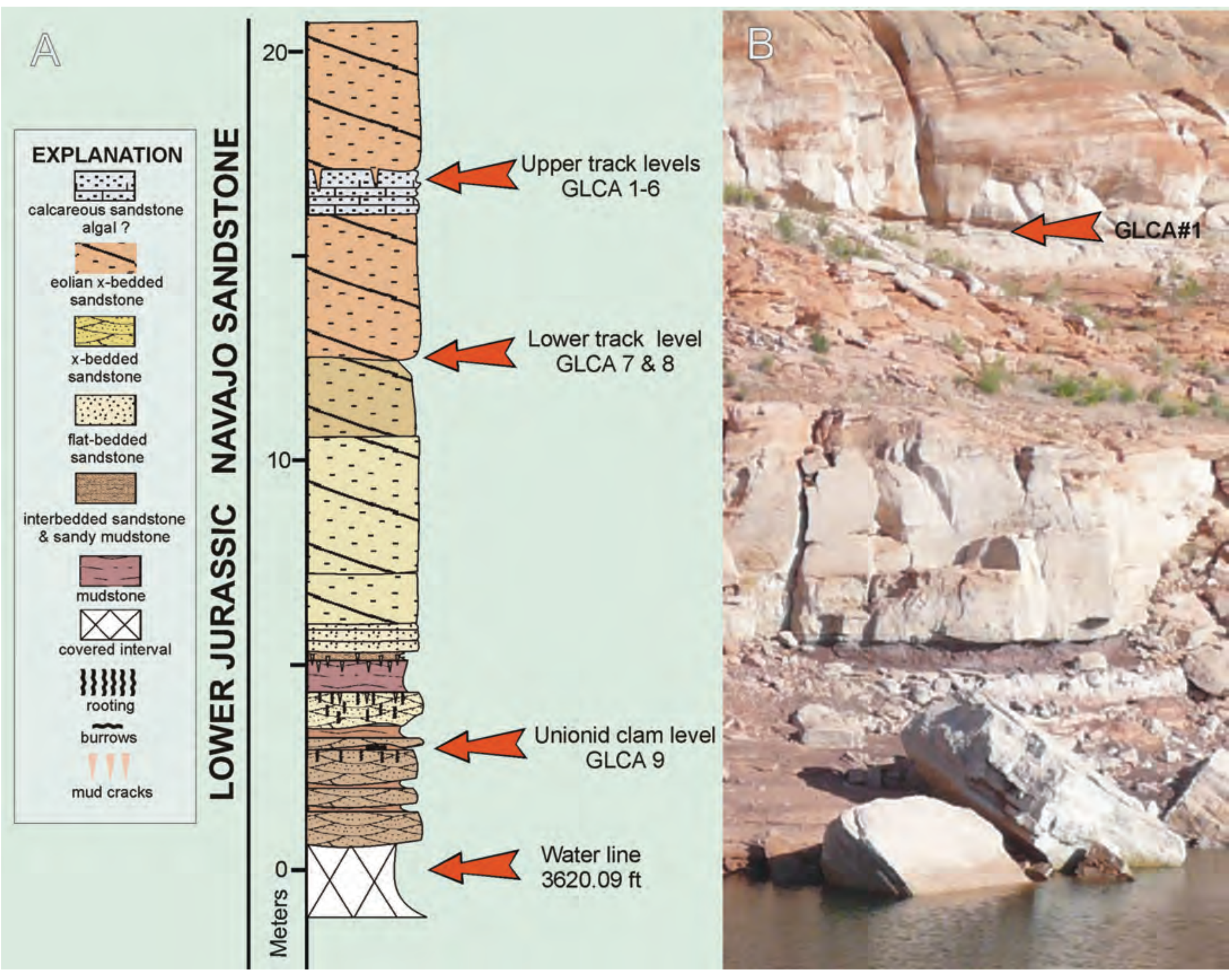

FIGURE 10. Measured section. **A**, Measured stratigraphic section on the south end of Slick George Dinosaur Tracksite GLCA#1 with stratigraphic positions of main sites in the Lockley's Cove PSC (Fig. 1); **B**, Outcrop on the south end of Slick George Dinosaur Tracksite GLCA#1, stratigraphic section was measured April 26, 2010, at a lake level of 3620.09 ft.

siliferous intervals and their relationships with these rocks were documented (Fig. 10).

NPS personnel at GLCA will continue to make regular visits to Lockley's Cove to document long-term natural and visitor-induced changes at the site.

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ARTICLE

THE KEYA PAHA FAULT AND RELATED STRUCTURES; THEIR SIGNIFICANCE TO THE GEOLOGY OF SOUTH DAKOTA

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ABSTRACT—A major geological structural feature, the Keya Paha Fault, occurs in south-central South Dakota and appears to extend northwestward across South Dakota. The fault is subparallel to the well-documented White Clay Fault, occurring farther west in South Dakota, and to other lineaments occurring between the two faults. To the east of the Keya Paha Fault, Ponca Creek and even a portion of the Missouri River lie subparallel. The trends of all these structural features suggest a northwesterly directed structural fabric across western South Dakota that is probably the result of basement offsets. The Keya Paha Fault is demarked by the absolutely straight trend of the Keya Paha River across Tripp and Todd counties, offset of Oligocene fossiliferous beds in the Badlands, and perhaps the trend of the Northern Black Hills Tertiary Intrusive Province. Additional subparallel lineaments occurring along the South Dakota-Nebraska border may also eventually prove to be of fault origin in South Dakota. Recent investigations along the Missouri River have indicated smaller scale faults and clastic dikes. These too are typically trending northwesterly and some have been found with glacial debris within the fault gauge, suggesting relatively recent movement. Overall, this northwesterly trending structural fabric has great impact upon the distribution of natural resources in South Dakota, including, among others, water, petroleum, minerals, and fossils.

KEYWORDS—Keya Paha Fault, South Dakota, Lineaments, Structural Geology

INTRODUCTION

During the compilation of the geological map of the state of South Dakota (Martin et al., 2004), one of the overall most striking features noted was the paucity of documented structures. Anticlines and synclines were more commonly mapped than faults, but neither had been extensively mapped. In the western portion of the state, with the exception of the Black Hills, only the White Clay Fault in Shannon and Fall River counties, small-scale faults in Badlands National Park in eastern Pennington and western Jackson counties, and the swarm of small-scale faults in the Slim Buttes area of Harding County in northwestern South Dakota were well-documented. During map production, the Keya Paha River was noted to be distinctly linear, trending directly northwesterly at North 65–70^{o} West (Fig. 1). This trend continues to the northwest, leading to the faults in the Badlands and, farther north, Tertiary intrusives of the northern Black Hills that extend from the Vanocker Intrusive in Meade County across the cutting stock of the Lead-Deadwood area to the Missouri Buttes/Devil's Tower intrusives in Crook County, Wyoming. The Keya Paha structure parallels the White Clay Fault in Shannon and Fall River counties to the west (Fig. 1). Moreover, a number of other smaller lineaments appear to subparallel the Keya Paha and White Clay structures along the South Dakota-Nebraska border. Although the late Cenozoic Sand Hills obscure these structures, they are discernible based on subparallel stream directions.

In 2006, I investigated the area during continued research for the South Dakota Geological Survey and noted significant displacement along the Keya Paha River. At that time, I stated,

> "The Keya Paha River exhibits one of the most unusual morphologies of any river within the state of South Dakota. The Keya Paha River has its source in north-central Todd County near the town of Mission, but trends directly southeast to the Nebraska border in southeastern Tripp County. Therefore, the River trends in a nearly straight line for over 75 miles in South Dakota in a northwest-southeast direction. Most of the major structural fabric of South Dakota, for example, the White Clay Fault in southern Shannon County, trends in this direction. A fault seems to be the most likely explanation for the straightness of the River coupled with the northwesterly direction. …" Martin (2006:27).

The Keya Paha trend may extend northwesterly into southwestern Mellette County, beyond the limit of the Keya Paha River. This area lies between the straight Keya Paha valley and the small offsets in Badlands National Park. McCormick (2010) of the SD Geological Survey dashed the structure on her map concerning the Precambrian basement terrane, but she did not formally describe the structure; she also illustrated another fault by a solid line, the Reservation Fault which trends along Ponca Creek. McCormick did not address these faults specifically in her text, but their presence on her map suggests that they represent basement structures.

During the past twenty years, I have also noted stratigraphical relationships and geological structures while directing paleonto-

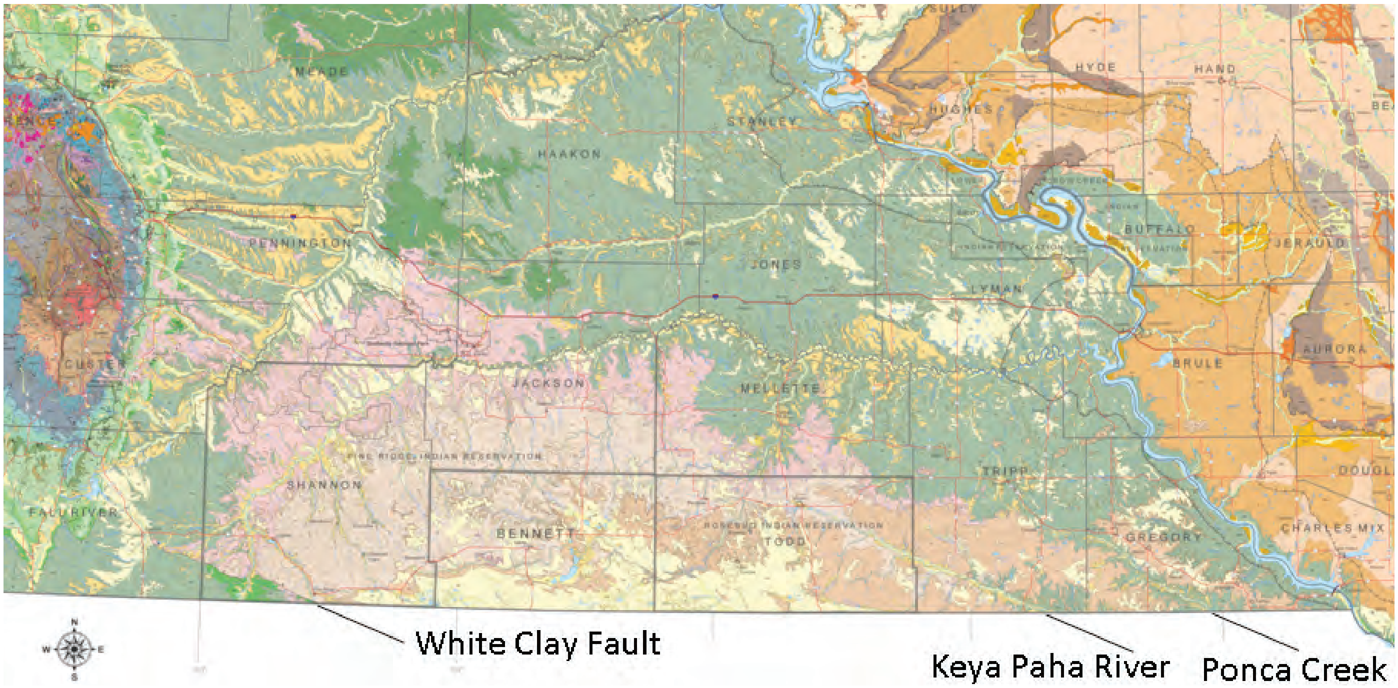


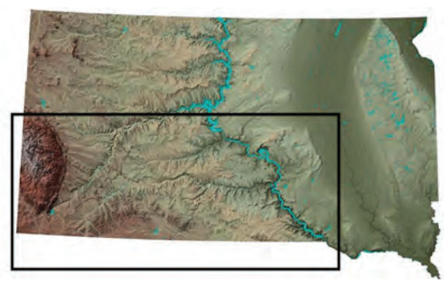
FIGURE 1. Location of Keya Paha River, Ponca Creek, and the White Clay Fault, shown on the Geological Map of the State of South Dakota (Martin et al., 2004). See Martin et al. (2004) for geological legend.

logical surveys along the Missouri River from Pierre in Hughes County south to Pickstown in Charles Mix County. Along with significant vertebrate and invertebrate fossils, I noted numerous small-scale faults, many of which exhibit a northwesterly trend. Although the tops of most faults were covered, making it difficult to assign a date more precise than post-deposition of the Late Cretaceous Pierre Shale Group (Martin et al., 2007), a fault south of Chamberlain in Brule County (Sawyer and Martin, 2004) and a clastic dike across the Missouri River in Lyman County exhibit glacial debris within the fault gouge.

Overall, this contribution represents a model concerning the structural fabric of the Northern Great Plains that requires extensive testing, particularly geophysical investigations, prior to substantiation. If this model is eventually proven, the ramifications are widespread for nearly all aspects of geologically related activities from petroleum to paleontological resources.

STRUCTURES ALONG THE SOUTH DAKOTA-NEBRASKA BORDER: THE KEYA PAHA FAULT

The Keya Paha River exhibits one of the most unusual morphologies of any river within the state of South Dakota (Fig. 1). The river has its source in north-central Todd County near the town of Mission, but trends directly southeast to the Nebraska border in southeastern Tripp County and continues along the same trend across the northern portions of Keya Paha and Boyd counties, Nebraska. In northern Boyd County, the Keya Paha River flows into the Niobrara River. At this point, the Niobrara River turns southeasterly and follows the same trend as



that of the Keya Paha River. This southeasterly trend continues into Knox County, south of the town of Niobrara. Therefore, the Keya Paha River trends in a nearly straight line (North 65–70^{o} West) for over 120 km in South Dakota and continues into Nebraska along the Keya Paha and Niobrara rivers in a northwest-southeast direction for another 160 km. This northwest-southeast trend (Fig. 1) parallels other structures in South Dakota, for example, the White Clay Fault in southern Shannon County (See Martin et al., 2004).

Faulting is the most likely explanation for the straight, northwesterly direction of the Keya Paha River (Fig. 2). Stratigraphic evidence is found in T95N, R76W, Tripp County, South Dakota. Turtle Butte, composed of the Pierre Shale, possibly White River, the Arikaree, and the Ogallala Group sediments, lies in secs. 9, 10, and 11 (See Fig. 3, for regional stratigraphic relationships). Skinner (1968) mentioned Chadron-like deposits of the White River Group above the Pierre Shale and below the Rosebud Formation of the Arikaree Group, but these White River sediments are not obvious. Arikaree Group sediments consist of the pink Rosebud Formation lying subjacent to the greenish Turtle Butte Formation, and also occur in high-elevation road cuts about nine km to the south of Turtle Butte in secs. 31 and 32. The Pierre-Arikaree contact occurs at about the 670-m (2200-

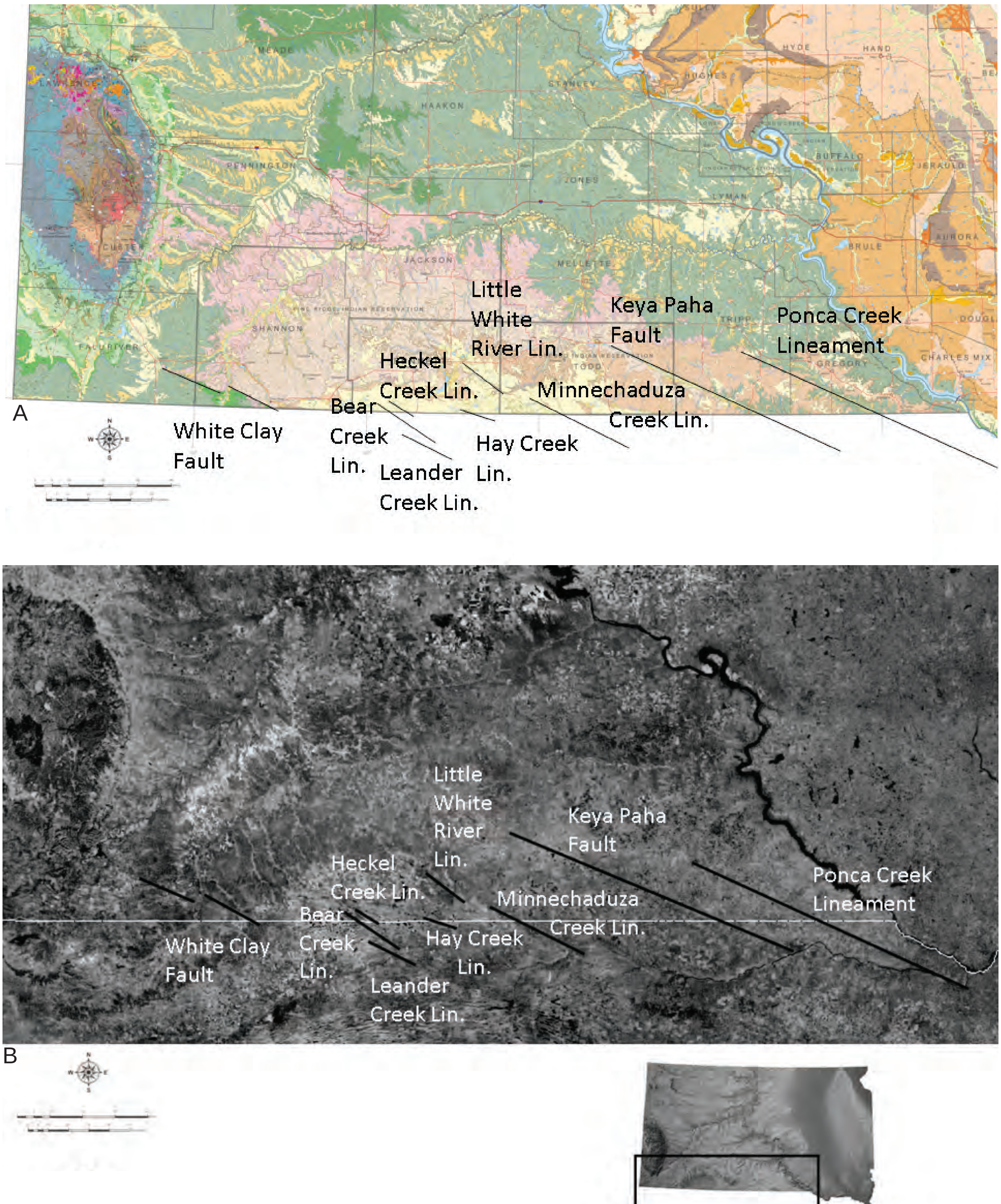


FIGURE 2. Placement of faults and structural lineaments along the South Dakota-Nebraska border on **A**, the Geological Map of the State of South Dakota (See Martin et al., 2004, for geological legend) and on **B**, satellite base.

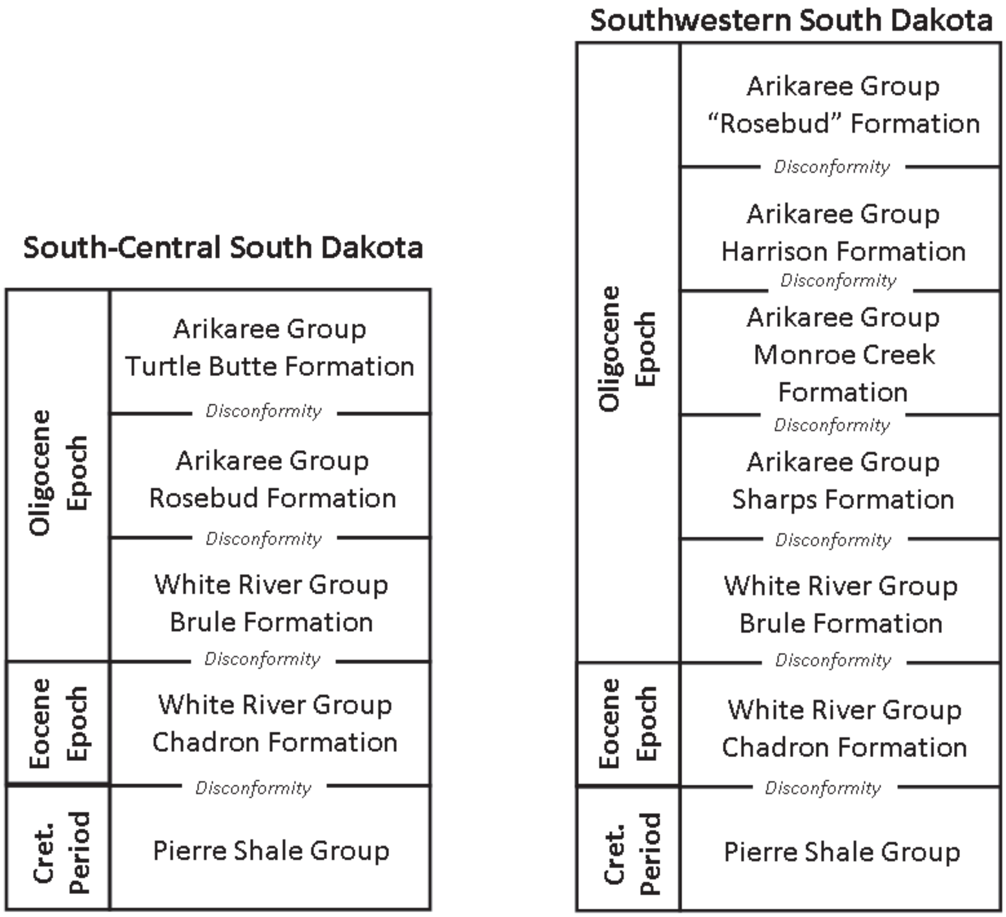


FIGURE 3. Stratigraphic nomenclature of southern South Dakota west of the Missouri River (adapted from Martin, 1983).

foot) elevation on the southern side of the Keya Paha River in sec. 20, but on the northern side in sec. 11, the contact occurs at 710 m (2330 feet). As the contact is lower on the western side of Turtle Butte, this differential may be the result of paleotopography on the Pierre Shale. The Rosebud-Turtle Butte contact lies approximately at 713 m (2340 feet) on Turtle Butte, whereas the contact lies at the 722-m (2370-foot) elevation in secs. 31 and 32. The Ash Hollow Formation of the Ogallala Group occurs at the 740-m (2430-foot) level on Turtle Butte, but at 729 m (2390 feet) in secs. 31 and 32. Although differential cut and fill at the base of the various formations, along with estimation error, account for some of the elevational differences, consistently higher-elevation formational contacts on the southern side of the Keya Paha River indicate a fault with at least 9 meters displacement in the Wewela area. The north-side down throw mirrors the displacement direction of the White Clay Fault farther west.

The Keya Paha structure may extend farther northwesterly into the southwestern portion of Mellette County, north of the town of Norris. Here, the Oligocene deposits appear to be offset, and the trace of the structure may be represented by Berry Springs in the NE1/4, sec. 26, T39N, R32W. The type area of the upper Oligocene Rosebud Formation occurs to the south in west-central Todd County, whereas the Sharps Formation and the subjacent Brule Formation occur to the west, principally in western Bennett and Shannon counties, although exposures also occur in Jackson and Mellette counties. The upper Oligocene Rosebud Formation can be traced from its type area to north of the town of Norris. The lower Oligocene Scenic Member of the Brule Formation occurs 3.2 km north of Norris near St. Paul Church, and the Brule Formation and the suprajacent Sharps Formation are superposed 7.2 km farther north, near the town of Corn Creek. More exposures of the Sharps Formation occur to the west of Corn Creek at a point 6.9 km east of the intersection with Highways 44 and 73. Berry Spring, an area of wetlands, lies between exposures of the Rosebud Formation and the Scenic Member of the Brule Formation. If this area represents the continuation of the Keya Paha structure, the south side is down. If the North 65–70^{o} West trend is followed northerly into Badlands National Park, the trend intersects the small-scale faults observable along the Badlands Loop Road (Martin et al., 2004). Clark et al. (1967) illustrated a series of five linear faults in the Badlands trending North 70^{o} West that typically exhibit south-side down displacement, although the opposite throw may be noted. Clark et al. termed one as the Sage Fault, which he considered the northern bounding fault of a trough bounded on the south by the White Clay Fault (his Pine Ridge Structure). Nearly all later workers have abandoned this interpretation and illustrate only the series of short displacements illustrated on the compilation of Martin et al. (2004). Clark et al. (1967) also felt the linear faults controlled the drainage pattern of streams flowing easterly from the Black Hills; he extended the Sage Fault west along Boxelder Creek. Lisenbee (2007) also believed that multiple basement-cored blocks occur along the eastern margin of the Black Hills. Additional geophysical investigations are required to determine if one or more of these structures do represent northern extensions of the Keya Paha structure.

STRUCTURES ALONG THE SOUTH DAKOTA-NEBRASKA BORDER: PONCA CREEK LINEAMENT

Ponca Creek, which parallels the direction of the Keya Paha Fault from South Dakota into northern Nebraska, lies just to the east of the Keya Paha River in Gregory County in south-central South Dakota (Fig. 1). In her study of the basement geology of South Dakota, McCormick (2010) illustrated the Reservation Fault in this area but did not include formal description or explanation. Having informally used the Ponca Creek lineament for this structure, I herein formalize the structure as the Ponca Creek Lineament until actual offset is documented.

The structure nearly parallels the Keya Paha Fault and extends at least 130 km from eastern Todd County in South Dakota to the area south of the town of Niobrara in Boyd County, Nebraska (Fig. 2). McCormick (2010) illustrated a North 60° West trend for the fault, whereas the creek ranges from North 60–75° West, with most areas in South Dakota averaging North 70° West. Moreover, if the overall direction of the creek is projected northwesterly, it parallels the trend of the postulated fault in the Big Badlands north of the Sage Fault, which nearly defines the northern margin of the White River Badlands in Clark et al. (1967). If this projection is substantiated, the throw of this fault would also be south-side down suggesting en echelon structures forming the northern margin of the graben in which the White River Badlands are preserved. Moreover, the trend of this structure along with that of the Keya Paha Fault can be extended across the northern Black Hills and might have provided the zones of weakness that result in a line of laccolithic structures from the Vanocker and Bear Butte laccoliths on the eastern margin of the Black Hills to the Missouri Buttes area to the west of the Black Hills. Again, extensive geophysical and stratigraphic analyses should be performed to substantiate these projections.

ADDITIONAL LINEAMENTS ALONG THE SOUTH DAKOTA-NEBRASKA BORDER

Another North 60–70° West-trending lineament extends along Minnechaduza Creek for 29 km from Valentine in Cherry County, Nebraska, to the South Dakota-Nebraska border (Fig. 2). From the border, it continues another 19 km northwesterly to the Little White River in southwestern Todd County. Eight kilometers to the west, the Little White River trends North 60° West for at least 24 km. These are collectively named the Little White River-Minnechaduza Creek Lineament (Fig. 2). Much of this trend is through the Nebraska Sand Hills, which may have somewhat altered its linear expression and obscured stratigraphical relationships on either side of the lineament.

Additional lineaments occur in Cherry County, Nebraska, farther west than the Little White River-Minnechaduza Creek Lineament along northwesterly-trending Hay, Heckel, and Bear-Leander creeks (Fig. 2). Like the Little White River-Minnechaduza Creek Lineament, these are covered by the relatively recent Sand Hills, which obscure their extent and possible displacement. The Hay Creek Lineament is defined here to extend 12 km and trends North 75° West; the Heckel Creek Lineament extends 13 km and is oriented at North 60° West, and the Bear-Leander Creek Lineament is similar to the Little White River-Minnechaduza Creek Lineament in being slightly offset. Both segments trend northwesterly and together extend over 45 km; the Leander Creek portion trends North 70–75° West and extends 26 km, whereas the Bear Creek portion trends North 60–65.5° West and extends for 29 km.

Occurrence of these shorter, northwesterly-trending lineaments between the Keya Paha Fault and the White Clay Fault suggests relationship to these larger structures. Geophysical and other geological investigations may indicate that these lineaments are the result of an overall northwesterly-trending structural fabric along the South Dakota-Nebraska border.

DISCUSSION AND HYPOTHESES

Bearing out the geological adage that small structures mirror larger structures, two major lineaments (Fig. 4) are observed to follow the same trend as the White Clay, Keya Paha, and Ponca Creek structures. First, the North Platte River trends North 70–75° West from the town of Ogallala in Keith County, Nebraska, at least to the town of Guernsey in Platte County, Wyoming; nearly east-west from Ogallala east to North Platte in Lincoln County, Nebraska; and resumes the northwest-southeast trend (N70°W) to near Lexington in Dawson County, Nebraska—a total distance of 435 km. The 290 km extent maintaining the North 70° West trend across the panhandle of Nebraska and into eastern Wyoming is herein termed the North Platte Lineament. In central Nebraska, the South Loup, Middle Loup, North Loup, and Elkhorn rivers also follow this general trend. The lineaments are named: South Loup River Lineament trending North 70° West and extending over 100 km from Pleasanton in Buffalo County to past Arnold in Custer County, Middle Loup River Lineament trending North 80° West and extending nearly 200 km from Sargent in Custer County to its source in southern Cherry County, North Loup River Lineament trending North 75–80° West and extending at least 150 km from Taylor in Loup County to near its source in central Cherry County, and Elkhorn River Lineament trending North 65–75° West and extending over 150 km from near Stanton in Stanton County to Stuart in Holt County, Nebraska.

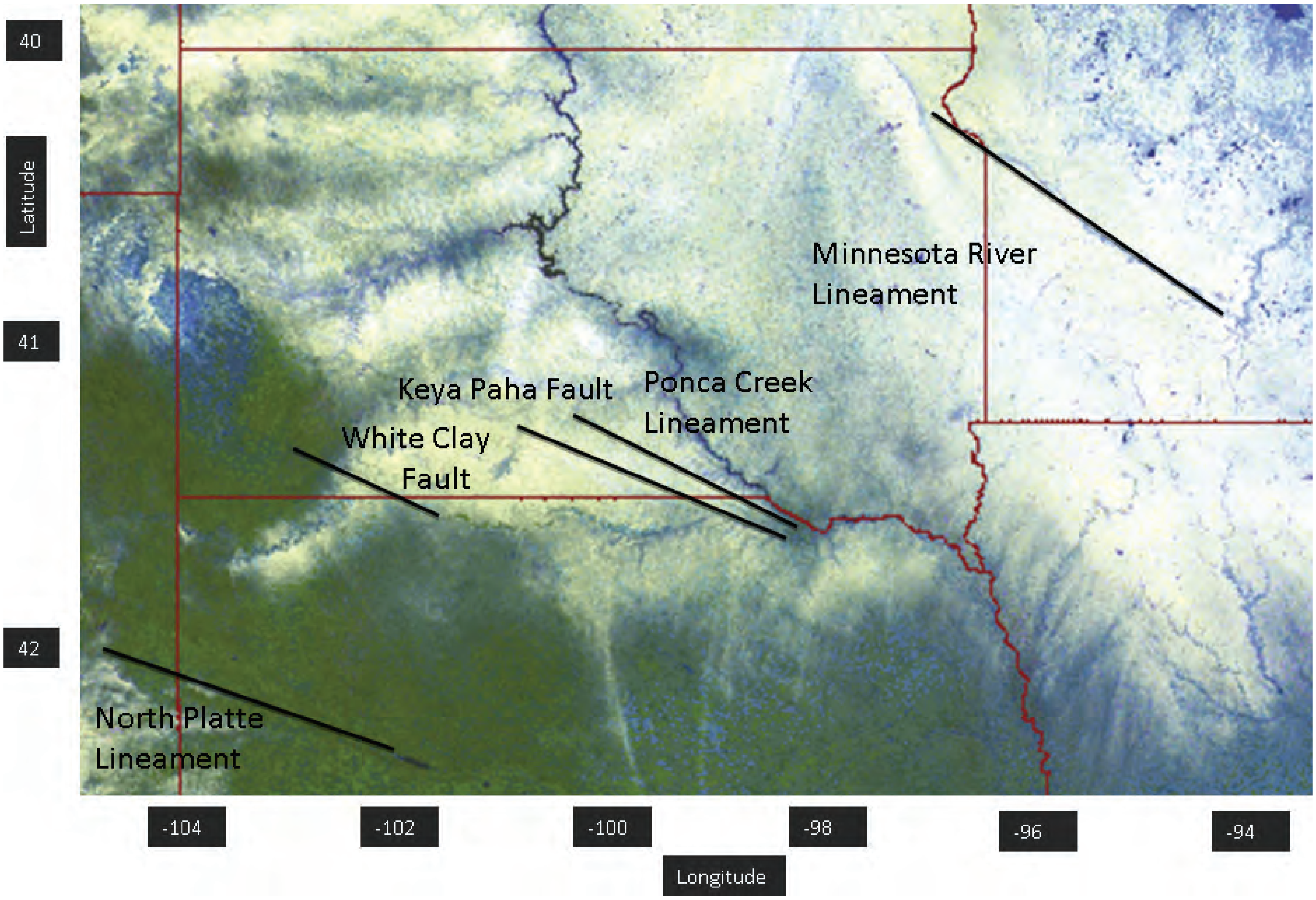


FIGURE 4. Regional distribution of the major lineaments in the Northern Great Plains on satellite base.

Second, the Minnesota River subparallels the same trend from Mankato in south-central Minnesota northwest from North 60–75° West to the eastern South Dakota border for an extent of at least 240 km. This trend is considered the Minnesota River Lineament (Fig. 4). Shorter creeks, such as the Heart, Cannonball, and Cedar rivers, subparallel this trend in the unglaciated southwestern portion of North Dakota and are designated the Heart River Lineament (extending nearly 100 km from the Heart Butte Dam in Grant County to near its source north of Dickinson, Cannonball River, trending North 65–75° West), the Cannonball Lineament (extending over 120 km from its intersection with Highway 31 in southern Grant County to near its source in Slope County trending North 70° West), and the Cedar River Lineament (extending nearly 100 km from near the eastern border of Adams County to its source in Slope County, trending North 65–70° West). Similar trends occur along rivers in northwestern South Dakota, including: Sulphur, Rabbit, and the North Fork of the Grand rivers. These are considered the Sulphur Creek Lineament (extending 100 km from the eastern edge of Meade County to its source in Butte County, trending North 70–75° West), the Rabbit River Lineament (extending nearly 100 km from near Iron Lightning in Ziebach County to its source in easternmost Harding County, trending North 65–70° West), and the Grand North Fork Lineament (extending approximately 140 km from western Corson County to Bowman Haley Lake in southwestern North Dakota, trending North 65–70° West). Together, these structures indicate a structural fabric composed of faults and joints trending northwesterly through the Northern Great Plains and probably mirror basement structures that have been periodically regenerated.

SMALL FAULTS ALONG THE MISSOURI RIVER

Since 1989, parties from the Museum of Geology have conducted geological and paleontological surveys along the Missouri River in central South Dakota, during which I documented numerous smaller faults with offsets in the tens of meters. Many of these structures trend northwesterly, with two providing some evidence of timing. One occurs south of the town of Chamberlain in Brule County, near the Burning Brule area where the petroliferous Boyer Bay Member of the Sharon Springs Formation previously caught fire (hence the name). The fault trends North 25° West and is well exposed along the shore of the Missouri River where the Sharon Springs Formation is faulted against the Niobrara Formation, which was originally deposited below. The northeastern side is down, with the Burning Brule and Boyer Bay members of the Sharon Springs faulted against the upper Niobrara chalk; maximum displacement appears to be over 12 meters and the fault plane dips 45° NE. As with other small faults along the Missouri River, this offset, which I term the Burning Brule Fault, has poor exposure, making determination of lateral extent difficult. When I first encountered the fault, Missouri River erosion had exposed the fault plane, and in the fault gouge were blocks of black shale at random orientations along with cobble to small boulder-sized glacial erratics. Granites, quartzites, and other resistant lithologies derived from glacial deposits suggest this fault might have occurred relatively late or been reactivated in the Pleistocene, as reported in an abstract in 2004 (Sawyer and Martin, 2004).

We were reluctant to emphasize this timing based upon one occurrence, but last summer, a clastic dike with similar characteristics was discovered. The dike is termed the Pontoon Bay Dike where it occurs near the town of Oacoma on the western side of the Missouri River in Lyman County. Once again, the high water of the Missouri River had scoured the area, resulting in excellent exposure of the dike. Pontoon Bay Dike occurs in the Niobrara Formation, trends North 42° West, and could be traced 10 meters laterally before being lost in vegetative cover. The dike is 10 cm wide and filled with small angular blocks of black Pierre shale and gray Niobrara chalk, so the dike is of the same hardness as the country rock. Therefore, the dike neither weathers in relief nor recess. In addition to randomly oriented angular blocks, rounded cobbles and pebbles of granite, quartzite, quartz pebbles, and other resistant erratics appear derived from glacial deposits and suggest a post-glacial opening and fill of the dike. The Burning Brule Fault and Pontoon Bay Dike indicate late movement of these two structures, maximally from the time of the Pleistocene glaciations possibly to the Holocene. Whether these offsets are the result of the northwesterly structural fabric or are the result of isostatic readjustment following ice removal cannot yet be determined. The trends suggest the latter, although their conjugal nature cannot be dismissed.

CONCLUSIONS

The Keya Paha Fault is identified along the South Dakota-Nebraska border extending 280 km from near the town of Niobrara in Knox County, NE, northwesterly to the source of the Keya Paha River in north-central Todd County, SD. The fault follows the trace of the Keya Paha River in a straight trend of North 65–70° West. This trend may be projected into Mellette County, SD, and possibly into Badlands National Park in Pennington and Jackson counties, extending the structure another 150 km. All lithostratigraphic formational contacts on the southern side of the Keya Paha River are higher than their counterparts on the northern side of the river. This suggests a fault with the northern side down and a displacement of at least 80 meters in the Wewela area of Tripp County, SD. The fact that Arikareean (North American Land Mammal Age) formations are displaced indicates that the faulting occurred after the Oligocene Period.

A parallel structure, the Ponca Creek Lineament occurs 25 km to the northeast of the Keya Paha Fault along Ponca Creek, and like the Keya Paha Fault, extends from near the town of Niobrara well into South Dakota. McCormick (2010) illustrated a structure in this area, but showed a different trend than the North 60–75° West direction of the creek. McCormick termed her structure the Reservation Fault but did not formally describe the fault and provided no evidence for offset. When the Keya Paha Fault and Ponca Creek Lineament are extended northwesterly, they appear in the position of the postulated Sage Fault and others of Clark et al. (1967), which form the northern wall of the White River Badlands exposure between Wall, Pennington County, and Cedar Pass in Jackson County. If these lineaments are found to be continuous, the Sage Fault in conjunction with the Keya Paha Fault may form important structures that control much of the geology of western South Dakota, perhaps including the Northern Black Hills Tertiary Intrusive Province and perhaps even later uplift of the Northern Black Hills and Bear Lodge blocks (Lisenbee, 1978). This hypothesis would require post-Oligocene movement, which matches with the relative occurrences of high-elevation Brule Formation deposits throughout the Black Hills (the highest occurring deposits of the Scenic Member of the Brule Formation occur in the Bear Lodge Mountains and successively lower deposits occur southerly to the Wind Cave area). Certainly, the possibility of these extensive structures should be considered when assessing fluid migration, be it water or petroleum, geological hazards, prospecting, or others.

A number of shorter lineations with the same approximate trends occur between the Keya Paha Fault and the White Clay Fault, which following additional investigations, may represent similar faults. These include from east to west the Little White River-Minnechaduza Creek Lineament, the Hay Creek Lineament, the Heckel Creek Lineament, the Bear Creek Lineament, and the Leander Creek Lineament. The latter two may be of similar geometry as the Little White River-Minnechaduza Creek Lineament.

On a larger scale, many creeks and rivers in the Northern Great Plains appear to have similar northwesterly trends. The North Platte Lineament in western Nebraska and the Minnesota River Lineament in western Minnesota are examples. On the other end of the scale, portions of many smaller creeks in the Northern Great Plains subparallel the northwesterly trend of these major lineaments. With additional investigation, these lineaments may be found to control faulting. The North 65–70° West trend of the Keya Paha Fault appears to be the dominant structural trend, although the trends deviate from North 60–80° West. Overall, a structural fabric appears to underlie the Northern Great Plains that represents a series of faults and joints that may reflect basement structures. The faults may have been active at different periods through geological time, and the Keya Paha Fault and other major faults were active after the Oligocene. Smaller faults and dikes indicate structural activity even at relatively recent geological times. The Burning Brule Fault and the Pontoon Bay Dike both contain glacial debris, indicating post-glacial movement during the Quaternary. The relatively recent dates of these movements are of great concern during land-use planning.

Overall, the northwesterly-southeasterly structural fabric of the Northern Great Plains may explain the distribution of geological phenomena that impact the search for natural resources and serve as the basis for land-use decisions. Many geological disciplines may be affected by this structural fabric. The occurrence of fossiliferous deposits in Badlands National Park and the Harris Ranch badlands in southwestern South Dakota may be the result of preservation in downthrown blocks, the result of major fault activity. The occurrences of ground and surface water are also affected by the structural trend. Petroleum plays may be guided by understanding the extensive faulting, particularly in South Dakota and Nebraska where relatively little petroleum production has occurred. Concentrations of uranium and rare earths may be controlled by these structures. Mining activities may also be dictated by this structural trend if the Northern Black Hills Tertiary Intrusive Province can be tied to basement lineations. Overall, many pertinent geologic phenomena are impacted by these dominant northwesterly directed structures.

ACKNOWLEDGMENTS

I sincerely thank the South Dakota Geological Survey for providing time to investigate these structures, both through compilation of the geological map of South Dakota and thereafter. The United States Army Corps of Engineers have supported geological and paleontological investigations along the Missouri River in South Dakota since 1989. Many geological observations were the result of these investigations. I have benefitted greatly over the years from discussions with Dr. Alvis Lisenbee concerning structural geology. I thank the many students, volunteers, and colleagues who have aided in our scientific investigations in South Dakota. This contribution was greatly enhanced by the technical reviews of Dr. Brian Lock, Department of Geology, University of Louisiana, Lafayette, and Dr. J. Foster Sawyer, Department of Geology and Geological Engineering, South Dakota School of Mines and Technology, Rapid City.

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ARTICLE

MANAGEMENT OF PALEONTOLOGY RESOURCES IN LANCE CREEK FOSSIL AREA

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ABSTRACT—Huge numbers of fossils were collected and excavated from the Lance Creek Fossil Area beginning in the 1880s and are now scattered to museums and other institutions all over the globe. The National Park Service recognized the significance of these fossil discoveries by designating the area a National Natural Landmark (NNL) in 1973. The area designated was approximately 16 sections and consisted of a mixture of public lands, split estate, and private lands and minerals. The Bureau of Land Management (BLM) Newcastle Field Office Resource Management Plan (RMP) developed in the 1990s initially proposed designating the BLM lands within the NNL as an Area of Critical Concern (ACEC). During RMP scoping many private landowners became aware for the first time that their ranches were inside an NNL. Public outcry led to de-designating the NNL in 2006. An ACEC designation was also dropped from the BLM RMP signed in 2000, partly due to lack of survey data identifying exactly where fossils were located. The large amount of split estate and private lands and the scattered locations of BLM lands make it difficult to manage paleontology resources on the public lands. Large numbers of fossils are still collected from the Lance Creek Fossil Area reputedly from private lands. However, following a widely publicized fossil theft trial in 1995, fossils documented as removed from Federal lands were returned to the BLM.

KEYWORDS—National Natural Landmark, Bureau of Land Management, History of Paleontology

LANCE FORMATION PALEONTOLOGICAL RESEARCH

The most prolific unit for Late Cretaceous vertebrate fossils in Wyoming is the Lance Formation (Breithaupt, 1997). This rock unit is found statewide and reaches thicknesses of more than 750 meters. The formation encompasses approximately 1.5 million years at the end of the Maastrichtian and has been assigned to the Lancian "age" (Russell, 1975; Lillegraven and McKenna, 1986) because of its mammalian fauna. The Formation is dominated by nonmarine, coastal floodplain sandstones, mudstones, and marls, with marginal marine sandstones and shales in its lower parts. During the latest Cretaceous, Wyoming was a warm temperate to subtropical, seasonal floodplain on the west coast of an eastward-regressing inland seaway. The physical environment and biotic diversity of the Late Cretaceous of Wyoming was comparable to the subtropical Gulf Coast of the United States today. The lush lowland vegetation, meandering streams with coastal connections, and areas of occasional ponding with seasonal water restrictions are the best modern correlative to the floodplain environments associated with the western epicontinental sea during latest Cretaceous time (Breithaupt, 1982).

The Lance Formation is named for a small drainage—Lance Creek—in the eastern part of Wyoming and is best known for the exposures found in that region of the Powder River Basin. The discovery that first indicated the paleontological importance of this rock unit, however, was made in the western part of the state, where crews working for Ferdinand Vandeveer Hayden's Geological Survey of the Territories found the partial skeleton of a dinosaur in 1872 (Breithaupt, 1982; 1994). Edward Drinker Cope (1872) collected and described this partial skeleton, naming a new species of dinosaur, *Agathaumas sylvestris* (currently thought to be a form of *Triceratops*). The genus *Triceratops* (the most common horned dinosaur found in Wyoming and Wyoming's State Dinosaur) was defined by Othniel Charles Marsh (1889) on material he had originally called *Ceratops horridus* from the "Ceratops Beds" of Niobrara County, Wyoming. Abundant remains of vertebrate fossils were collected for Marsh by John Bell Hatcher during the years 1889–1894 (Hatcher, 1893; Hatcher et al., 1907), including large numbers of *Triceratops*. These "Ceratops Beds" represent the type area for the Lance Formation and have produced hundreds of *Triceratops* fossils, including at least 100 skulls (Derstler 1994). Derstler (1994) calculates that *Triceratops* represents 85% of the dinosaurs found in the Lance Formation, with the hadrosaur *Edmontosaurus* making up another 12%.

Since the discovery of *Agathaumas*, literally tens of thousands of Late Cretaceous vertebrate remains have been recovered from the Lance Formation. Fossil vertebrates have ranged from important microvertebrate elements to extensive bonebeds which contain nearly complete, sometimes articulated dinosaur skeletons. Some of these monospecific bonebeds have densities of more than 10 bones per square meter (Derstler, 1994). Spectacular specimens like the dinosaur "mummies" (hadrosaur skeletons surrounded by skin impressions) have also been found in the Lance Formation (Lull and Wright, 1942). Carpenter (1982) reported baby dinosaur fossils in this unit from various microvertebrate sites. In addition, diverse trackways have been discovered in the Lance Formation (Lockley et al., 2003). Further, some of the first discoveries of *Tyrannosaurus rex* can be traced to the Lance Formation of eastern Wyoming. In 1900 famed dinosaur hunter Barnum Brown discovered a partial skeleton that Henry Fairfield Osborn (1905) named *Dynamosaurus imperio-*

sus ("powerful imperial lizard") in the same paper in which he named *Tyrannosaurus rex* ("king of the tyrant lizards"). Eventually, *Dynamosaurus* was synonomized with T*yrannosaurus rex* (Breithaupt, et al., 2006; 2008). Clemens (1963) provides an excellent summary of historical investigations done in the Lance Formation of eastern Wyoming.

Because the Formation contains one of the best-known Late Cretaceous vertebrate faunas, including various cartilaginous and bony fishes, frogs, salamanders, champsosaurs, turtles, lizards, snakes, crocodiles, pterosaurs, mammals, birds, and some of the best known Cretaceous dinosaurs (e.g., *Triceratops, Torosaurus, Tyrannosaurus, Edmontosaurus, Pachycephalosaurus, Ankylosaurus, Edmontonia, Thescelosaurus, Troodon, Dromaeosaurus*, and *Ornithomimus*) (Archibald, 1996; Estes, 1964; Clemens, 1960, 1963, 1966, 1973; Derstler, 1994; Breithaupt, 1982, 1985; Whitmore, 1985; Whitmore and Martin, 1986; Webb, 1998, 2001), it has been assigned a Potential Fossil Yield Classification (PFYC) rating of 5 (very high fossil potential).

LANCE CREEK FOSSIL AREA

The Lance Creek Fossil Area (LCFA) is located in eastern Wyoming along the southeastern margin of the Powder River Basin just beyond the southwestern edge of the Black Hills. It is entirely within Niobrara County and extends from the Weston County border south almost to the small town of Lance Creek. Although the majority of bedrock in the LCFA is Lance Formation, the area also encompasses some outcrops of Fox Hills Sandstone, Pierre Shale, the White River Formation, and the Fort Union Formation.

Huge numbers of fossils collected from the LCFA are now scattered to museums and other institutions all over the globe. In one of the earliest collecting expeditions Hatcher spent several years collecting tons of fossils and hauling them by wagon to the railroad at Lusk, Wyoming, for shipment to Yale University. Upon recovering the first *Triceratops* skull found in the Lance Creek Fossil Area, Hatcher reported to Marsh:

> "The big skull is ours . . . It is badly broken up, but was in good condition when found three years ago. They (the discoverers) broke the horn cores off it (with a lariat) and rolled it down the bluff and broke lots of it into small pieces some of which we found over 100 yards below . . . lower jaws were there . . . when packed (in four boxes) it will weigh 1,000 lbs. or over " (Schuchert and Levene, 1940).

The Lance Creek Fossil Area is also known for the *Edmontosaurus* mummy the Sternbergs found in 1908 (Osborn, 1912). Although Sternberg was working under contract for the British Museum of Natural History in London, he sold the fossil to the American Museum of Natural History in New York for $2000. He found a second *Edmontosaurus* mummy a few years later and shipped it to the Senckenberg Museum in Frankfurt, Germany. Studies of the fossil flora from the LCFA began in the 1930s (Dorf 1940; 1942). These were some of the first significant studies of Late Cretaceous vegetation and led to the discovery that plants also went extinct at the end of the Cretaceous (Johnson, 2007). In the 1950s, the University of California conducted a substantial microvertebrate screen-washing effort, which recovered more than 30,000 small vertebrate specimens representing over 75 species, with many new genera and species recognized (Estes, 1964; Clemens, 1960; 1963; 1966; 1973).

In order to ensure that the world-famous locations where ceratopsian dinosaurs were collected in the late 1800s would be preserved from unscientific exploitation (Boyd 1987), the National Park Service (NPS) designated the Lance Creek Fossil Area as a National Natural Landmark (NNL) in 1966. A later proposal to expand the Landmark boundaries evaluated the area as significant for producing some of the first horned dinosaurs and Cretaceous mammals in North America and recommended extending the northern boundary to include locations where several important fossils had been found (McGrew and Hager, 1972). As expanded in 1973, the boundaries encompassed an area 3 miles east–west by 5.25 miles north–south. The new area included 4.75 square miles to the north as well as a strip of two half sections and a whole section on the south where outcrops included Pierre Shale, White River Formation, and some Lance Formation. The area designated consisted of approximately 15.75 sections (9,920 acres) and was a mixture of public lands, split estate, and private lands and minerals. The report recommending expansion of the Landmark indicated that there were up to 70 landowners in the designated area (McGrew and Hager, 1972). The northern boundary was arbitrarily set at the Niobrara /Weston county border. Most of the historically well-known areas where vertebrates and plants had been collected were within the designated area.

More recent research, though, demonstrates that important fossils continue to be found north of the NNL. In 1994, archeologists surveying in the US Forest Service (USFS) Thunder Basin National Grassland discovered pieces of fossil bone in Lance Formation sandstone in Weston County. The USFS notified the University of Wyoming (UW) Geological Museum and the South Dakota School of Mines and Technology (SDSM) Museum of Geology of the new finds. A crew from SDSM returned to the site the following summer and recovered the first associated partial skeleton of a nodosaurid ankylosaur from eastern Wyoming. The specimen was prepared and catalogued at the SDSM Museum of Geology laboratory. Close examination indicated that the specimen represents the armored dinosaur *Edmontonia* (Finlayson, 1997). During the fieldwork, several microvertebrate sites were found in the region and collected for screen-washing (see Martin and Finlayson, 1997). In 1999, this material was transferred to the UW Geological Museum for use during the Passport-In-Time (PIT) Microvertebrate Fossil Project (the first paleontology PIT project ever developed). Volunteers learned standard microvertebrate wet screen-washing techniques (Hibbard, 1949; McKenna, 1962; McKenna et al., 1994) and discovered an interesting Late Cretaceous microvertebrate fauna (Breithaupt, 2001). Also in the 1990s, a partial *Tyrannosaurus rex* skeleton was found on private land in the Lance Formation near these sites in Weston County.

MANAGEMENT OF THE LANCE CREEK FOSSIL AREA

Although the Lance Creek Fossil Area was listed as a NNL, a memorandum to the BLM from the NPS stated that the status was complex (Ugolini 1978). LCFA was retained on the Landmark register because of its national significance, but it was never "registered" by all of the landowners due to the complex land ownership and large number of landowners. In a 1975 memorandum, the BLM agreed to "register" the BLM parcels in the Landmark, indicating intent to manage them to protect the fossil resources. BLM surface amounted to only 12% of the area, although the BLM managed approximately 70% of the mineral estate within the NNL.

Because the BLM was charged with protecting BLM lands within the LCFA, a Casper District archaeologist and geologist asked University of Wyoming paleontologist Paul McGrew to show them fossil localities within the LCFA that should be monitored. On the field trip in 1978, McGrew showed them four localities—two on private land and two on BLM-administered land. The group could not inspect one of the private locations due to lack of access and observed only a single vertebrate rib fragment at the second location. One of the federal sites was a quarry that had been excavated in 1946 and had no fossil material exposed on the quarry face or in adjacent outcrops at the time of the site visit. At the other Federal location they observed a dinosaur vertebral column and scattered ribs and vertebrae. The BLM concluded from this very limited field trip that few fossils were currently exposed and possibly most of the museum quality material had been removed during years of excavation and collection.

In the 1980s and 1990s, the NPS usually inspected the LCFA every other year for a report to congress on the condition of National Natural Landmarks. BLM management directed employees to assist the Park Service by providing information concerning anything they had heard from informants or observed in the LCFA while working on other tasks. In preparing their report, NPS representatives often called the BLM to ask if anyone had observed changes in the condition of the fossil resources in the NNL and occasionally they drove around the NNL. Although fossils had been collected from numerous locations in the distant past, the Newcastle Field Office knew of only one vertebrate fossil location on BLM-administered land that could be monitored. The main sources of information that the BLM received regarding the condition of fossil resources in LCFA were reports from professional paleontologists conducting surveys in the area and occasional reports by local ranchers.

During development of the BLM Newcastle Field Office Resource Management Plan (RMP) in the 1990s, the BLM proposed designating the BLM lands within the NNL as an Area of Critical Environmental Concern (ACEC). As a result of this proposal, many private landowners became aware for the first time that their ranches were inside an NNL. Public outcry led to de-designating the NNL in 2006. Considering BLM's lack of survey information on the current exposure and location of fossils, the proposal to manage the area as a fossil ACEC may indeed have been premature. In addition, the plan lacked specifics on how fossil resources would be protected and an analysis of the potential impacts. Furthermore, the map of the proposed ACEC in the draft plan appeared to include private land, which led to public protest. As a result, the proposal of an ACEC designation was dropped from the BLM RMP signed in 2000, due in part to lack of survey data indicating where fossils were currently exposed, as well as the fact that no specific management measures were proposed other than the designation.

The large amount of split estate and private lands and the scattered locations of BLM-administered lands make it difficult to manage paleontology resources on these public lands. Much of the Lance Creek Fossil Area is remote and requires driving interminably on dirt roads in variable condition. An excerpt from Johnson (2007:55) describes the area well, including the time it takes to get anywhere:

> "We turned off to the west onto ranch roads that seemed to go on forever. We lost track of the turns and gates. Finally, we drove through the Fox Hills Formation and into the Lance Formation, with its characteristic rusty sand beds. Here and there, the sand formed huge, elaborately swirled concretions that were as large as our truck. Some of these weathered out to form garish hoodoos in stark contrast to the conservative landscape. By now, the sun was low in the sky and the shadows were lengthening."

The remoteness of the Lance Creek Fossil Area would make it easy to remove fossils without detection, although local ranchers generally notice when non-local people are in the area for any length of time. A rumored illegal collecting ploy is to tell local ranchers that the fossils are on BLM land (so that the excavator does not have to pay the rancher for them), but then tell any official that they are on private land (thus do not require a permit). Unfortunately, theft of fossils does occur. Following a widely publicized fossil theft trial in 1995, fossils documented as removed from Federal lands were returned to the BLM. Fossils removed from BLM lands included a LCFA *Triceratops* (represented by two large plaster jackets and four boxes of fossil fragments), turtles, crocodile bones, and a large museum quality ammonite. The BLM negotiated an assistance agreement with the South Dakota School of Mines and Technology to curate the specimens. Unfortunately, in cases of illegal activity, by the time that the BLM receives a report of someone excavating fossils, they have usually finished the fieldwork and departed. In two locations where unauthorized excavations were reported by a professional paleontologist who was surveying in LCFA, some of the fossils had been collected and others had been partially jacketed, protected by tarps, and reburied. No one ever returned to finish the excavation. Subsequently, the BLM encouraged the Tate Geological Museum in Casper to complete the excavations at one of these locations, where they recovered a portion of a *Triceratops*.

Large numbers of fossils, many of museum quality and scientific importance, are still collected from the Lance Creek Fossil Area, reputedly from private lands. The amount of material on the commercial market indicates the potential abundance of fossils still to be found in the area. Internet searches on 'Lance Formation fossils' will show links to a variety of commercial fossil companies, such as Black Hawk Fossils or Black Hills Institute, where numerous fossils from the LCFA are available for sale. Over the last 20 years skeletons of *Triceratops* and *Edmontosaurus*, as well as skulls of *Tyrannosaurus* and *Pachycephalosaurus*, have been collected and sold from the LCFA. Sometimes these fossils are sold to private individuals or organizations and are not available for study. In other cases, these fossils have been sold to museums that make them available to scientists and use them for public education. An example of the latter is the *Triceratops* "Kelsey," which was excavated from private land within the LCFA and now resides at the Indianapolis Children's Museum, where it contributes to an excellent education program. The Zerbst Ranch, source of this fossil as well as a second *Triceratops* with preserved sections of skin impressions, has developed an educational center called PaleoPark.

Although many tons of fossils have been removed from the LCFA since the 1880s, the area also continues to produce fossils of significance and scientific information on BLM-administered land. In recent years professional paleontologists have excavated and collected several *Triceratops* specimens from the BLM portion of the LCFA. Christian Sidor (Burke Museum of Natural History and Culture in Seattle, Washington) collected a partial *Triceratops* skull in 2008. Luis Chiappe (Natural History Museum of Los Angeles County-LACM) surveyed portions of the LCFA during 2001–2003 and collected partial *Triceratops* skeletons as well as hadrosaur and ankylosaur fossils from several locations. The most important specimen collected by LACM crews (consisting of students from six universities as well as paleontologists from Argentina) was a 35–40% complete *Triceratops* post-cranial skeleton, which Chiappe described as being in an exquisite state of preservation. The specimen was immediately used for public education as preparation took place in a viewable laboratory at the Natural History Museum of Los Angeles County. Staff in the exhibit hall explained how fossils are collected and what interpretations can be made from the material. Currently, this specimen is part of a newly exhibited *Triceratops* skeleton in the museum. A partial *Triceratops* skull from the LCFA was also placed on exhibit in the museum's Discovery Center for children.

Paul Sereno (University of Chicago) surveyed in the LCFA from 2000 to 2004 with teams of graduate and undergraduate students. In addition, he ran college field schools in the area and provided a paleontology educational experience for advanced high school students participating in Chicago's Project Exploration, which targets minority students with a strong interest in science. In 2001 these students helped remove a partial *Tyrannosaurus* skeleton from a site known to the BLM since 1978. This specimen contributed useful scientific information as well (see Lipkin et al., 2007). University of Chicago crews also collected remains of *Triceratops, Edmontosaurus, Thescelosaurus,* marsupials, and two fairly complete turtle specimens (baenid and trionychid) including skulls. This material has been used in the Dinosaur Lab at the University of Chicago. Based on data acquired during several years of survey in the LCFA, Sereno provided the BLM with a database of over 200 fossil localities. This information has helped the BLM to better manage fossil resources in the area.

CONCLUSIONS

The 2009 Omnibus Public Land Management Act-Paleontological Resource Preservation Section (OPLMA-PRP) formally defines paleontological resources as "any fossilized remains, traces, or imprints of organisms, preserved in or on the earth's crust, that are of paleontological interest and that provide information about the history of life on earth." The legislation states that paleontological resources on Federal land shall be managed and protected using scientific principles and expertise. The Act directs that appropriate plans for inventory, monitoring, and scientific and educational use of these resources shall be developed. "These plans shall emphasize interagency coordination and collaborative efforts where possible with non-Federal partners, the scientific community, and the general public." The Act further directs that the Federal agency shall "establish a program to increase public awareness about the significance of paleontological resources." Vertebrate fossils are especially in need of protection, because of their rarity and unique educational and scientific values.

BLM lands contain important paleontological resources and paleontology partnerships are an essential management tool for the protection of these resources. Fossils on public lands can help document the rich history and diversity of life on our planet. The BLM's responsibility for the management and protection of public lands includes stewardship of its scientific resources. To better protect and manage paleontological resources for present and future generations, the BLM works closely with paleontologists at museums and universities to discover, document, and interpret the fossils found on public lands. The fossils in the LCFA are among many paleontological resources that are best studied through the collaborations of scientists, students, volunteers, and land managers.

The BLM is working to establish projects that are beneficial to proper management of paleontological resources on public lands. One such objective is to get the public involved with paleontology through participation in scientific research, in the hope of increasing understanding of the management of fossil resources on Federal lands. Dinosaur projects run by various paleontologists have accomplished this in recent years. In addition to large dinosaur remains, Lance Formation microvertebrate fossils represent important components of the latest Mesozoic vertebrate faunas of the Western Interior, and the USFS PIT project introduced volunteers to this type of resource. This PIT project was an excellent example of how paleontological resources can be studied through the collaborations of scientists, students, volunteers, and land managers. As the public becomes more involved in the scientific process, people gain a better understanding of fossil resources and the importance of studying them. Programs like PIT encourage people with different backgrounds to become partners in paleontological resource management.

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ARTICLE

ANCHISAURUS FROM SPRINGFIELD ARMORY

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ABSTRACT—The term "dinosaur" was only 13 years old in 1855 when blasting operations at the Water Shops of Springfield Armory in Massachusetts uncovered the partial fossil skeleton of an extinct reptile. Paleontological discoveries were not new to the area; the Connecticut River Valley, which includes the Armory, was an early hotbed of vertebrate paleontology thanks to the combination of Late Triassic–Early Jurassic-age footprints and interested naturalists. The Armory specimen, now the holotype of *Anchisaurus polyzelus*, has passed through several generic names and been classified with theropods, prosauropods, and sauropods. Views on its paleobiology have changed from an active carnivore, to an herbivore, to an omnivore. Along the way, it has been discussed in print by numerous well-known figures in paleontology.

The holotype of *A. polyzelus* is one of a handful of tetrapod body fossils from the Hartford Basin. As part of the history of Springfield Armory National Historic Site, it is also one of many historically and scientifically significant fossil specimens associated with National Park System areas.

KEYWORDS—*Anchisaurus*, Springfield Armory National Historic Site, Portland Formation, Hartford Basin, History of Paleontology

INTRODUCTION

Although today Western states are better known for having fossils, the history of American paleontology started in the Northeast. In the United States, the first fossils now ascribed to dinosaurs were found in New England's Deerfield and Hartford basins. The uppermost Mesozoic rock unit in the Hartford Basin—the Early Jurassic-age Portland Formation—boasts North America's earliest-reported dinosaur tracks (1802) (Olsen et al. 1992) and the first dinosaur bones collected (1818) and published (1820) (Santucci 1998). Among other historic finds from the Portland Formation is a partial skeleton of a basal sauropodomorph (prosauropod in traditional usage) discovered at Springfield Armory in 1855. This specimen later became the holotype of *Anchisaurus polyzelus*.

Springfield Armory, a manufacturing site for U.S. military small arms from 1794–1968, located in Springfield, Massachusetts (Point1 in Fig. 1), was the nation's first federal armory. It included two main sites: the Hill Shops (or Hillshops), which were used as a storage depot during the American Revolutionary War era and have been partly protected as Springfield Armory National Historic Site since1974; and the Water Shops (or Watershops)—three locations on the Mill River approximately 1.6 km (1 mile) south of the Hill Shops, constructed as heavy manufacturing sites around the turn of the 19th century and presently under private ownership. Although the Water Shops are not formally administered or managed by the National Park Service as part of the National Historic Site, the national historic site maintains a relationship with the owners and interprets the Water Shops (A. MacKenzie, pers. comm., March 2010). The *Anchisaurus* skeleton was discovered when the three Water Shops were consolidated in 1855 .

The Springfield Armory complex is located in the Connecticut River Valley just east of the Connecticut River in the Hartford Basin, an early Mesozoic-age structural feature (Fig. 1). The underlying geology consists of red sandstone and siltstone bedrock (the Portland Formation) (Zen et al. 1983) overlain by much younger surficial deposits of Quaternary till and glacial lake delta outwash (Hartshorn and Koteff 1967).

GEOLOGICAL CONTEXT: THE HARTFORD BASIN

The Hartford Basin formed with the breakup of the supercontinent Pangaea during the Late Triassic. The Deerfield Basin to the north was probably continuous with it (P. Olsen, pers. comm., November 2010). The two basins belong to a series of rift basins paralleling the Appalachian Mountains from northern South Carolina to Nova Scotia. Sediments deposited in the rift basins are together known as the Newark Supergroup and record 35 million years of continental rifting (Olsen 1980a). The supergroup's formations are divided into three groups, in ascending order: the Chatham Group, Meriden Group, and Agawam Group (including the Portland Formation) (Weems and Olsen 1997). Structurally, the Hartford Basin is a half-graben that is tilted to the east and bounded on one side by a major fault (Hubert et al. 1978). Because the fault is on the east side of the basin, the formations within thicken to the east, and the younger formations, including the Portland Formation, are found in the eastern portion of the basin (Horne et al. 1993).

Flood basalts, faulting, and folding accompanied the rifting (Olsen 1980b). The eruption of the Newark Supergroup's flood basalts probably occurred over fewer than 600,000 years at about 201 Ma (Olsen et al. 1996, 2003b), straddling the Tri-

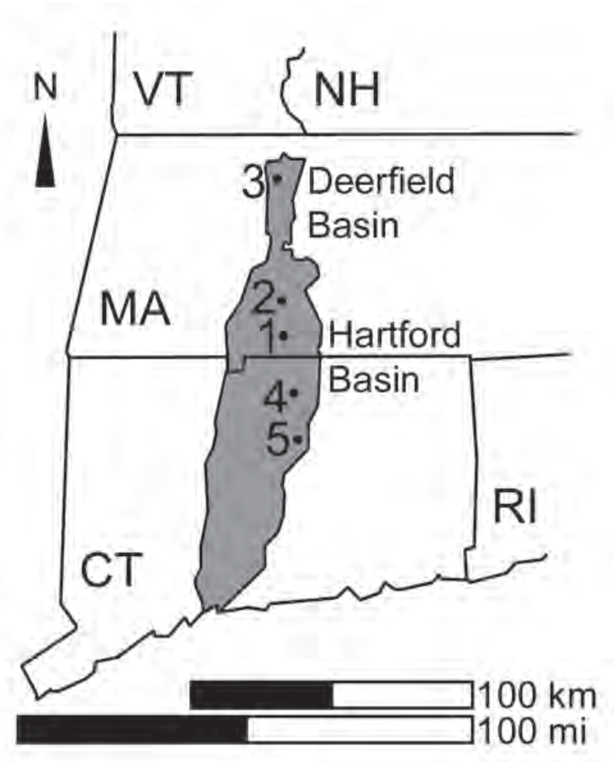

FIGURE 1. A schematic diagram of the Hartford Basin and smaller Deerfield Basin to the north, with significant locations discussed in the text denoted by points as follows: 1 represents Springfield, 2 represents South Hadley, 3 represents Greenfield, 4 represents East Windsor, and 5 represents Manchester. After Robinson and Kapo (2003), Fig. 1, courtesy of the U.S. Geological Survey.

assic–Jurassic boundary (Kozur and Weems 2010). Current research indicates an age of approximately 201.4 Ma for the oldest basalts of the Supergroup and approximately 201.3 Ma for the Triassic–Jurassic boundary (Schoene et al. 2010). The volcanic rocks are part of the Central Atlantic Magmatic Province (CAMP), one of the largest known volcanic provinces on Earth, found in outcrops from Europe and West Africa to central Brazil and eastern North America (Marzoli et al. 1999).

The Newark Supergroup is known for its cyclic depositional patterns, shifting between mud flat, shallow lake, and fluvial deposition (Olsen 1980c). Such cycles are evidence of ancient Milankovitch cycles (Olsen 1997), which are keyed to various characteristics of Earth's movement in space (Olsen and Whiteside 2008). Their modern durations can be used to establish chronologies in the rocks. The foundational cycle is the Van Houten cycle of lake transgression and regression, interpreted as representing the approximately 20,000-year cycle of the precession of the equinoxes (Olsen 1986; Olsen and Kent 1996). Several other cycles are also evident in the Hartford Basin rocks, including cycles with durations of approximately 100,000 years, 405,000 years, and 1.75 million years (Olsen 1997; Olsen and Kent 1999; Olsen et al. 2002).

THE PORTLAND FORMATION

The Portland Formation is composed of arkosic and nonarkosic sandstone, siltstone, conglomerate, and shale (Krynine 1950), deposited on top of the uppermost volcanic units of the basin, the Hampden Basalt (Hubert et al. 1978) and Granby Tuff (Olsen 1997), and dated to the first half of the Early Jurassic (Weems and Olsen 1997; Olsen et al. 2002; Kent and Olsen 2008; Kozur and Weems 2010). It varies substantially in composition vertically and horizontally (LeTourneau and McDonald 1985), and has distinct lower and upper portions: the lower half is mostly composed of fine- to medium-grained red arkose and siltstone, with some dark shale, while the upper is mostly medium- to coarse-grained red arkose with conglomerate (Krynine 1950). Cyclical rocks including lacustrine deposition are found in the lower half, while the upper half lacks cyclical rocks and is composed of fluvial rocks (Olsen et al. 2003a). Conglomerates generally represent alluvial fans, sandstones braided river systems or distal alluvial fans, siltstones floodplains, gray sandstones and siltstones lake margins, and dark siltstones and shales rift lake deposits (LeTourneau 1985). The lower Portland Formation can be interpreted as a closed basin where subsidence exceeded deposition, allowing for the formation of large lakes. The opposite was true of the upper part (Olsen 1997)—as subsidence decreased, fluvial processes came to dominate (Hubert et al. 1992). Springfield Armory's bedrock is sandstone-dominated (LeTourneau and McDonald 1985) and is from the upper, entirely fluvial part of the formation (P. Olsen, pers. comm., February 2010).

The paleogeography of the Portland Formation has been described in some detail (see for example LeTourneau and McDonald 1985). Large alluvial fans accumulated along the eastern margin of the depositional basin, near the border fault. Most of the sediment came from a narrow band of rocks to the east, immediately adjacent to the fault (Krynine 1950). During wet periods, lakes and rivers were common, whereas alluvial fans and ephemeral streams were the major depositional environments during dry periods (Horne et al. 1993). Lakes were deepest and longest-lived in the deeper eastern part of the basin, while much of the western and central basin was occupied by broad, low-gradient plains with shallow alkaline lakes (McDonald and LeTourneau 1988).

Paleoclimatological interpretations of the formation emphasize seasonality and semi-aridity (Lull 1912; LeTourneau and McDonald 1985). Deposition occurred at tropical paleolatitudes of approximately 21° to 23° N (Kent and Tauxe 2005) and the climate oscillated between humid and semi-arid over long periods (McDonald and LeTourneau 1988). Relatively arid conditions prevailed for the lower Portland Formation, but the upper part of the formation was deposited under a more humid and possibly cooler climate, perhaps due to regional uplift (Cornet 1989).

The Portland Formation boasts a diverse fossil assemblage. Microbial and plant fossils include oncolites and stromatolites (McDonald and LeTourneau 1988; McDonald 1992), palynomorphs (including fern spores and cycad pollen; Cornet and

Traverse 1975), the horsetail *Equisetites* (LeTourneau and McDonald 1985), bennettitales (McMenamin and Ulm 2004), and conifers (Cornet 1989), particularly *Brachyphyllum, Hirmeriella,* and *Pagiophyllum* (Huber et al. 2003). Significant turnover in the floral assemblage occurred midway through deposition, when plants from the Deerfield Basin spread south (Cornet 1989). Invertebrates are represented by bivalves, conchostracans, ostracodes, beetles, cockroaches, possible orthopterans, insect fragments and larvae (Huber et al. 2003), and arthropod burrows and trails, including possible crayfish and insect traces (Olsen 1980d, 1988).

Vertebrates known from body fossils include the semionotid fish "*Acentrophorus*" and *Semionotus*, the redfieldiid fish *Redfieldius*, the coelacanth *Diplurus*, the crocodylomorph *Stegomosuchus*, the coelophysoid theropod *Podokesaurus*, and *Anchisaurus* (here including *Ammosaurus*) (Olsen 1980d, 1988; LeTourneau and McDonald 1985; McDonald 1992). Tetrapod body fossils are rare in the formation, limited to eight published specimens of more than one bone and a few isolated bones (Galton 1976). They are mostly known from the formation's coarse red beds, which formed in floodplain or alluvial fan settings (McDonald 1992) in the upper fluvial part of the formation (Olsen et al. 2003a). Vertebrate trace fossils include the ichnogenera *Batrachopus* (from crocodylomorphs), *Anchisauripus*, *Eubrontes*, *Grallator* (from theropods, although a theropod maker for *Eubrontes* is not universally accepted; see Weems 2003 and 2006), *Otozoum* (from sauropodomorphs), and *Anomoepus* (from ornithischians), as well as coprolites (Olsen 1988; LeTourneau and McDonald 1985). The taxonomy of the Portland Formation tracks is convoluted (Olsen et al. 1998; Olsen and Rainforth 2003): at one point there were 98 ichnospecies in 43 ichnogenera (Lull 1912) for what are now recognized as a half-dozen common ichnogenera. Restudy has greatly simplified the taxonomy (Weems 1992; Olsen and Rainforth 2003; Rainforth 2005). Most footprints are found in shoreline or mudflat rocks immediately above or below lake sequences (Olsen and Rainforth 2003).

EARLY PALEONTOLOGY

The history of fossil discovery in the Portland Formation dates to 1802, when Pliny Moody found tracks at his family's farm in South Hadley, Massachusetts (Point 2 in Fig. 1), about 16 km (10 miles) north of Springfield. At the time, the tracks were identified with "Noah's Raven" of Biblical fame; they are now known today as examples of the ichnogenus *Anomoepus* (Olsen et al. 1992). These tracks represent the earliest report of dinosaur tracks in North America (Olsen et al. 1992).

Scientific study of fossil footprints in the Connecticut River Valley began during the 1830s. In 1835, tracks were reported at Greenfield, Massachusetts (Point 3 in Fig. 1), 53 km (33 miles) north of Springfield in what is now known as the Turners Falls Formation. The finds attracted the attention of Edward B. Hitchcock of Amherst College, who made the study of the valley's tracks his life's work (Weishampel and Young 1996). Most of Hitchcock's work was done in the Turners Falls Formation (Olsen et al. 1992), a unit older than the Portland Formation in the Deerfield Basin to the north (Weems and Olsen 1997). As the title of one of his early works made clear (Hitchcock 1836), Hitchcock first conceived of the trackmakers as birds. In hindsight, this is understandable—he was dealing with tracks of bipedal bird-like tridactyl dinosaurs. By the end of his life, Hitchcock had described enough tracks and traces to envision a diverse bestiary of invertebrates and bipedal and quadrupedal vertebrates (Hitchcock 1858, 1865).

In 1818, workmen blasting a well through Portland Formation rocks at Ketch's Mills, East Windsor, Connecticut (Point 4 in Fig. 1), 24 km (15 miles) south of Springfield, discovered what would become the first collection of dinosaur bones found in North America (Santucci 1998). Because the value of the fossils was not immediately recognized, some were accidentally partially destroyed before recovery while others were taken by workmen. Solomon Ellsworth retained most of what was left and brought the bones to the attention of Nathan Smith, who made the first published description (Smith 1820). His identification of the material as possibly human was rejected by Jeffries Wyman (1855), who described the bones as reptilian and crocodile-like but hollow. Othniel Charles Marsh later identified them as dinosaurian (Marsh 1896). The specimen, now YPM 2125 (Peabody Museum of Natural History, Yale University, New Haven, Connecticut), consists of at least three partial caudal vertebrae, part of the left femur, traces of the lower leg bones, and an articulated partial arm (Galton 1976). While at one time assigned to *Anchisaurus colurus* (Lull 1912; see below), it is now regarded as an indeterminate sauropodomorph (Galton 1976; Yates 2010). Several details of the arm and hand suggest that it is distinct from the other Portland Formation sauropodomorphs (Yates 2004, 2010).

ANCHISAURUS FROM SPRINGFIELD ARMORY

The second dinosaur body fossil from the Portland Formation is the Springfield Armory specimen of *Anchisaurus*, now reposited at Amherst College's Pratt Museum of Natural History as ACM 41109 (Fig. 2) (K. Wellspring, Pratt Museum of Natural History collections manager, pers. comm., December 2009; AM 41/109 in some sources). The specimen consists of eleven dorsal and caudal vertebrae, a partial scapula, an almost complete right manus, portions of the right forearm, a partial left hindlimb (femur, partial tibia, fibula, and pes), and two partial Ischia, some partially damaged. Its publication history spans more than 150 years (Hitchcock 1855, 1858, 1865; Cope 1870; Huene 1906; Ostrom 1971; Galton 1976; Galton and Cluver 1976; Santucci 1998; Yates 2004, 2010; Fedak and Galton 2007; Sereno 2007): ACM 41109 was found during blasting operations for improvements to the Water Shops at Mill Pond (Santucci 1998) in 1855 (A. MacKenzie, pers. comm., March 2010) in a rock unit earlier referred to as the Longmeadow Sandstone (Galton 1976). Most of the remains were discarded (Hitchcock 1855) or taken by workmen before the intervention of an excavation superin-

FIGURE 2. Among the bones recovered from Springfield Armory are a femur (**A**) and fused ischia (**B**). Photos by Kate Wellspring, courtesy of Amherst College Museum of Natural History, The Trustees of Amherst College.

tendent, William Smith. General James S. Whitney, the superintendent of the Armory, ordered further investigation, so Smith gathered as much as he could and sent the remains to Hitchcock (Hitchcock 1858). The press at the time took little notice of the find: dinosaurs had yet to enter the American consciousness (Santucci 1998) (the term itself had just been coined in 1842); moreover, the specimen was not identified as dinosaurian until fifteen years later (Cope 1870).

Hitchcock was the first to publish notice of the fossils (1855), then Wyman described them for Hitchcock's seminal 1858 work. As with the Ketch's Mills specimen, he recognized them as reptilian and drew attention to the hollowness of the bones, which he considered very bird-like. After consulting Sir Richard Owen, Hitchcock's son, Edward Jr., named the bones *Megadactylus polyzelus* in an appendix to the supplement to Hitchcock's 1858 work (Hitchcock 1865). Later, the skeleton was briefly described by Edward Drinker Cope (Cope 1870), but his rival Marsh, who described similar skeletons from Connecticut, was responsible for its current name. When *Megadactylus* proved to have already been used for another animal, Marsh renamed the genus *Amphisaurus* and created the family Amphisauridae (Marsh 1882). *Amphisaurus* was also already in use, so he substituted Anchisaurus and Anchisauridae (Marsh 1885). ACM 41109 is the specimen upon which *Anchisaurus polyzelus* was founded, making it the holotype for the genus and species.

THE BUCKLAND QUARRY SAUROPODOMORPHS, PORTLAND FORMATION

During the 1880s, three sauropodomorph skeletons were found at the Buckland Quarry (or Wolcott Quarry) in Manchester, Connecticut (Point 5 in Fig. 3), 35 km (22 miles) south of Springfield (Hubert et al. 1982) in a locality interpreted as a setting of ephemeral braided streams with occasional high-energy shallow floods, just west of the large alluvial fans that formed on the eastern border of the Hartford Basin. The climate at the site was seasonal and semi-arid, and streams flowed from south to north (Hubert et al. 1982). Although the Buckland Quarry is the most productive locality for dinosaur skeletons on the East Coast to date (Weishampel and Young 1996), today the quarry is overgrown and abandoned (P. Olsen, pers. comm., November 2010) and the area has been developed for a shopping mall.

All three specimens are individuals of the same taxon, probably *Anchisaurus*, and each was first described as its own species by Marsh. When quarriers discovered the first skeleton in October 1884, Charles Wolcott, the quarry owner, set it aside for Marsh. Unfortunately, the block thought to contain the anterior half and skull was incorporated into an abutment for the Hop Brook bridge in south Manchester before Marsh could take possession. When the bridge was demolished in the summer of 1969, a diligent search by a crew working for John Ostrom of Yale University recovered the missing half of the right femur and some miscellaneous dinosaur bones, but the rest of the bones reputed to have been present remain missing (Hubert et al. 1982). Marsh initially named the specimen *Anchisaurus major* in 1889 and gave it its own genus, *Ammosaurus,* two years later (Marsh 1891). Today, the specimen, YPM 208, consists of six dorsal vertebrae, the sacrum, ribs, most of the right scapula, most of the pelvis, the left leg, right femur, and right pes (Galton 1976).

In the same paper in which he named *Ammosaurus*, Marsh named another specimen from the quarry *Anchisaurus colurus* (Marsh 1891). Believing *Anchisaurus polyzelus* to be a species of the European genus *Thecodontosaurus* (Huene 1932), Friedrich von Huene coined the genus *Yaleosaurus* in 1932. The name *Yaleosaurus* was accepted by Lull (1953) and was commonly seen in dinosaur books from the middle of the 20th century, but was synonymized with *Anchisaurus* (and *A. colurus* with *A. polyzelus*) by Galton (1971, 1976). Although YPM 1883, the partial skeleton on which *A. colurus* was based, is missing much of the neck, the tail, and much of the left side (Galton 1976), the specimen is more complete than ACM 41109 and is often refer-enced for depictions of *Anchisaurus* and used in phylogenetic analyses.

Marsh named the third skeleton from the quarry *Anchisaurus solus* in 1892. This specimen, YPM 209, consists of a nearly complete but poorly preserved skeleton of a young individual, with only the end of the tail and part of the right arm missing (Galton 1976; Fedak and Galton 2007). Galton synonymized *Anchisaurus solus* with *Ammosaurus major*, regarding *A. solus* as a juvenile of that species (Galton 1971, 1976; Galton and Cluver 1976).

TAXONOMY AND SYSTEMATICS OF ANCHISAURUS AND AMMOSAURUS

The separation of *Anchisaurus* and *Ammosaurus*, as proposed by Marsh and later detailed by Galton (Galton 1971, 1976; Galton and Cluver 1976), was generally accepted until the late 1990s. Of recent studies to consider the matter, one favors retaining separate genera (Galton and Upchurch 2004) while five find the foot and pelvic details cited by Galton's earlier works to be inadequate and conclude that only one genus and species is represented (Sereno 1999, 2007; Yates 2004, 2010; Fedak and Galton 2007). These five publications agree that the three Buckland Quarry specimens represent one taxon; assessments of ACM 41109, however, vary. Yates (2004, 2010) and Fedak and Galton (2007) unite ACM 41109 and the Buckland Quarry specimens under *Anchisaurus polyzelus*, but Sereno (2007) considers ACM 41109 to be undiagnostic and recommends classifying the Buckland Quarry specimens as *Ammosaurus major*. Yates (2010) disagrees, finding the form of the ischia and first sacral rib in ACM 41109 to be diagnostic.

Anchisaurus is currently regarded as a basal sauropodomorph (Yates 2010), though its classification has changed as researchers piece together the evolution of dinosaurs. Marsh thought that both *Anchisaurus* and *Ammosaurus* were theropods (Marsh 1896) while Huene assigned *Ammosaurus* to Ornithischia (1906), then back to Theropoda in Ammosauridae (1914). Further complicating matters, he later assigned *Anchisaurus* and *Yaleosaurus* to Prosauropoda and transferred *Ammosaurus* to the theropod group Coelurosauria (1932), where it remained for decades (Galton 1971). The name of the ichnogenus *Anchisauripus*, which is now seen as tracks left by theropod dinosaurs (Galton 1971), reflects this confusion

Anchisaurus recently attracted attention as potentially the most primitive and smallest sauropod (Yates 2004), though Yates revised this assessment as part of ongoing research on basal sauropodomorph relationships (2010). *Anchisaurus* "became" a sauropod when the definition of Sauropoda (all sauropodomorphs more closely related to the sauropod *Saltasaurus* than to the prosauropod *Plateosaurus*) did not take into account the possibility that the traditional prosauropods did not form a group. Thus, when Yates (2004) found Anchisaurus to be closer to sauropods than to *Plateosaurus*, it became a sauropod by definition. Similar work has resulted in other prosauropods becoming sauropods, so Yates (2010) favored a modification of the definition of Sauropoda to better conform to the traditional content of the group. This would leave Anchisaurus out of Sauropoda. Complicating matters is the possibility that all known specimens of *Anchisaurus* and *Ammosaurus* represent immature individuals (Fedak and Galton 2007 [but see Yates 2004]).

PALEOBIOLOGY OF ANCHISAURUS

Views on the paleobiology of *Anchisaurus* have changed substantially since Cope described "*Megadactylus polyzelus*" in the 1870s as a leaping carnivore that dispatched prey with its claws (Cope 1870). *Anchisaurus* and *Ammosaurus* were interpreted as carnivores well into the 20th century (Lull 1912, 1953; Krynine 1950), though anchisaurs, like other basal sauropodomorphs, had iguana-like teeth and probably were mostly herbivorous, supplementing their diet with carrion and small prey (Barrett 2000). Known specimens of *Anchisaurus* were of modest size for dinosaurs. The femurs of ACM 41109, YPM 1883, and YPM 208 are 18.0 cm (7.1 in) (estimated), 21.1 cm (8.3 in), and 22.1 cm (8.7 in) long, respectively (Carrano 2006; Fedak and Galton 2007), with the length of the largest specimen (YPM 208) estimated at 3 m (10 ft) (Galton 1976). If indeed all known specimens are immature, the adult size is not yet known. Although commonly interpreted as quadrupeds, basal sauropodomorphs like *Anchisaurus* were probably unable to walk on all

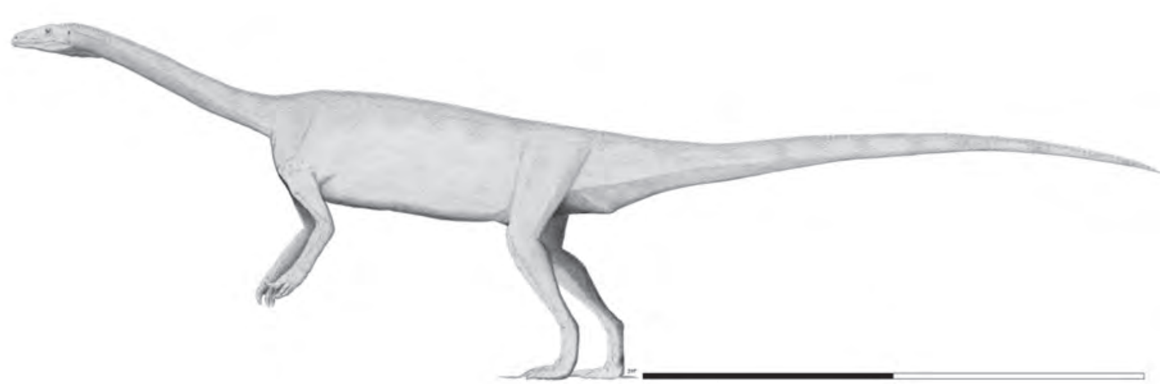

FIGURE 3. A modern restoration of Anchisaurus polyzelus as a biped, primarily after Yates (2010), with reference to Marsh (1893), Galton (1976), Carpenter (reproduced in Glut [1997]), and Paul (2010). Scale bar represents 1 m.

fours, based on their arm anatomy (Fig. 3) (Bonnan and Senter 2007). Anchisaurs may have been members of a rarely preserved upland fauna (Galton and Cluver 1976). They are known from the upper, fluvial part of the Portland Formation, along with the crocodylomorph *Stegomosuchus* (Olsen et al. 2003a).

ANCHISAURUS AMONG NATIONAL PARK SERVICE FOSSIL RESOURCES

ACM 41109 is unusual in several ways among fossil resources associated with National Park Service areas, especially in comparison to other National Park System units in the East. As a Mesozoic dinosaurian fossil, it is virtually unique among units east of 100° W longitude. Furthermore, it is the holotype specimen of a well-known genus and species. As a Portland Formation specimen, it dates from a time when tetrapods were undergoing diversification after an extinction event, representing a region with few contemporary tetrapod body fossils. Historically, ACM 41109 is among the fossils discovered and described during the formative years of American vertebrate paleontology, and is one of the first partial dinosaur skeletons found in the nation. It has been described and discussed by noted paleontologists from Hitchcock through to Cope and Marsh, von Huene, Lull, and Ostrom, as well as an assortment of contemporary workers.

At the same time, ACM 41109 is among a wealth of fossil resources associated with National Park System lands, including many other historically significant finds such as Hiram Prout's "*Palaeotherium*" in Badlands National Park (Prout 1846) and dozens of mammals described by Joseph Leidy from an area now including Niobrara National Scenic River (Leidy 1858). If recent finds are any indication (Chure et al. 2010), important fossils will be discovered in National Park System areas for as long as the National Park Service exists.

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FIELD TRIP GUIDE

PALEONTOLOGY AND STRATIGRAPHY OF THE MIDDLE EOCENE BRIDGER FORMATION, SOUTHERN GREEN RIVER BASIN, WYOMING

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ABSTRACT—The middle Eocene Bridger Formation is located in the Green River basin in southwest Wyoming. This richly fossiliferous rock unit has great scientific importance and is also of historic interest to vertebrate paleontologists. Notably, the Bridger Formation is the stratotype for the Bridgerian North American Land Mammal Age. The fossils and sediments of the Bridger provide an important record of biotic, environmental, and climatic history spanning approximately 3.5 million years (49.0 to 45.5 Ma). Additionally, the high paleontological sensitivity of the formation, in combination with ongoing energy development activity in the southern Green River Basin, makes the Bridger Formation a paleontological resource management priority for the Bureau of Land Management. This paper features a detailed field excursion through portions of the Bridger Formation that focuses on locations of geologic, paleontologic and historical interest. In support of the field excursion, we provide a review of current knowledge of the Bridger with emphasis on lithostratigraphy, biochronology, depositional and paleoenvironmental history, and the history of scientific exploration.

"A large part of the collection in this region was of the remains of small animals. The fossils were generally found in the buttes, and on account of their minuteness, their discovery was attended with much difficulty. Instead of riding along on the sure-footed mule and looking for a gigantic tell-tale vertebra or ribs, it was necessary to literally crawl over the country on hands and knees…Often a quarter of a mile of the most inviting country would be carefully gone over with no result, and then again someone would chance upon a butte which seemed almost made of fossils."

—A description of fossil collecting in the Bridger Formation written by an unnamed member of the 1871 Yale College Expedition, led by paleontologist O.C. Marsh.

INTRODUCTION AND STRUCTURAL SETTING

Situated to the north of the Uinta Mountains in the southern Green River basin, Wyoming, the Bridger Formation is of great scientific importance and is of historic interest to vertebrate paleontologists. The Bridger Formation has been the focus of paleontological investigations for the last 140 years. Because of its economic importance and exquisitely preserved vertebrate, invertebrate and plant fossils, the Green River Formation is perhaps the most familiar of the rock units within the Green River basin. Despite the geological and paleontological importance of this world-renowned lacustrine rock unit, this field excursion is focused on the stratigraphically adjacent and overlying fluvial and lacustrine Bridger Formation, best known for its middle Eocene vertebrate fossils. The Bridger Formation is the stratotype for the Bridgerian North American Land Mammal "Age" (NALMA) (Gunnell et al., 2009; Wood et al., 1941). The fossils and sediments of the Bridger provide a critically important record of biotic, environmental, and climatic history spanning approximately 3.5 million years (49.0 to 45.5 Ma).

The greater Green River basin occupies 32,187 km^2 of southwestern Wyoming and northwestern Colorado (Roehler, 1992a). Structurally, it is a large asymmetrical syncline with mostly gently dipping flanks (3º to 5º) with steeper dips along the southern margin of the basin, and an approximately north-south axis (Koenig, 1960; Roehler, 1992a). The greater Green River basin is divided into four smaller basins by three intrabasin arches. The largest of these arches, the north-south trending Rock Springs uplift, divides the basin into roughly equal halves, with the Green River basin to the west, and the Great Divide, Sand Wash, and Washakie basins to the east. The Bridger basin is located within the southern part of the Green River basin. The term Bridger basin (Hayden, 1871) traditionally refers to an area located north of the Uinta Mountains and south of the Blacks Fork of the Green River in Uinta and Sweetwater counties, Wyoming, and is a physiographic, not a structural basin (Figure 1).

The greater Green River basin began forming during the Laramide orogeny, a period of tectonism in western North America that was initiated during the late Cretaceous and continued for approximately 30 million years until the late Eocene. In addition to the uplifting of surrounding mountain ranges, Laramide tectonism resulted in rapid subsidence in basin depositional centers, and lacustrine and fluvial deposition in the intermontane basins was mostly continuous. Lacustrine deposition was characterized by a complex history of expansions and contractions in response to basin subsidence, climatic conditions, and volcanic activity (Murphey, 2001; Murphey and Evanoff, 2007; Roehler, 1992b).

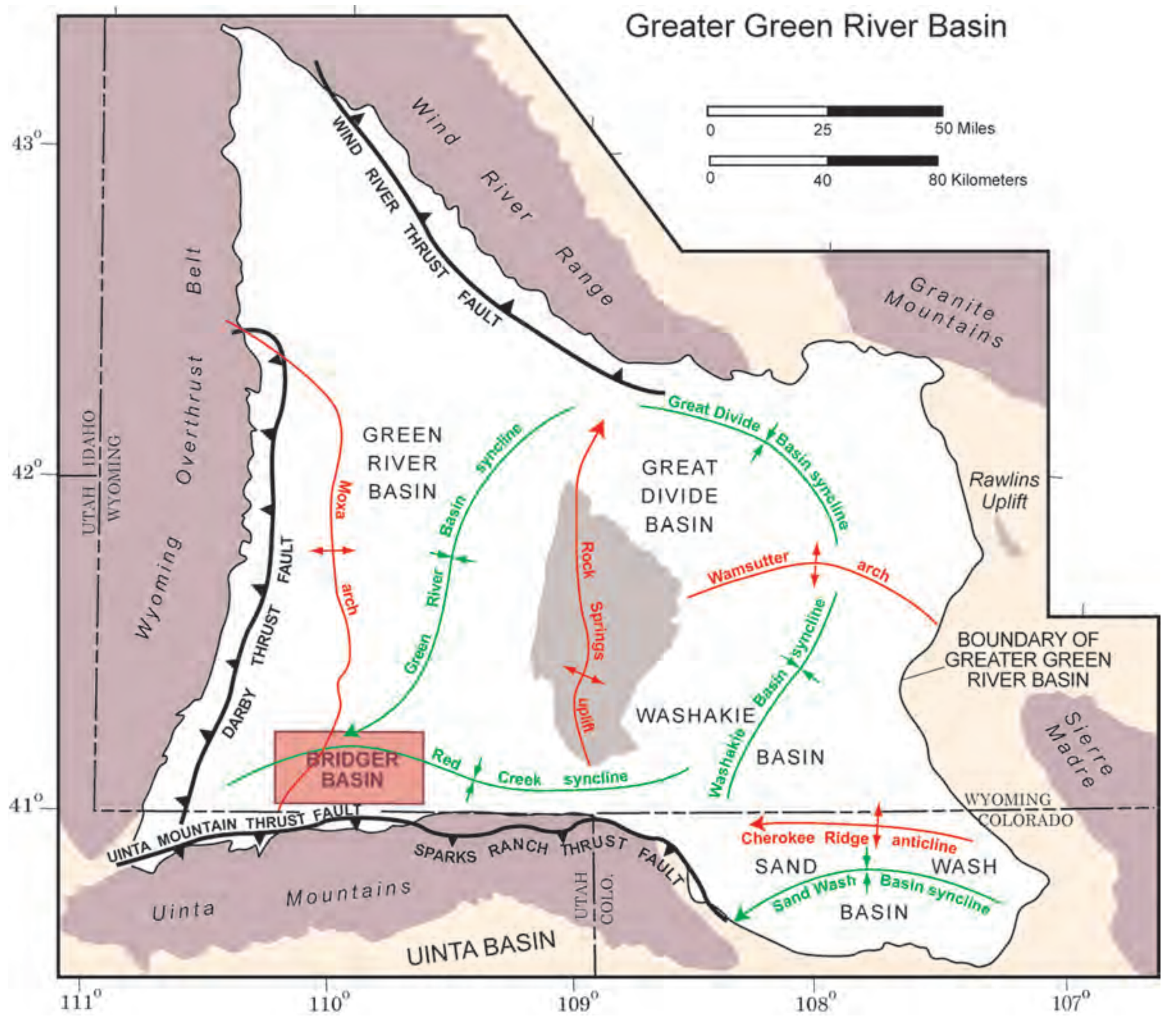

FIGURE 1. Index map of the Greater Green River Basin showing the approximate location of the Bridger basin (type area of the Bridger Formation), major structural features, and surrounding uplifts (modified from Murphey and Evanoff, 2007).

With its abundant and diverse vertebrate fossils and extensive exposures, the Bridger Formation provides an excellent opportunity to study middle Eocene continental environments of North America. The dramatic and picturesque Bridger badlands are an 842 meter (2,763 feet) thick sequence dominated by green-brown and red mudstone and claystone, with interbedded scattered ribbon and sheet sandstone, widespread beds of micritic, sparry, and silicified limestone, and thin but widespread beds of ash-fall tuff (Evanoff et al., 1998; Murphey and Evanoff, 2007).

From a resource management perspective, the richly fossiliferous Bridger badlands present a challenge to land managers—in particular the Wyoming Bureau of Land Management. With a Potential Fossil Yield Classification (PFYC, BLM 2008-007) ranking of 5 (very high paleontologic potential) (Murphey and Daitch, 2007), the Bridger Formation contains fossils in both surface accumulations and subsurface occurrences, and both are vulnerable to direct impacts as the result of surface disturbing actions and indirect impacts from increased public access to public lands. Fortunately, as will be discussed during the field trip, well documented fossil distribution patterns in the upper Bridger Formation provide a reliable source of information upon which to base management decisions.

This field trip offers participants the opportunity to examine paleontologically significant strata of the Bridger Formation in the southern Green River basin. The following sections of the field trip guide provide a summary of the Cenozoic geologic history of the Green River basin, as well as the history of investigations, stratigraphy, depositional and paleoenvironmental history, and fossils of the Bridger Formation. This is followed by a detailed road log. Discussions during the field trip will also focus on some of the resource management issues that relate to the exquisite fossils of this world renowned rock unit.

PALEOGENE GEOLOGIC HISTORY OF THE GREEN RIVER BASIN, WYOMING

The greater Green River basin was filled with Paleocene and Eocene fluvial and lacustrine sediments; sedimentation appears to have been continuous in most of the basin during the Eocene. The oldest Cenozoic rock units in the greater Green River basin—the Paleocene Fort Union Formation and the early Eocene Wasatch Formation—are exposed mostly along its eastern and western flanks. During the Paleocene and earliest Eocene, deposition in the greater Green River basin was predominantly fluvial, with epiclastic sediments accumulating in river drainages and on adjacent floodplains. The onset of lacustrine deposition associated with the Green River lake system may have commenced as early as the late Paleocene (Grande and Buchheim, 1994). Lake sediments accumulated on broad floodplains of low topographic relief, and the lake waters expanded and contracted numerous times over the next approximately five million years in response to climatic changes, tectonic influences, and episodic volcanic activity.

Occupying the center of the basin in the shape of a large, irregular lens (Bradley, 1964; Roehler, 1992b, 1993), the Green River Formation is the result of at least five million years of lacustrine deposition lasting from about 53.5 to 48.5 Ma (Smith, 2003), although lacustrine deposition may have persisted later in the southernmost part of the basin along the Uinta Mountain front (Murphey and Evanoff, 2007). The Green River Formation was deposited in a vast ancient lake system that existed from the late Paleocene to the middle Eocene in what is now Colorado, Utah, and Wyoming. The smallest and oldest of these lakes, Fossil Lake, was deposited in Fossil basin, which is located in the Wyoming overthrust belt just to the west of the Green River basin in southwestern Wyoming. Lake Gosiute was deposited in the greater Green River basin, which includes the Green River and Washakie basins in southwestern Wyoming, and the Sand Wash basin in northwestern Colorado. Fossil Lake and Lake Gosiute may never have been physically connected (Surdam and Stanley, 1980). Lake Uinta was deposited in the Uinta basin in northeastern Utah and the Piceance Creek basin in northwestern Colorado. Lithologically, the Green River Formation in the greater Green River basin is a complex sequence of limestone, shale, and sandstone beds with a maximum thickness of approximately 838 meters (2,750 feet) (Roehler, 1993). It was deposited lateral to and above the predominantly fluvial Wasatch Formation, and lateral to and below the fluvial and lacustrine Bridger and Washakie formations. The Laney Member is the uppermost member of the Green River Formation in Wyoming and represents the final expansion of Lake Gosiute.

Most volcaniclastic sediments deposited in the Green River basin during the middle Eocene were apparently transported from the Absaroka Volcanic Field in what is now northwestern Wyoming. These sediments were washed into the basin in rivers and streams. Some volcaniclastic sediments were transported into the basin via eolian processes and deposited as ash fall in lakes and on floodplains. A large influx of fluvially transported volcaniclastic sediment is believed to have led to the final middle Eocene filling of Lake Gosiute (Mauger, 1977; Murphey, 2001, Murphey and Evanoff, 2007; Surdam and Stanley, 1979). Mauger (1977) and Surdam and Stanley (1979) estimated that Lake Gosiute was ultimately extinguished by about 44 Ma.

The Bridger, Green River, and Washakie formations are locally and unconformably overlain by the Oligocene Bishop Conglomerate and the middle-to-late-Miocene Browns Park Formation. Since the Eocene, the greater Green River basin has been modified by erosion, regional uplift, and normal faulting, but the basic structure of the basin remains the same as it was during deposition of the Wasatch, Green River, Washakie, and Bridger formations.

HISTORY OF PALEONTOLOGICAL INVESTIGATIONS IN THE BRIDGER FORMATION

John Colter, who traveled to the headwaters of the Green River in 1807, was probably among the first non-Native Americans to visit the Green River basin (Chadey, 1973). Hundreds of subsequent trappers and explorers traversed the basin during the first half of the nineteenth century, and a number of records of these early explorations make reference to fossils and coal (Roehler, 1992a). The earliest scientific observations on the geology of the Green River basin were made by Army Lt. John C. Fremont. After entering the basin through South Pass at the southern end of the Wind River Mountain, Fremont (1845) described varicolored rocks (now known as Eocene-age Wasatch Formation) along the Big Sandy and New Fork rivers. He also collected fossil shells from near Cumberland Gap (Veatch, 1907). The earliest vertebrate fossils reported from the Green River basin were fishes discovered in the Green River Formation. In 1856, Dr. John Evans collected a specimen of a fossil fish from an unknown Green River Formation locality west of Green River City. He sent this specimen to paleontologist Joseph Leidy in Philadelphia for study, and Leidy named it *Clupea humilis* (later renamed *Knightia humilis*) (West, 1990). Hayden (1871) described the discovery of a locality he referred to as the “petrified fish cut” along the main line of the Union Pacific Railroad about 2 miles west of Green River. Employees of the railroad had initially discovered the locality and later turned many specimens over to Hayden. Paleontologist Edward Drinker Cope described the fish fossils from the petrified fish cut in Hayden’s (1871) expedition report.

The initial discovery of mammalian fossils in the Green River basin was probably made by a long-time local resident. Trapper Jack Robinson (also called Robertson) found what he described as a “petrified grizzly bear” sometime in the late 1860s in what is now called the Bridger Formation but had initially been named the “Bridger Group” by Ferdinand V. Hayden in 1869. This story was related to Joseph Leidy by Judge William Carter of Fort Bridger as an explanation for the name “Grizzly Buttes,” an area 10 to 15 miles southeast of Fort Bridger where fossils were particularly common (the name Grizzly Buttes has since disappeared from the local geographic vocabulary).

Several government geological and topographical surveys with specific but overlapping territories were operating in the southern Green River basin between 1867 and 1879. Hayden and his party collected along the Henrys Fork valley and further north in the vicinity of Church Buttes in 1870 as part of the 1867 to 1878 U.S. Geological and Geographical Survey of the Territories (Hayden, 1873). Fossils collected by Hayden's group were sent to Joseph Leidy in Philadelphia for study and were described in his 1873 monograph on fossil vertebrates. Later paleontological studies for the Hayden Survey were carried out by E. D. Cope. Under the direction of John Wesley Powell, the U.S. Geological and Geographical Survey of the Territories, Second Division (1875–1876), worked along the Henrys Fork River in 1869, and in a corridor 10 to 20 miles wide on either side of the Green River in 1871 (Powell, 1876). The U.S.Geological Survey of the Fortieth Parallel (1867–1872), directed by Clarence King, worked in the Green River basin in 1871 and 1872. The fossils collected by the King Survey were sent to Othniel Charles Marsh for description. Most of the fossils collected during these surveys were discovered in the Bridger Formation.

Many of the early scientific expeditions to the Green River basin were based out of Fort Bridger that was originally set up as a trading post in 1843 by trapper and guide Jim Bridger and his partner Louis Vasquez. The fort became an army post after the 1857 Mormon War. Judge Carter and Dr. J. Van A. Carter, later residents of Fort Bridger, maintained an active correspondence with Joseph Leidy in Philadelphia during the late 1860s and early 1870s. This correspondence included mailing fossils to Leidy, which were described in subsequent publications (Leidy, 1869, 1871, 1872a,b, 1873). Leidy, who is often regarded as the father of North American vertebrate paleontology (Lanham, 1973), named the first Bridger Formation fossil to be formally described, the omomyid primate *Omomys carteri*, after Dr. Carter (Leidy, 1869). *Omomys carteri* was also the first-described fossil primate from North America.

Early reports of fossils from the Green River basin did not go unnoticed by rival paleontologists O. C. Marsh and E. D. Cope. The incidents that set the stage for the long and bitter conflict between these two men began in the Green River basin while they were prospecting in the Bridger Formation in 1872. Sometimes referred to as the "bone wars," the dispute between Marsh and Cope lasted for more than 30 years and included efforts by each man to destroy the scientific reputation and integrity of the other. This conflict soured Leidy's interest in paleontology and led to his eventual abandonment of the discipline after 1872.

Professor Marsh was the first professional paleontologist to collect fossils from the Bridger Formation; he brought crews with him from Yale College for four consecutive summers from 1870 to 1873. Leidy's only excursion to the West took place in 1872, when he visited the Bridger badlands guided by the Carter brothers of Fort Bridger. Cope's only visit to the Bridger badlands occurred in 1872, while Cope was attached to the Hayden survey as the paleontologist. This visit infuriated Marsh, who, at the time, considered the Green River basin and Bridger Formation his exclusive fossil-collecting territory. By the late 1870s, Cope and Marsh had left the Green River basin for good, although both men independently and at different times retained the services of paid fossil collector Sam Smith (West, 1990).

Other early fossil collectors who visited the Green River basin in 1877 and 1878 included Henry Fairfield Osborn, William Berryman Scott, and Francis Speir for Princeton University. Scott returned to the area with Speir in 1886. Jacob Wortman and James W. Gidley collected for the American Museum of Natural History (AMNH) in 1893. The early fossil-collecting expeditions to the Green River basin resulted in large collections of fossils primarily from the Bridger Formation at the Philadelphia Academy of Natural Sciences (Leidy), Yale University (Marsh), the AMNH (which purchased Cope's collection just before the turn of the century), and Princeton University (Osborn, Scott, and Speir). Unfortunately, these early collectors paid little attention to the stratigraphic provenance of the fossils they collected. Their collections do, nevertheless, contain the holotypes of most presently recognized Bridgerian mammal taxa.

In 1902, H. F. Osborn, who was then the USGS paleontologist, initiated the first program of stratigraphic fossil collection to take place in the Green River basin and one of the first in North America. Osborn charged Walter Granger and William Diller Matthew of the AMNH with the task of carrying out the study. Matthew was also directed to find a uintathere to display at the AMNH. The AMNH party, led by Granger, worked in the Bridger basin from 1902 to 1906 (Matthew, 1909). The second halves of the 1903 and 1905 field seasons were devoted to mapping and describing the stratigraphy of the Bridger Formation, while the remainder of the time was spent searching the badlands for fossils. The efforts of the AMNH parties over these four years resulted in an excellent fossil collection that was, for its time, very well documented stratigraphically.

These AMNH expeditions also resulted in the first paper to be published on the geology of the Bridger Formation, which was authored by William J. Sinclair (1906), who had joined the AMNH field party for the summer of 1905. In Matthew's classic 1909 monograph, *The Carnivora and Insectivora of the Bridger Basin, Middle Eocene*, the geology of the Bridger Formation was described briefly, and a system of stratigraphic subdivisions for the formation was introduced. These subdivisions, Bridger A–E, were based on areally extensive limestone beds, which Matthew called "white layers."

Following the early fossil-collecting expeditions of the nineteenth century and initial scientific field studies conducted by AMNH crews in the early twentieth century, the Bridger Formation in the Green River basin has remained the focus of almost continuous paleontologic inquiry because of its abundant and diverse vertebrate fossils, although Matthew's (1909) original stratigraphy was only recently refined. West (1990) wrote an excellent historical summary of vertebrate paleontological work in the Green River basin from 1840 to 1910.

H.F. Osborn (1929) devoted considerable discussion to the Bridger Formation and its fossils in his monograph, *The Titanotheres of Ancient Wyoming, Dakota, and Nebraska*. Horace Elmer Wood (1934) divided the Bridger Formation into two members. The Blacks Fork Member corresponds to Matthew's Bridger A and B, and the Twin Buttes Member corresponds to Matthew's Bridger C and D, with the Sage Creek White Layer marking their boundary. Contrary to rules of stratigraphic nomenclature, these members were defined on perceived faunal differences rather than lithologic differences. The informal usage of the terms "Blacksforkian" and "Twinbuttean" as land mammal subages derives from the names of the two Bridger members. Under the direction of J. W. Gidley, followed by C. Lewis Gazin, the Smithsonian Institution began an active collecting program in the Bridger Formation beginning in 1930. Gazin was active in the Green River basin from 1941 to 1968. This period of activity resulted in a relatively large and well-documented collection that was the subject of numerous publications by Gazin focused primarily on the systematic paleontology of Bridgerian mammal fossils (e.g., 1934, 1946, 1949, 1957, 1958, 1965, 1968, and 1976).

Paul O. McGrew and Raymond Sullivan worked on the stratigraphy and paleontology of the Bridger A in the late 1960s and published the results of their work in 1970. Robert M West began an active collecting program for the Milwaukee Public Museum in 1970 and worked in the basin until the late 1970s. West's work, which also resulted in a large number of paleontological publications, included the use of screen-washing techniques to collect microvertebrates, a portion of the fauna that had not been previously well sampled. Like Wood (1934) and Koenig (1960), West (1976) noted difficulties with the correlation of Matthew's white layers across the basin and suggested that a bipartite division of the Bridger into upper (Twin Buttes) and lower (Blacks Fork) members was most appropriate. West and Hutchison (1981) named Matthew's Bridger E the Cedar Mountain Member, adding a third member to the Bridger Formation. Paleontological and geological studies of Tabernacle Butte, an isolated remnant of the Bridger Formation of late Bridgerian age with an important fossil fauna, were published by McGrew (1959), McKenna et al. (1962), and West and Atkins (1970).

Evanoff et al. (1998), Murphey (2001), and Murphey and Evanoff (2007) significantly refined Matthew's (1909) Bridger Formation stratigraphic scheme. Their work included the addition of newly described marker units; the establishment of new stratigraphic subdivisions and correlation of marker units across the southern part of the basin where the most complete stratigraphic sequence is exposed; descriptions of detailed stratigraphic sections measured through the Bridger B, C, D, and E; renaming of the Cedar Mountain Member to the Turtle Bluff Member in order to conform with the rules of stratigraphic nomenclature; stratigraphic positioning of more than 500 fossil localities; isotopic dating of four ash-fall tuffs; and geologic mapping of more than 600 miles of the southern Green River basin at the scale of 1:24,000. Geologic maps and publications relating to the Bridger Formation are available at http://www.rockymountainpaleontology.com/bridger.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS OF THE BRIDGER FORMATION

The Bridger Formation was named the "Bridger Group" by Hayden (1869). The first stratigraphic framework for the Bridger Formation was established by W.D. Matthew (1909) of the AMNH in the southern Green River basin where the formation is thickest and best exposed. Matthew's (1909) stratigraphic subdivisions of the Bridger Formation were based primarily on five areally extensive limestone beds. These he named the Cottonwood, Sage Creek, Burnt Fork, Lonetree, and upper white layers, and some were used to subdivide the formation into five units: Bridger A, B, C, D, and E, from lowest to highest. Matthew's intent was to make it possible to stratigraphically locate the numerous known fossil localities in the formation. Because they are the most fossiliferous, the Bridger B, C, and D were further divided into five subunits corresponding to basal, lower, middle, upper, and top levels (e.g., B1, B2, B3, B4, B5). Because Matthew (1909) did not define the upper and lower boundaries of these subunits with stratigraphic markers or measured sections, correlations between them and the later subdivisions proposed by Evanoff et al. (1998), Murphey (2001), and Murphey and Evanoff (2007) are uncertain. See Figure 2 for the history of stratigraphic nomenclature for the Bridger Formation.

In his 1909 monograph, Matthew (1909:296) gave a brief description of his proposed five members and his white layers. "Horizon A" was 200 ft thick, composed primarily of calcareous shales alternating with tuffs, and with rare fossils. "Horizon B" was 450 ft thick, consisting of two benches separated by the Cottonwood white layer and containing abundant and varied fossils. He went on to note that the largest number of complete skeletons from the entire formation was found in the lower part of Horizon B (B2). "Horizon C" was 300 ft thick, "defined inferiorly" by the Sage Creek white layer, with the Burntfork white layer occurring at about its middle, and with abundant and varied fossils. He also noted that the Sage Creek white layer was the "heavy and persistent calcareous stratum" at Sage Creek Spring, thus designating a type locality where this unit had been previously described and illustrated, but not named, by Sinclair (1906). "Horizon D" was 350 ft thick, composed of harder gray and greenish-gray sandy and clayey tuffs, "defined inferiorly" by the Lonetree white layer, with the upper white layer about 75 ft from the top, and with abundant and varied fossils. "Horizon E" was 500 ft thick, composed of soft banded tuffs with heavy volcanic ash layers, with a high gypsum content and nearly barren of fossils. The total thickness of the Bridger reported by Matthew was 1,800 ft. Despite the lithologic descriptions of the five horizons made by Matthew (1909), subsequent workers have not been able to subdivide the Bridger Formation on the basis of lithologic differences (Bradley, 1964; Evanoff et al., 1998; Murphey, 2001, Murphey and Evanoff, 2007; Roehler, 1992a). Furthermore, with the exception of the Bridger B–C and D–E boundaries, Matthew's subdivisions do not correspond to major faunal changes (Murphey, 2001; Murphey and Evanoff, 2007; Simpson, 1933; Wood, 1934).

The Bridger Formation has been subdivided into three members. The Blacks Fork Member, or lower Bridger, is equivalent to Matthew's Bridger A and B; the Twin Buttes Member, or upper Bridger, is equivalent to Matthew's C and D; and the Turtle Bluff Member, also considered part of the upper Bridger, is equivalent to Matthew's Bridger E. A detailed history of geo-

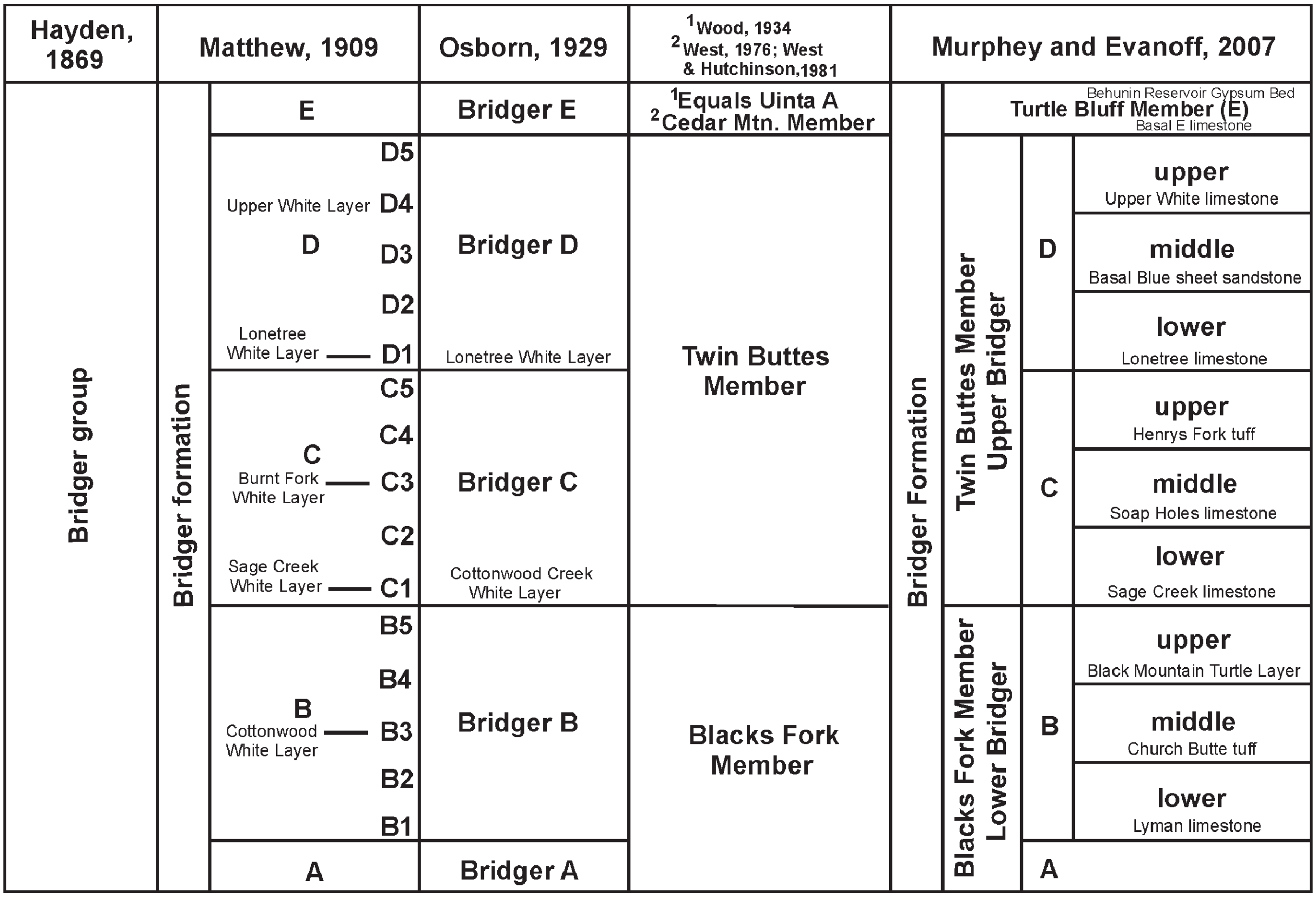

FIGURE 2. History of Bridger Formation stratigraphic nomenclature Bridger from 1869 until present. The correlation between Mathew's (1909) subdivisions (1–5) and the lower, middle, and upper subdivisions of Murphey and Evanoff (2007) are uncertain.

logic and paleontologic investigations focusing on the Bridger Formation, and the history of stratigraphic nomenclature for this unit, are provided by Murphey and Evanoff (2007).

Evanoff et al. (1998), Murphey (2001), and Murphey and Evanoff (2007) published the first major stratigraphic revision of the Bridger Formation since Matthew's (1909) stratigraphy. The most recent stratigraphic subdivisions are based on widespread limestone beds, tuffs, and tuffaceous sheet sandstones which are used as marker units. Fifteen such units were described, and seven of these were considered major markers. These were used to subdivide the Bridger C and D (Twin Buttes Member) into lower, middle, and upper informal subdivisions (Figs. 2 and 3). Two additional markers were used to redefine the base and define the top of the Bridger E (Turtle Bluff Member). Four of Matthew's original "white layers" were included in the stratigraphy of the Bridger C and D, and these were mapped and redescribed in detail. In conjunction with the latest stratigraphic revision, geologic mapping of ten 7.5-minute quadrangles which cover the area encompassed by the upper Bridger Formation was completed, and these maps are available from the Wyoming State Geological Survey. Because many marker units are not continuously exposed or traceable across the entire basin (from Hickey Mountain, Sage Creek Mountain, and Cedar Mountain east to Twin Buttes and Black Mountain), a distance of approximately 40 miles, accurate correlation was made possible by using the mineralogically diagnostic Henrys Fork tuff as a datum.

Rock accumulation rates, isotopic ages of ash-fall tuffs (Murphey et al., 1999), and fossils indicate that the 842-meter (2,763-feet) thick Bridger Formation was deposited over an approximately 3.5-million-year interval from about 49.09 to 45.57 Ma, and that the faunal transition from the Bridgerian to the Uintan Land Mammal Age was underway by about 46 Ma as indicated by fossils collected from the Turtle Bluff Member (Evanoff et al., 1994; Gunnell et al., 2009; Murphey, 2001; Murphey and Evanoff, 2007; Robinson et al., 2004). Recognized depositional environments of the Bridger Formation include fluvial, lacustrine, playa lacustrine, paludal, marginal mudflat, basin margin, and volcanic. Murphey and Evanoff (2007) concluded that an influx of fluvially transported volcaniclastic sediment to the Green River basin during middle Eocene time led to the filling of Lake Gosiute and the development of muddy floodplains of low topographic relief, which persisted for up to 85% of the time during which the upper Bridger was deposited. Occasional lapses in the flow of sediment to the basin permitted the development of shallow, mostly groundwater-fed lakes and ponds, which accumulated up to four times as slowly as floodplain deposits. These

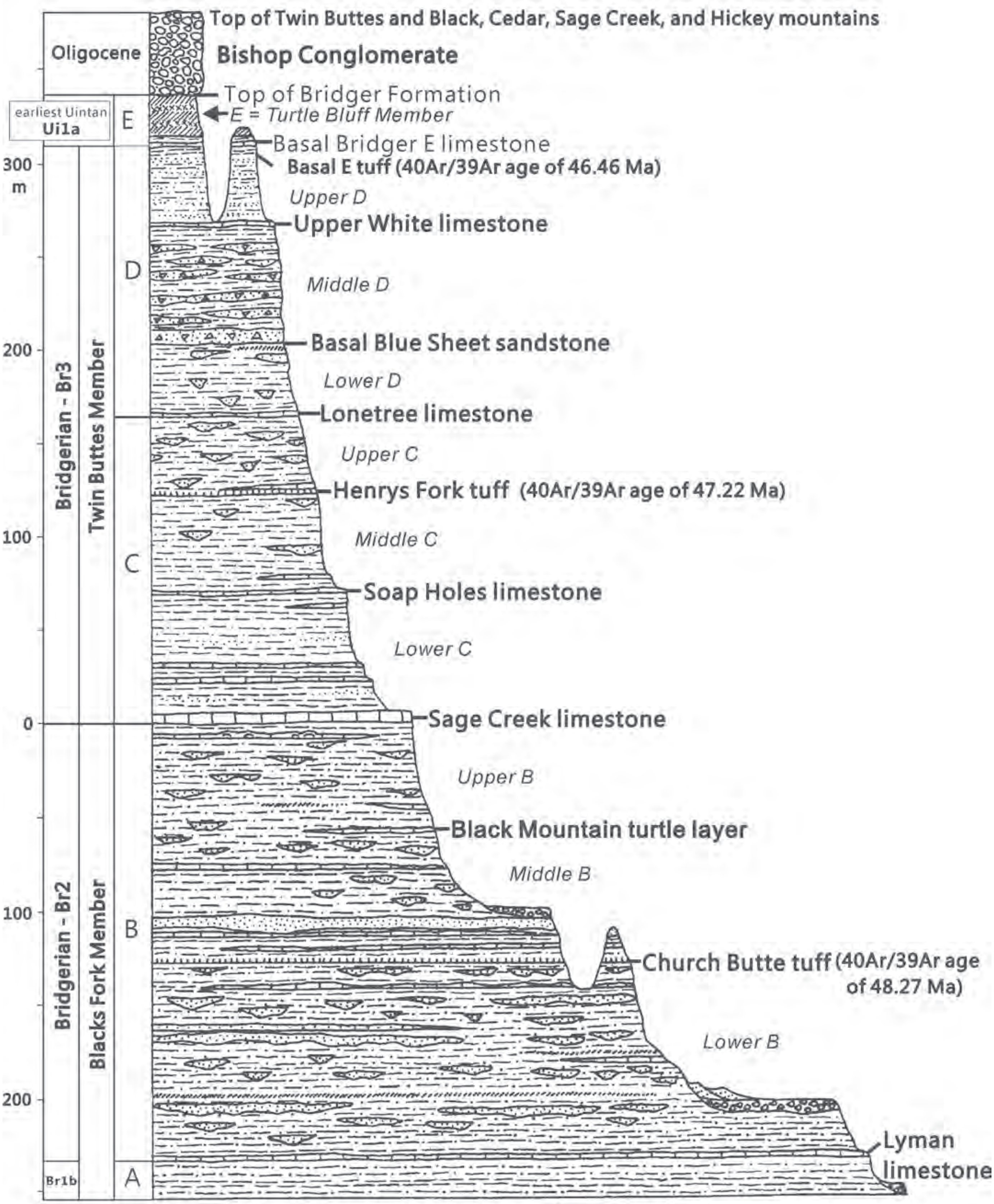

FIGURE 3. Generalized stratigraphic section of the Bridger Formation in the southern Green River Basin. Isotopic ages reported by Murphey et al. (1999) have been recalculated using the current 28.201 Ma sanidine standard for the Fish Canyon Tuff (Renne et al., 1998).

lapses decreased in frequency throughout deposition of the upper Bridger Formation. As indicated by fossil distribution and diversity, lakes and their margins provided favorable habitats for both aquatic and terrestrial organisms during deposition of the Bridger Formation.

MIDDLE EOCENE PALEOENVIRONMENTS OF THE GREEN RIVER BASIN

Numerous studies based on paleontological and geological evidence have concluded that the Eocene-age rock units in the greater Green River basin were deposited in warm temperate, subtropical, and tropical climatic conditions (Roehler, 1993). Perhaps the most reliable information concerning paleoclimates comes from analysis of plant mega- and micro-fossils. According to Leopold and MacGinitie (1972), early Eocene floras (based on palynology of samples collected from the Niland Tongue of the Wasatch Formation and the Luman and Tipton tongues of the Green River Formation) suggest a humid subtropical to warm temperate climate with summer rainfall and only mild frost and with a mean annual temperature of 55°F. Nichols (1987) concluded that the climate of the basin floor during deposition of the Niland Tongue was subtropical, without freezing temperatures.

The earliest middle Eocene climates pertaining to the Cathedral Bluffs Tongue of the Wasatch Formation and the Wilkins Peak Member of the Green River Formation were interpreted as generally hot and dry (Leopold and MacGinitie, 1972). Climatic conditions in the early–middle Eocene during deposition of the lower part of the Laney Member of the Green River Formation were characterized as warm and humid with tropical affinities. Floras of the upper part of the Laney Member indicate a change to cooler, subhumid conditions (Leopold and MacGinitie, 1972). Both pollen and leaf data from the Washakie Formation indicate a dry but temperate climate (Leopold and MacGinitie, 1972). Roehler (1993) reported in a written communication that MacGinitie reinterpreted temperature and precipitation ranges on the basis of palynology of samples collected from the Washakie basin by Roehler (1992a). His reinterpretation estimated mean annual temperatures of 65°F during the early Eocene, 63°F during the earliest middle Eocene, and 62°F during the middle Eocene. Average annual precipitation was estimated at more than 40 inches during the early Eocene, 25 to 35 inches during the earliest middle Eocene, and 15 to 20 inches in the middle Eocene. Sedimentological evidence of a more arid climate during the middle Eocene (transitional Uintan NALMA) includes massive beds of gypsum capping the Turtle Bluff Member of the Bridger Formation (Murphey, 2001; Murphey and Evanoff, 2007). The shift from dominantly tropical forest environments to more-open, savanna-like conditions in the Eocene intermontane basins during late Bridgerian (early middle Eocene) and Uintan (middle Eocene) times has also been studied by using ecological diversity analysis applied to mammalian faunas (Murphey and Townsend, 2005; Townsend, 2004).

As indicated by fossil distribution and diversity, the Green River lakes and their forested margins provided highly favorable habitats and preservational environments for both aquatic and terrestrial organisms. Lake margin habitats, riparian corridors, and adjacent floodplains were apparently vegetated during much of the time of Green River Formation deposition, as indicated by a paleoflora that includes a variety of trees and bushes such as palm, cinnamon, oak, maple, lilac, and hazel, as well as cattails and rushes. Insects of many varieties lived in the lakes and forests and are locally well preserved in lake sediments. A variety of terrestrial and aquatic mollusks (clams and snails) are also known to have inhabited the Green River lakes (Hanley, 1974). Crayfish, prawn, and ostracods inhabited the warm lake waters, as did a diversity of fish species, including relatives of the herring, perch, paddlefish, bowfin, gar, catfish, and stingray (Grande, 1984; Grande and Buchheim, 1994; McGrew and Casilliano, 1975). Frogs, crocodiles, and turtles were common residents of shallower proximal shoreline waters. A diversity of reptile species, including tortoise, lizards, and snakes, inhabited the forests surrounding Eocene lakes and ponds. Flamingos, hawks, rails, stone curlews, and other bird species frequented the forests, wetlands, and lakes (Murphey et al., 2001). The forests teemed with the primitive ancestors of many modern mammalian groups, including rodents, insectivores, bats, primates, perissodactyls (horse, rhinoceros, and tapir), and carnivores, as well as more bizarre archaic forms such as creodonts, brontotheres, and massive six-horned uintatheres (Gazin, 1976; Grande and Buchheim, 1994; Gunnell and Bartels, 1994; McGrew and Casilliano, 1975; Murphey et al., 2001).

FOSSILS AND BIOCHRONOLOGY OF THE BRIDGER FORMATION

The Bridger Formation preserves one of the world's most abundant and diverse middle Eocene vertebrate faunas, with more than 86 recognized species representing 67 genera, 30 families, and 13 orders of fossil mammals (Gazin, 1976). Bridger fossils have been the subject of numerous publications, including many classic papers by pioneers of American vertebrate paleontology (Cope 1872, 1873; Granger, 1908; Leidy, 1869, 1871, 1872a; Marsh, 1871, 1886; Matthew, 1909; Osborn, 1929). Like other highly fossiliferous formations, the Bridger contains an abundance and diversity of fossils that make it well suited for paleontological research, most of which has focused on the phylogenetics, systematic paleontology, and biostratigraphy of the vertebrate fauna (Covert et al., 1998; Evanoff et al., 1994; Gazin, 1957, 1958, 1965, 1968, 1976; Gunnell et al., 2009; Krishtalka et al., 1987; McGrew and Sullivan, 1970; Robinson et al., 2004; West and Hutchison, 1981). These fossils, which are preserved in a variety of sedimentary environments, preservational states, associations, and in locally varying abundances, include primarily vertebrates and mollusks, with less common plants and ichnofossils. Plant fossils include leaves, seeds, and wood, which is sometimes algal covered (see Murphey et al., 2001). Ichnofossils include solitary bee cases, earthworm pellets, caddis fly larvae, and fish pellets. Vertebrate fossils include fish, amphibians, reptiles (lizards, snakes, turtles, and crocodilians), a diversity of birds (see Murphey et al., 2001), and mammals. Mammalian fossils include apatotheres, artiodactyls, chiropterans, carnivores, condylarths, dermopterans, dinoceratans (uintatheres), edentates, insectivores, leptictids, marsupials, pantolestids, perissodactyls, primates, rodents, taeniodonts, and tillodonts (Gazin, 1976, Woodburne et al., 2009a,b; unpublished paleontological data, University of Colorado Museum, compiled in 2002). Despite the relative ease with which diverse and statistically significant fossil samples can be collected and the large historical collections of Bridger vertebrates available in many museums, relatively few taphonomic and paleoecologic studies of Bridger vertebrate faunas have been completed (Alexander and Burger, 2001; Brand et al., 2000; Gunnell, 1997; Gunnell and Bartels, 1994; Murphey et al., 2001; Murphey and Townsend, 2005; Townsend, 2004; Townsend et al., 2010).

Over the last twenty years, stratigraphically-documented fossil collections made by workers from the University of Colorado Museum, Denver Museum of Nature and Science, University of Michigan Museum of Paleontology, and more recently by the San Diego Natural History Museum, have added significantly to existing biostratigraphic knowledge of the Bridger Formation. These collections, together with precise provenance data, have made it possible to define formal biochronologic units for the Bridgerian NALMA, most of which are based upon stratotype sections that are located in the Bridger Formation. Gunnell et al. (2009) have divided the Bridgerian into four “biochrons.” Formerly referred to as Gardnerbuttean land mammal sub-age, or Br0, biochron Br1a is the only Bridgerian biochron not found in the Bridger Formation. Its stratotype section is the *Eotitanops borealis* interval zone of the Davis Ranch section of the Wind River Formation. Biochron Br1b is equivalent to the lower Blacksforkian, and its stratotype spans the Bridger A (lower part of the Blacks Fork Member). Biochron Br2 is equivalent to the upper Blacksforkian, and its stratotype section spans the Bridger B (upper part of the Blacks Fork Member). Biochron Br3 is equivalent to the Twinbuttean, and its stratotype section spans the entire Bridger C and D (Twin Buttes Member). The uppermost member of the Bridger Formation the Turtle Bluff Member, or Bridger E, is the stratotype section for the earliest Uintan biochron, Ui1a (Gunnell et al., 2009; Walsh and Murphey, 2007). In summary, the mammalian fauna of the Bridger Formation has been used to formally define biochrons Br1b, Br2, Br3, and Ui1a.

The fossil assemblages of the Bridger Formation and other Eocene rock units in the greater Green River basin provide an unprecedented opportunity to study ancient communities and environments. Studies of these fossils and the rocks in which they are preserved are the source of much of our knowledge of the Eocene Epoch of North America. The vertebrate faunas are of particular scientific importance because they represent an exceptional record of early Tertiary mammalian evolution and diversification spanning the Wasatchian, Bridgerian, and earliest Uintan NALMAs.

BRIDGER FORMATION FIELD TRIP STOPS

The field trip route travels through the Bridger basin in an approximately stratigraphic manner. After leaving historic Fort Bridger, the staging area for many of the early fossil collecting expeditions to the Bridger Formation, the route travels east along Interstate 80 crossing through badland outcrops of the Bridger B that are stratigraphically close to the Bridger A–B boundary (Blacks Fork Member). We examine the base of the Bridger B, defined by the Lyman limestone, near Little America. Travelling back west along I-80, we then visit exposures of the Bridger B near historic Church Butte. We then continue west to Lyman and then head south along Wyoming State Highway 414 to the historic Grizzly Buttes badlands in the Bridger B. We continue south along Wyoming 414, climbing stratigraphically through the Bridger C and D (Twin Buttes Member), and examine exposures of this interval in the vicinity of Sage Creek and Hickey mountains, and at the “Lonetree Divide” (base of Bridger D). Weather permitting, we will then make our way to the southwest rim of Cedar Mountain and visit exposures of the Bridger E (Turtle Bluff Member). Finally, we will head east along Highway 414 along the south side of Cedar Mountain with excellent vistas of the Bridger C, D, and E that are overlain by the Oligocene Bishop Conglomerate. The field trip concludes after visiting exposures of the Bridger C at the base of Black Mountain.

Note that all field trip distances are provided in statute (miles), whereas stratigraphic thicknesses are provided in both statute and metric units. All distances were measured using a handheld GPS device calibrated to the NAD27 datum.

STOP 1

Fort Bridger State Historic Site parking lot
(0.0 miles, cumulative 0.0 miles)

Fort Bridger was originally established as a trading post in 1843 by trapper Jim Bridger and his guide Louis Vasquez. The U.S. Army acquired the trading post in 1857 during the Mormon War. It was located along the emigrant trail to Oregon, California and Utah, and more than twenty years after the establishment of the trading post, the route of the newly constructed Union Pacific Railroad passed not far to the north. As discussed in greater detail above, many of the early scientific expeditions to the Bridger Formation were based out of Fort Bridger. Yale University paleontologist O.C. Marsh and his field classes stayed at Fort Bridger before heading out to the Bridger badlands in 1870, 1871, and 1873. Rival paleontologist E.D. Cope stayed at the fort in 1872 during his only fossil collecting expedition to the Bridger. Joseph Leidy, often regarded as the father of North American Vertebrate Paleontology and the first paleontologist to formally describe a Bridger Formation fossil, made his only fossil collecting trip to the west in 1872, and also stayed at Fort Bridger. Today, Fort Bridger is a state historical site and has been partially reconstructed.

The low butte just to the west of Fort Bridger is Bridger Butte, which is capped with Quaternary gravels and is composed of Bridger B strata.

Turn west out of the fort parking lot along the Interstate 80 business loop and then turn east onto I-80 (towards Green River). Drive for approximately 32 miles and take the Granger Junction exit (Exit 66) heading north along US Highway 30. Follow US 30 for 1.8 miles after exiting the interstate. Then turn east and cross the cattle guard onto a dirt road for 0.2 miles at which point you will arrive at the route of old Highway 30 (unmarked gravel road that is still paved in places). Park immediately after turning right (southeast) onto old Highway 30. Outcrops of the Lyman limestone are located just to the east.

STOP 2

The Lyman Limestone at Granger Junction
(36.3 miles from Stop 1, cumulative 36.3 miles)

This stop provides a close up look at the Lyman limestone, which marks the boundary between the Bridger A and the lower Bridger B within the Blacks Fork Member (Figs. 2 and 3). Here, the Lyman limestone is a gray limestone with locally abundant shells of the gastropod *Goniobasis*. The presence of this high-spired snail is a useful diagnostic indicator for this marker unit at many localities in the Bridger basin. The Lyman limestone is widespread in its distribution. It is exposed to the west where it forms the bench that is visible to the south of I-80 upon which its namesake the town of Lyman is situated, almost as far east as the Rock Springs uplift, at least 15 miles north of Granger, and almost as far south as the town of Manila, Utah.

Stratigraphically below the Lyman limestone are strata of the Bridger A. This interval has been problematic for paleontologists because it is sparsely fossiliferous. P.O. McGrew and R. Sullivan worked on the stratigraphy and paleontology of the Bridger A in the late 1960's and published the results of their work in 1970. More recently, Gregg Gunnell and colleagues from the University of Michigan Museum of Paleontology have greatly expanded the known diversity of the Bridger A (Gunnell, 1998; Gunnell and Bartels, 2001). This has made possible the recent formalization of new biochronologic units (Gunnell et al., 2009). As discussed above in "Fossils and Biochronology," the Bridger A contains a mammalian fauna (biochron Br1b) that is biostratigraphically distinct from the fauna of the Bridger B (Br2).

OPTIONAL STOP

Approximately 18 meters (59 feet) stratigraphically above the Lyman limestone 1.7 miles to the southeast along Old Highway 30 is an unusual type of deposit for the Bridger Formation. Park approximately one third of the way up the hill and look for abundant dark brown rock fragments littering the slopes underlain by a thick green mudstone interval. The thin dark brown bed contains abundant fossil caddis-fly larval cases and other more enigmatic fossils preserved in what appear to be algal covered logs (SDSNH Loc. 5783). The taphonomy and paleoecology of this unit has yet to be adequately studied. The fossil bearing bed is overlain by a 2.8 meter (9 feet) thick sequence of green to tan, well-indurated, platy, fine-grained, silty sandstone. It is underlain by a 1.5 meter (5 feet) thick, platy, grayish-brown, non-fossiliferous, mudstone with a distinct top contact. Insect and plant fossils are sparse in the Bridger Formation, and this bed contains the most abundant insect fossils known from the formation.

Return to I-80 and head west (note that throughout this field trip guide the mileages given refer to the prior stop unless specified otherwise). Heading west along I-80, the first prominent butte you come to south of the interstate is Jagged Butte, which is capped by the Jagged Butte limestone. The second prominent butte you come to (approximate highway milepost 56.5) is Wildcat Butte, which is capped by the Sage Creek limestone (Sage Creek white layer of Matthew, 1909), and which forms the base of the Twin Buttes Member. Exit I-80 at the Church Butte exit (Exit 53) and turn north onto Church Butte Road (no sign). At 19.2 miles from Stop 2, with Church Butte just to the east of your location, turn left (southwest) onto Granger Road, Uinta County Road (CR) 233. At mile 21.0, turn southeast off of CR 233 onto a two track road heading towards the westernmost point of Jackson Ridge. Park where the two track road crosses the pipeline right-of-way at 21.2 miles from Stop 2.

STOP 3

Church Butte and Jackson Ridge
(21.2 miles from Stop 2, cumulative 57.5 miles)

Church Butte is a large-linear badland knob formed by the erosion of rocks of the middle Bridger Formation (lower Bridger B beds, Figs. 3, 5 and 6a). The butte was a landmark along the old Oregon-California-Mormon Trail, now Uinta County Road 233. Just to the west of the butte is a north-south trending rim separating Porter Hollow on the east with the valley of the Blacks Fork River on the west. The trail dropped off the rim just to the southwest of Church Butte, and the outcrops of Bridger Formation below the rim were easily accessed by early geologists and paleontologists who travelled along the trail.

Church Butte and the rim exposures are all within the middle part of the Blacks Fork Member of the Bridger Formation of Wood (1934), or the lower Bridger B of Matthew (1909). The rocks in the area are primarily interbedded brown to green mudstone sheets and brown to gray sandstone ribbons and sheets. The sequence includes two sandstone-dominated intervals and three mudstone-dominated intervals (Fig. 4). Four thin but regionally widespread marker units occur in the sequence that is 120 meters (394 feet) thick. The following descriptions are of the Bridger exposures along the west side of the rim, over an area approximately three square miles south of where the county road crosses the rim.

The two sandstone-dominated intervals are characterized by a series of thick ribbons to broadly lenticular sheet sandstone bodies within a sequence of stacked, thin, muddy sandstone and

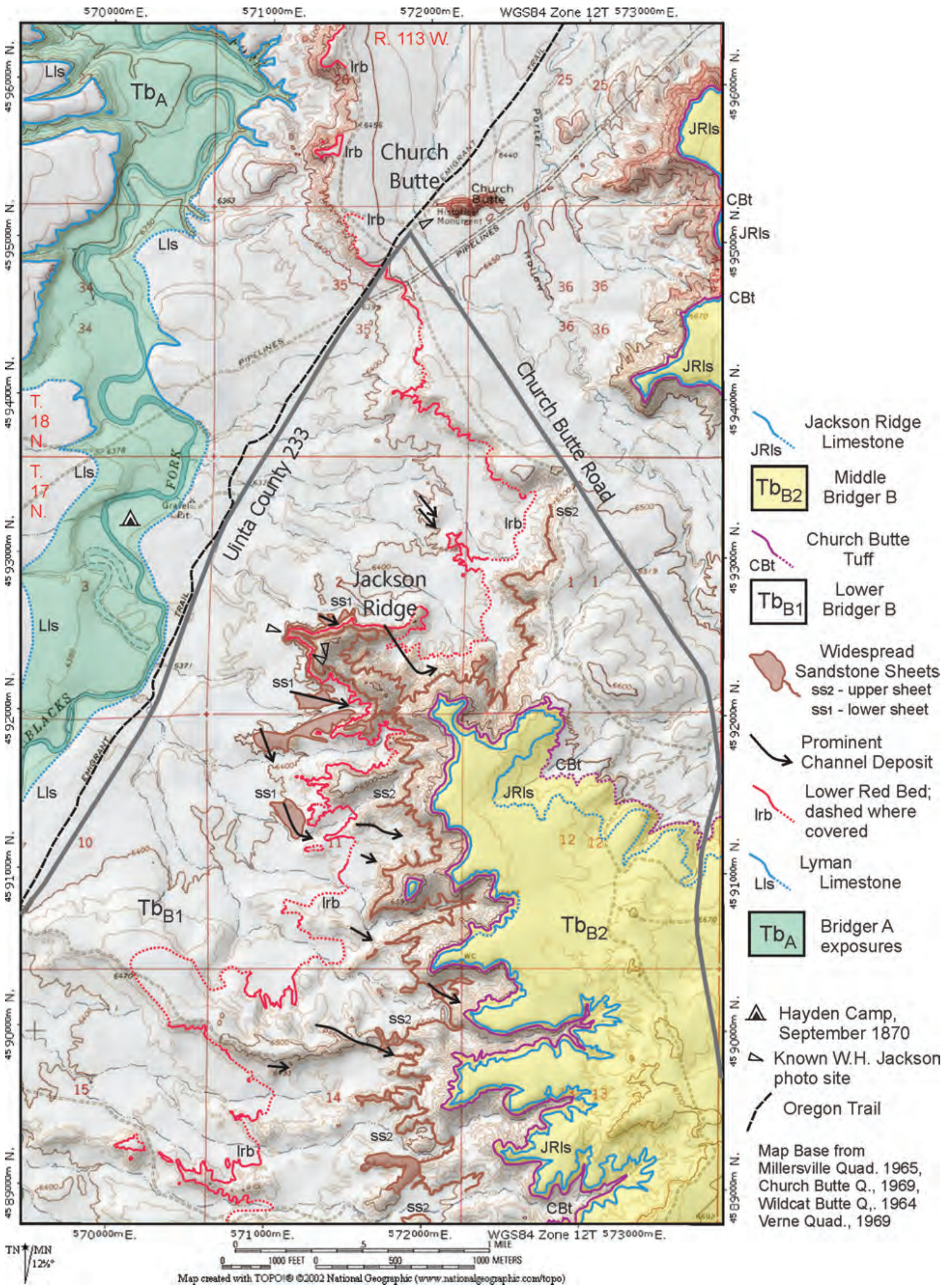

FIGURE 4. Geologic map of the Church Butte – Jackson Ridge area showing major marker beds in the lower Bridger B interval, laterally extensive sandstone sheet intervals, and trends of major sandstone channel-belt deposits. Also shown are important sites of the Hayden 1870 expedition, including known sites where W.H. Jackson took photos. See the text for details.

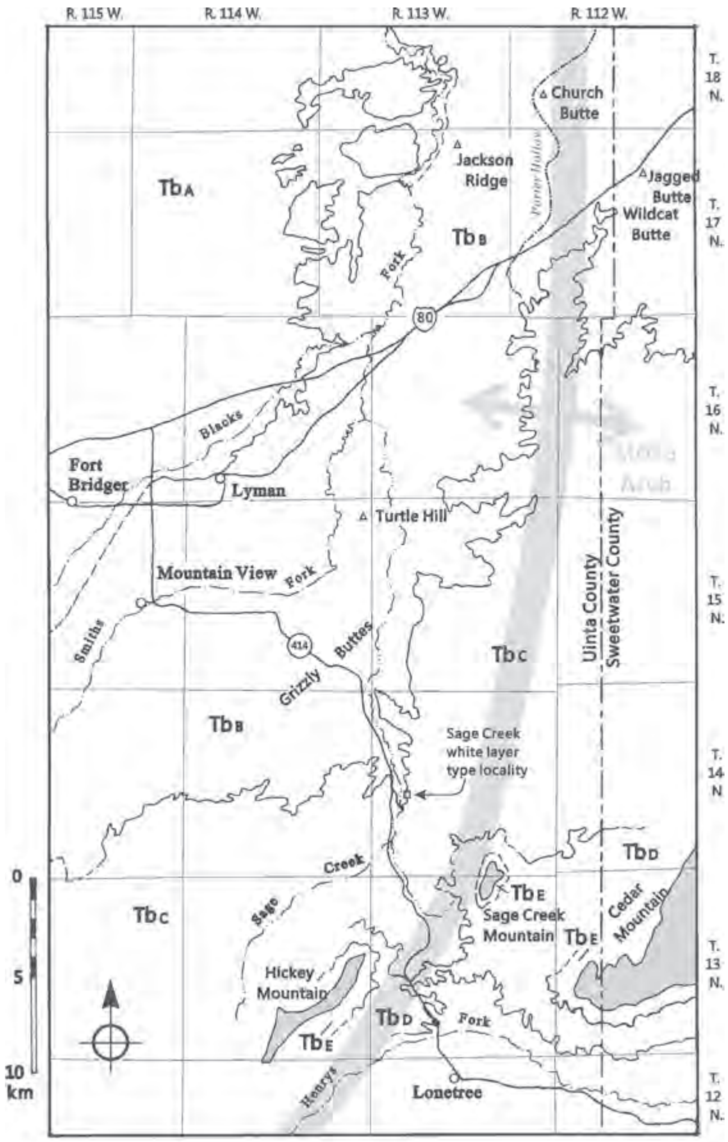

FIGURE 5. Index map of the western Bridger basin, Uinta and Sweetwater counties, Wyoming.

mudstone sheets. Sandstones can comprise 100% of the total thickness within the sandstone-dominated interval, but the lower interval averages 58% sandstone and the upper interval averages 84% sandstone within a minor amount of mudstone. The thick sandbodies within these sandstone-dominated sequences are highly connected both laterally and vertically. The thick sandbodies have a reticulate pattern, with some sandbodies oriented toward the south-southeast (vector mean of 173°) and others oriented toward the east-southeast (vector mean 118°). The sinuosities of the individual sandbodies are low (mean 1.02). These sandstone-dominated intervals represent a river system with numerous splays and local avulsions. The two intervals outcrop as cliffs in the badland exposures.

The mudstone-dominated intervals are characterized by thick ribbon sandstone bodies that are typically separated from adjacent sandstones by extensive mudstone beds. Mudstone-dominated intervals have sandstone contents that range from 10% to 35% of total interval thickness. The sandstone ribbons represent large channels carrying mostly medium sand within a mud-dominated system. The paleocurrent indicators in these ribbons (mostly medium- to thick-trough cross-bed sets) and sandbody orientations indicate an original flow toward the east-southeast (vector mean of 120°). The sinuosities of the sandstone bodies are low (mean 1.03) and their geometry is in a "broken stick" pattern with long straight reaches and short sharp bends. Sandbody widths and thicknesses are relatively small in straight reaches, but at bends the sandbodies are thicker and wider and contain well-developed lateral accretion sets. Fossil bones typically accumulate near the bases of these bends. Thin sandstone sheets representing overbank splay deposits are rare and are limited to near their source channels. The mudstone-dominated intervals outcrop as benches and slopes in the badland exposures.

The Eocene streams which deposited the lower Bridger B channel sandstones in this area were perennial and flooded every year. This is indicated by the abundance of freshwater turtles, gar-pike scales (and other fish bones), and a large freshwater snail fauna in the overbank deposits. The channel-belt deposits also contain the shells of numerous freshwater mussels (unionid clams), which indicate perennial, well-oxygenated waters in streams and rivers. Fossil plants of this time (MacGinitie and Leopold, 1972) indicate subtropical temperatures and mesic moisture with seasonal precipitation.

There are four regionally widespread marker beds in the Bridger exposures in this area. Two widespread thin limestone sheets occur at the base and top of the section in the Church Butte area. The lower limestone is the Lyman limestone at the base of the Bridger B (along the Blacks Fork), and in this area it is a brown to gray ostracodal limestone with scattered catfish bones. The upper limestone occurs on the flat-surface on top of the rim, just south of the county road. This upper limestone is a brown micrite with brown to black banded chert masses and scattered large planorbid snail shells (*Biomphalaria* sp.). Both limestone beds can be mapped over much of the Bridger basin in lower Bridger B exposures. The predominantly fluvial sequence preserved in the Church Butte area was bracketed by these widespread lacustrine deposits.

Two lithified volcanic ashes (tuffs) occur in the section. The lower tuff is represented by a red clayey mudstone that ranges from 0.2 to 0.6 meters (0.6 to 2 feet) thick, 33 meters (108 feet) above the Lyman limestone. The bed does not contain euhedral crystals in this area, but in other parts of the Bridger basin this bed thickens and is white with euhedral biotite crystals. This bed has not been radiometrically dated. This red tuff has been mapped over much of the western Bridger basin. A second tuff bed occurs between 10.1 and 11.7 meters (33 and 39 feet) below the upper limestone and ranges in thickness from 0.5 to 0.7 meters (1.6 and 2.3 feet) thick. It is a tan to olive clayey mudstone bed that weathers gray and contains abundant euhedral crystals of biotite and hornblende. Sanidine in this tuff has produced a 40Ar/39Ar age of 48.27 Ma (Murphey et al., 1999, given as 47.96±0.13 Ma) recalculated using the current 28.201 Ma sanidine standard for the Fish Canyon Tuff (Renne et al., 1998). This upper tuff is called the Church Butte tuff, with the type locality located at the north side of the point on the east end of the long ridge called Jackson Ridge (UTM coordinates of Zone 12T, 572123mE, 4592105mN, WGS 84). The Church Butte tuff occurs throughout the Bridger basin wherever lower Bridger B rocks are exposed.

Many of the first fossils collected from the Bridger Formation came from the Church Butte area. The first geologist known to have collected fossils from the area was Ferdinand V. Hayden. In 1868 he collected fragments of a fossil turtle that were later described as *Trionyx guttatus* by Leidy (1869). Hayden returned to the area as part of the Geological and Geographical Survey of the Territories of 1870. The survey camped just to the west of the area along the Blacks Fork River and collected fossils in the Church Butte area on September 10 and 11 of 1870 (Hayden,

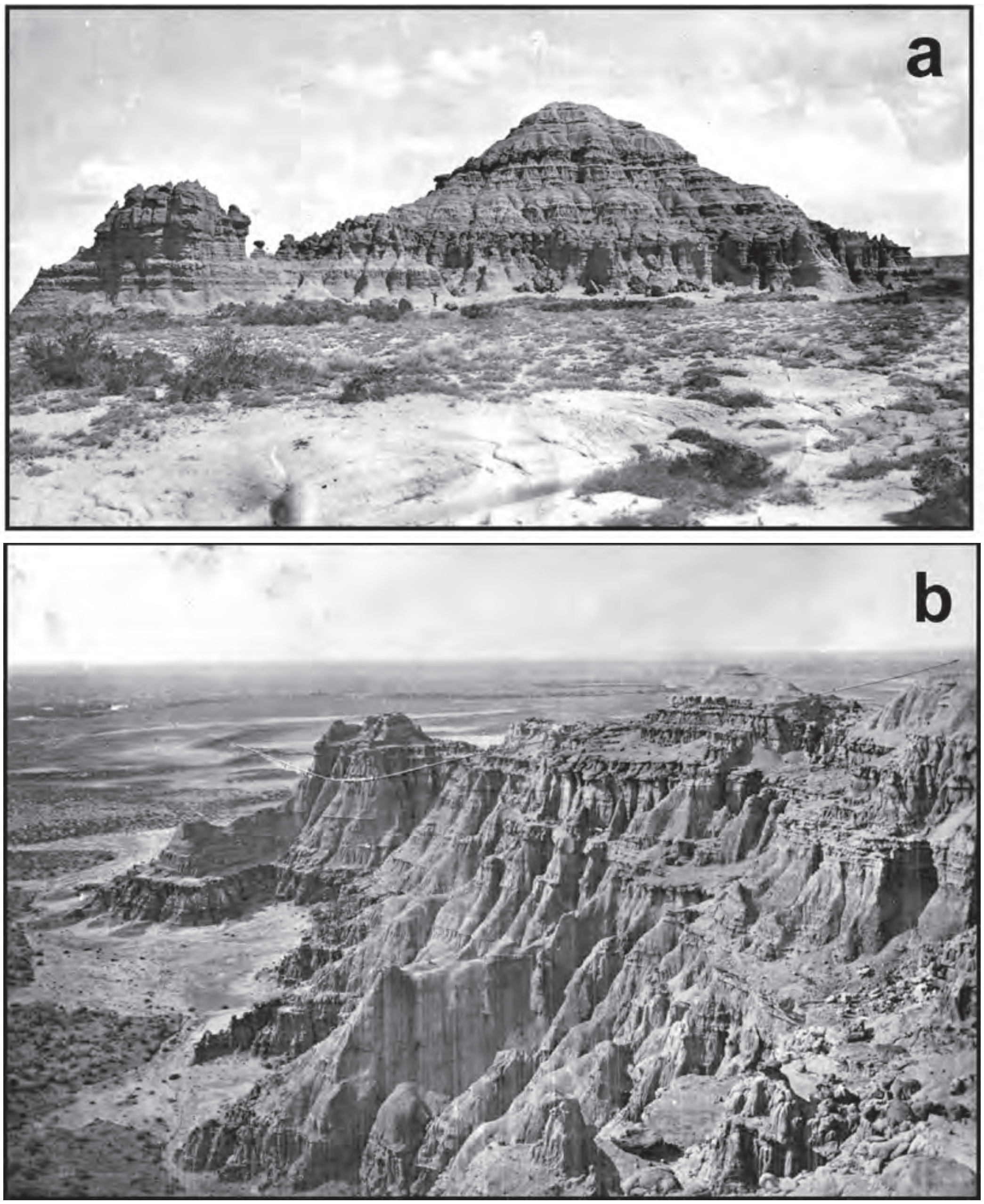

FIGURE 6. **A**, William H. Jackson photo of Church Butte taken on September 10 or 11, 1870. The view is to the east northeast. The UTM location of the photo site is Zone 12T, 571955mE, 4595101mN, WGS84 datum (USGS photo jwh00462);**B**, William H. Jackson photo of the west end of Jackson Ridge, taken mid-day either on September 10 or 11, 1870. The view is toward the northwest, and includes the Hayden Survey campsite along the Blacks Fork River. Notice the crack that was in the original glass-plate negative. The UTM location of the photo site is Zone 12T, 571318mE, 4592360mN, WGS84 datum (USGS photo jwh00309).

1872, p. 41). The 1870 survey was the first time the pioneer photographer W.H. Jackson accompanied Hayden. Years later, Jackson recalled these two days:

> "Twelve miles farther on we came to Church Buttes, a remarkable formation in the Bad Lands and a famous landmark along the old trail. While Gifford [an artist of the 1870 expedition who assisted Jackson] and I were making pictures of the interesting scenes, the geologists under the lead of Dr. Hayden were digging for fossils. They collected a wagon load of ancient turtles, shell fish, and other creatures... For my part, I made seventeen negatives during the day, something of a record for wet plate work, considering the many changes of location I had to make in getting the different views" (Jackson and Driggs, 1929, p. 89,91).

The best known of Jackson's photos from the area (Fig. 6b) was taken near the end of a long badlands ridge that is herein named Jackson Ridge in honor of the photographer. The upper limestone bed marker in the area is named the Jackson Ridge limestone.

Jackson's photos of the area document the type area of such fossil mammals as *Notharctus tenebrosus*, *Palaeosyops paludosus, Hyrachyus agrestis*, and *Microsus cuspidatus*, all described by Leidy (1870, 1872b) and illustrated in 1873. The mollusk type specimens collected at Church Butte by the Hayden survey include *Physa bridgerensis, "Viviparus" wyomingensis* (a land snail that is similar in form to the aquatic *Viviparus*), and *"Unio" leanus* described by Meek (1870, 1871, 1872). Seven other species of fossil mammals have their type area in or near the Church Butte area, and these were collected by such paleontologists as E.D. Cope, O.C. Marsh, and J. Wortman. Type species of fossil mammals collected from the Church Butte area are listed in Table 1.

TABLE 1. Type Species of Fossils from the Church Butte - Blacks Fork area. Data compiled from Leidy, 1872a; Meek, 1872; Henderson, 1935; and Gazin, 1976

MAMMALS		
	Marsupialia	
		Peratherium innominatus (Simpson) 1928
	Pantolesta	
		Pantolestes longicaudus Cope 1872
	Primates	
		Notharctus tenebrosus Leidy 1870
	Tillodontia	
		Tillodon fodiens (Marsh) 1875
	Rodentia	
		Microparamys minutus (R.W. Wilson) 1937
		Sciuravus bridgeri R.W. Wilson 1937
	Carnivora	
		Miacis parvivorus Cope 1872
	Hyaenodontida	
		Sinopa major Wortman, 1902
	Condylarthra	
		Hyopsodus paulus Leidy 1872
	Perissodactyla	
		Orohippus major Marsh 1874
		Palaeosyops paludosus Leidy 1870
	Cetartiodactyla	
		Microsus cuspidatus Leidy 1870
TURTLE		
	Trionychidae	
		"Aspideretes" guttatus Leidy 1869
MOLLUSKS		
	Bivalvia, Unionidae	
		"Unio" leanus Meek 1870
	Gastropoda, Pulmonata	
		Physa bridgerensis Meek 1872
		"Viviparus" wyominensis Meek 1871

Drive back onto CR 233, and turn left (southwest) towards Lyman. Turn left at mile 5.5 onto CR 237 which then crosses the Blacks Fork River, winding south to I-80. Turn westbound (towards Evanston) onto I-80 at mile 7.4. Pass the Lyman exit and drive to the Mountain View-Fort Bridger (Exit 39, 15.5 miles from Stop 3). Turn south onto Wyoming State Highway (SH) 414, crossing the Blacks Fork River and climbing up onto the Lyman limestone at the top of the hill. Continue through Urie and Mountain View, where the highway will bend to the east near the center of town. Refer to Figure 7 for a map that shows the major geographic features of the remainder of the field trip route. As you drive east from the center of Mountain View along Highway 414, the badlands to the south that are visible beginning at SH 414 milepost 105 were known to the early residents and explorers as "Grizzly Buttes" (lower and middle Bridger B). The north end of the badlands to the northeast constitute the type area of the Blacks Fork Member. Continue southeast on Highway 414 and the highway rises onto the Cottonwood Bench. Immediately after reaching the top of this bench, at 29.7 miles from Stop 3, turn east and then immediately north. At 0.2 miles from the turn off, do not turn east on Burnt Fork Road (BLM 4315) and instead continue traveling north. At mile 30.4 mile from Stop 3, turn west onto the two track road and follow it for 0.6 miles to the Grizzly Buttes overlook.

STOP 4

Grizzly Buttes
(31.0 miles from Stop 3, cumulative 88.5 miles)

Heading southeast from Mountain View, Wyoming State Highway 414 rises through a panel of badland exposures and climbs onto a high flat, called the Cottonwood Bench. The bench is capped by gravels derived from the Bishop Conglomerate and transported to the area by Cottonwood and Sage Creeks. Below the gravel-flat is a series of badlands cut by Leavitt Creek, Little Dry Creek and their tributaries. The badland hills directly west of the overlook comprise the traditional "Grizzly Buttes" of the early explorers, but the name is not known to the modern popu-

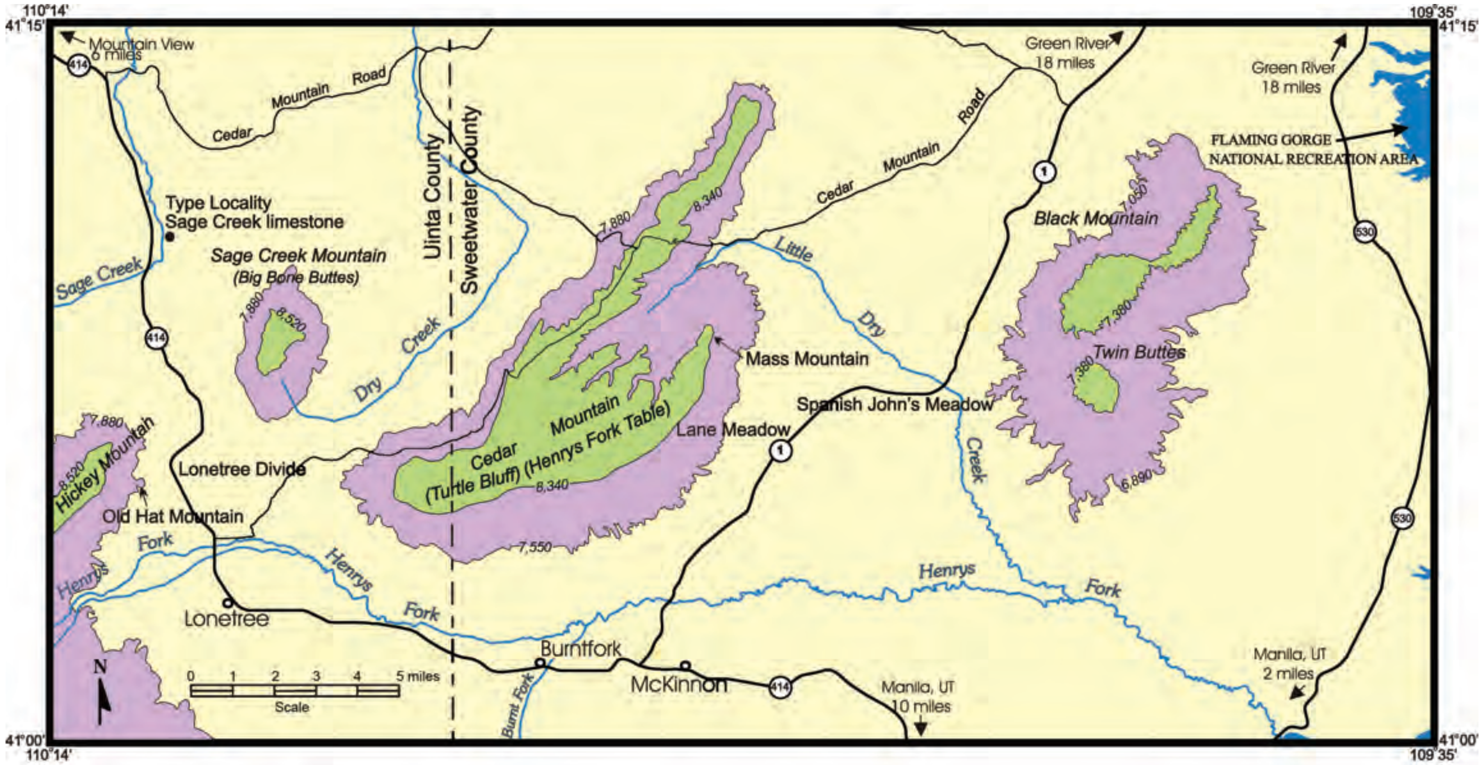

FIGURE 7. Map of a part of the southern Green River basin encompassing most of the area of outcrop of the upper Bridger Formation. Map shows both modern and historic geographic terminology (from Murphey and Evanoff, 2007).

TABLE 2. Type Species of Fossil Mammals from Grizzly Buttes. Data compiled from Gazin, 1976.

Lipotyphla
- *Entomolestes grangeri* Matthew 1909
- *Nyctitherium serotinum* (Marsh) 1872
- *Nyctitherium dasypelix* (Matthew) 1909

Plesiadapiformes
- *Mycrosyops elegans* (Marsh) 1871

Primates
- *Smilodectes gracilis* (Marsh) 1871

Tillodontia
- *Trogosus castoridens* Leidy 1871

Pholidota
- *Metacheiromys marshi* Wortman 1903
- *Metacheiromys tatusia* Osborn 1904
- *Metacheiromys dasypus* Osborn 1904

Rodentia
- *Thisbemys plicatus* A.E. Wood 1962
- *Leptotomus parvus* A.E. Wood 1959
- *Reithroparamys delicatissimus* (Leidy) 1871
- *Pseudotomus robustus* (Marsh) 1872
- *Ischyrotomus horribilis* A.E. Wood 1962
- *Mysops minimus* Leidy 1871
- *Mysops parvus* (Marsh) 1872
- *Sciuravus nitidus* Marsh 1871
- *Tillomys? parvidens* (Marsh) 1872

Hyaenodontida
- *Sinopa rapax* Leidy 1871
- *Sinopa minor* Wortman 1902
- *Tritemnodon agilis* (Marsh) 1872
- *Limnocyon verus* Marsh 1872

Carnivora
- *Thinocyon velox* Marsh 1872
- *Viverravus gracilis* Marsh 1872
- *Oödectes proximus* Mattehw 1909
- *Vulpavus profectus* Matthew 1909

Perissodactyla
- *Palaeosyops major* Leidy 1871
- *Limnohyops priscus* Osborn 1908
- *Helaletes nanus* (Marsh) 1871

Cetartiodactyla
- *Helohyus plicodon* Marsh 1872

lation of the Smith's Fork valley (see history of paleontological investigations). Matthew (1909, p.297) stated about the buttes: "This is the richest collecting ground in the basin; thousands of specimens have been taken from it, and many skulls and skeletons more or less complete." Type species of fossil mammals collected from the Grizzly Buttes area are listed in Table 2.

The lower half of the Bridger B is exposed in the Grizzly Buttes and along the Cottonwood Bench escarpment. Not far below the Quaternary gravels at this overlook is a widespread limestone that was named by Matthew (1909) the Cottonwood white layer (now known as the Cottonwood limestone). It is a white micritic limestone that is very widespread but is locally absent in the Church Butte area. The Cottonwood limestone is typically 5 meters (16 feet) above the Church Butte tuff, but in this area it is 10.4 meters (34 feet) above the tuff. The thickness of intervals between the widespread marker beds increases from the Church Butte area toward the southwest. The Jackson Ridge limestone has been eroded by Cottonwood Creek on the bench, but in this area it is typically 6 meters (20 feet) above the Cottonwood White Layer. The Church Butte tuff is a prominent gray band about half way down the escarpment. Notice that channel sandstones are not as abundant in the lower Bridger B rocks below you as they are in the Church Butte area.

To the east is a prominent escarpment rising far above the Cottonwood Bench. This escarpment is capped by the Sage Creek White Layer, the boundary between the Blacks Fork and Twin Buttes members of the Bridger Formation (the boundary between Matthew's Bridger B and C). Almost all the upper half of the Bridger B is exposed in the west face of the escarpment.

Return to Wyoming State Highway 414 and travel north for 5.7 miles. Then turn east and drive for 0.2 miles and park on the north side of the road. A short walk to the northeast will lead you to Sage Creek Limestone and the type locality of the Sage Creek white layer.

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SAGE CREEK SPRING.
Detail of one of the white layers.

FIGURE 8. Photograph of the Sage Creek white layer taken by W.H. Sinclair in 1906 (Sinclair, 1906, Plate 38). Note the unit numbers penned in near the left edge of the photo.

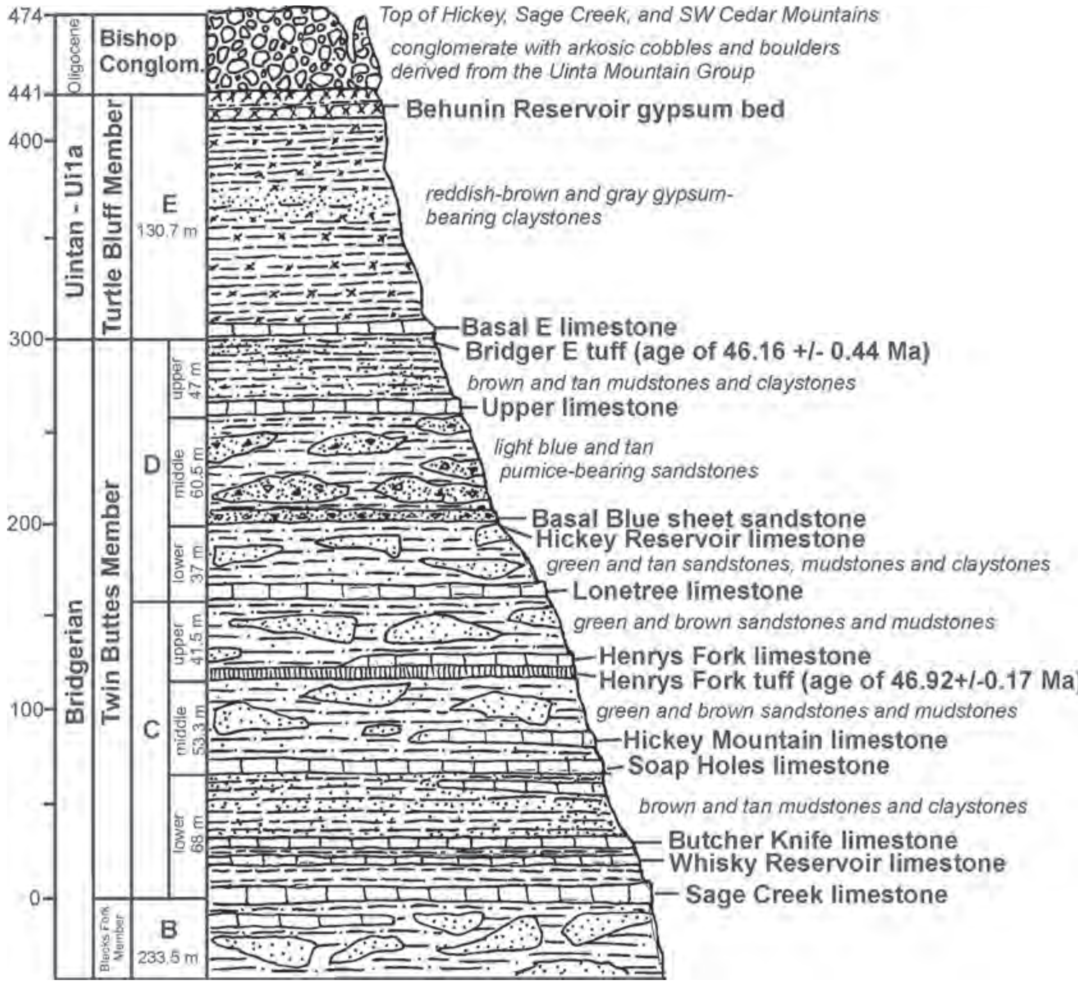

FIGURE 9. Generalized stratigraphic section of the upper Bridger Formation in the Sage Creek Mountain area, Uinta County, Wyoming. The diagram shows widespread and more localized markers, as well as informal submembers of Matthew (1909). Thicknesses taken from the reference section of the Twin Buttes Member and the type section of the Turtle Bluff Member (from Murphey and Evanoff, 2007).

STOP 5

Sage Creek white layer type locality
(5.9 miles from Stop 4, cumulative 94.4 miles)

This outcrop of the Sage Creek white layer is located next to site of the old Sage Creek stage station and Sage Creek Spring along the old Lonetree stage road. It was first described and photographed by Sinclair in 1906 (Fig. 8), and then named and mapped by Matthew (1909). The Sage Creek white layer is the base of Matthew's Bridger C, the base of the Twin Buttes Member, and the base of the upper Bridger Formation as presently defined. Since Matthew's (1909) work, this unit has been renamed the Sage Creek limestone, and is the base of the lower Bridger C of Evanoff et al. (1998), Murphey (2001), and Murphey and Evanoff (2007). The general stratigraphy of the upper Bridger Formation in the Sage Creek Mountain area is illustrated in Figure 9.

At its type locality, the Sage Creek limestone is 4.1 meters (13.5 feet) thick. It consists of a lower massive tan micritic limestone, a middle shaly limestone with dark gray to black chert bands, and an upper platy to shaly limestone. Elsewhere, it includes massive to blocky marly and micritic limestone, ledgy marlstone, and platy calcareous shale, and is locally interbedded with green to brown mudstone and claystone and thin carbonaceous shale. Fossils of this unit consist of scattered gastropods, bone fragments (mostly fish), and turtle shell fragments, and the limestone within it is locally stromatolitic. The Sage Creek limestone supports a very widespread bench, and it is the thickest and most widespread lacustrine deposit in the upper Bridger Formation.

Stratigraphically overlying the Sage Creek limestone within the lower Bridger C are two other limestone beds that are much thinner but are also widespread, the Whisky Reservoir limestone and the Butcher Knife limestone (see Fig. 9). The lower Bridger C is the least fossiliferous subunit of the upper Bridger Formation (Twin Buttes and Turtle Bluff members), despite the fact that it is by far the most geographically widespread.

Continue south along Highway 414 for 3.2 miles. Travelling south, the highway route travels up section through the lower Bridger C and into the middle Bridger C. Sage Creek Mountain is the highest point on the west side of the highway and Hickey Mountain is the highest point on the east side of the highway. Both of these mountains are capped by the Oligocene Bishop Conglomerate. At 3.2 miles from Stop 5, pull into the Henry #1 gas well pad on the east side of the road.

STOP 6

Soap Holes and Hickey Mountain and limestones (3.2 miles from Stop 5, cumulative 97.6 miles)

The Soap Holes limestone, the lower of the two thin rusty brown limestone beds visible at this cliffy exposure, is a widespread marker unit that forms the base of the middle Bridger C (Evanoff et al., 1998; Murphey, 2001; Murphey and Evanoff, 2007). It is believed that Matthew (1909) considered this bed to be equivalent to his Burnt Fork limestone, which is a lithologically similar unit that is exposed to the southeast in the Henrys Fork Valley but is actually not present in the section in this part of the basin. In the Henrys Fork Valley, however, it is in fact is 33 meters (108 feet) higher than the Soap Holes limestone. The Soap Holes limestone contains few fossils, but it is noteworthy that it is stratigraphically closely associated with fossil logs at several localities. Fossils of the Soap Holes limestone include isolated, disarticulated and poorly preserved bones of fish, reptiles (especially turtles), and mammals within and on top of the unit. In the Black Mountain area it is locally underlain by thin carbonaceous shale beds which preserve plant fragments. The Sage Creek and Soap Holes limestones have yielded the fewest vertebrate fossils of any upper Bridger lacustrine deposits.

Situated within the middle Bridger C 10.5 meters (34 feet) above the base of the Soap Holes limestone (in the upper Bridger Formation reference section, Murphey and Evanoff, 2007), the Hickey Mountain limestone is a well studied and very important unit paleontologically. It has a relatively limited areal distribution, occurring over a distance of approximately 5.6 miles north of Hickey Mountain and west of Sage Creek Mountain, and is the upper limestone bed exposed on the cliff at this stop. This unit provides an excellent example of one of the most paleontologically prolific depositional settings in the upper Bridger Formation.

The early fossil collectors were the first to notice the close association between vertebrate fossils and the “white layers,” which are typically limestone and marlstone beds that were deposited in shallow lakes and ponds. More recently, paleontologists observed that it is not the marlstone beds that contain the majority of vertebrate fossils, but the immediately overlying and underlying mudstone beds. These mudstones, which are occasionally carbonaceous, are inferred to have been deposited along lake margins during lake transgressions and regressions (Murphey, 1995; Murphey et al., 2001). Typically, the limestone and marlstone beds contain the remains of mostly aquatic organisms such as snails, clams, fish, amphibians, pond turtles, and crocodilians. The lake margin mudstones contain a mixed aquatic and terrestrial assemblage, and the terrestrial elements include locally abundant reptiles such as lizards, as well as bird bones and mammal bones and teeth. One particularly prolific fossil locality, the *Omomys* Quarry, is located approximately ½ mile west of this stop in the Hickey Mountain limestone and overlying mudstone. This unusual fossil accumulation has produced over 2,300 specimens of vertebrates, gastropods, and plants from an 8–10 centimeter thick deposit in a 4 square meter area (Murphey et al., 2001). What makes the assemblage so unusual is that it contains a high concentration of dental and post-cranial remains of the primate *Omomys*, avian skeletal remains, and eggshell fragments. The unusual components of the fauna are superimposed on a more typical Bridger fauna that occurs at the quarry and lateral to it in the same stratigraphic interval. Four taphonomic agents have been postulated for the formation of the *Omomys* Quarry fossil accumulation: 1) an attritional accumulation of aquatic taxa in lacustrine sediments; 2) an attritional accumulation of both aquatic and terrestrial taxa in shoreline sediments;

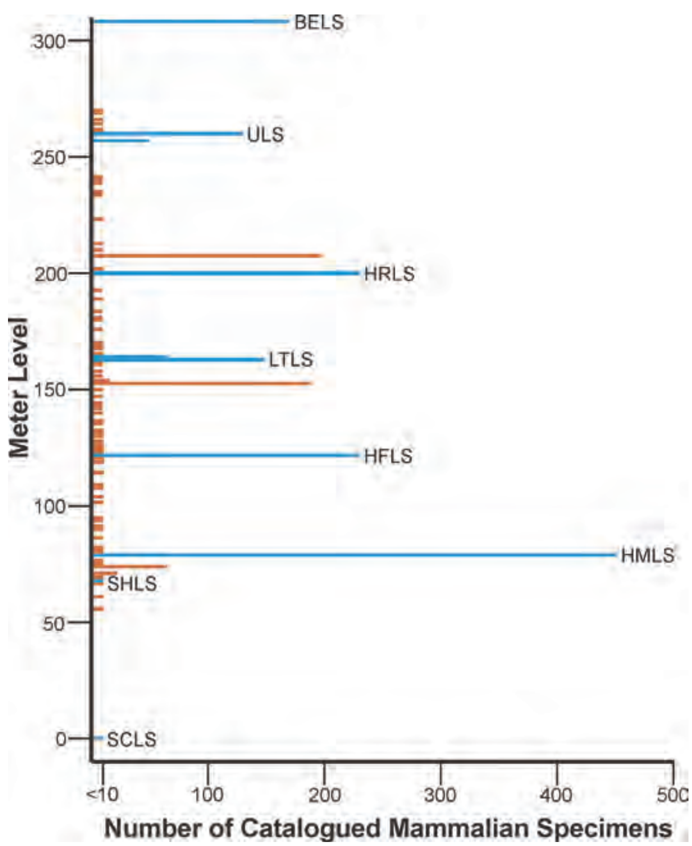

FIGURE 10. Stratigraphic distribution of catalogued mammalian specimens from the upper Bridger Formation (University of Colorado Museum collections) (SCLS, Sage Creek limestone; SHLS, Soap Holes limestone; HMLS, Hickey Mountain limestone; HFLS, Henrys Fork limestone; LTLS, Lonetree limestone; HRLS, Hickey Reservoir limestone; ULS = Upper White limestone; BELS, Basal Bridger E limestone).

TABLE 3. Fauna and flora of the Omomys Quarry with number of identifiable specimens for vertebrates shown in right column. Eggshell is not included. From Murphey et al., 2001

TAXA	NISP
PLANTAE	
Division Chlorophyta	
Chara sp.	
Division Tracheophyta	
Dennstaedtiopsis aerenchymata (fern)	
2 types of dicotyledenous wood	
ANIMALIA	
Phylum Mollusca	
Class Gastropoda	
Order Lymnophila (freshwater pulmonates)	
Biomphalaria sp.	
Omalodiscus sp.	
Stagnicola? spp.	
Physa spp.	
Order Geophilia (land pulmonates)	
Gastrocopta spp.	
Oreoconus? sp.	
Phylum Chordata	
Coprolites	4
Class Osteichthyes	
Osteichthyes undet.	200
Order Amiiformes	
Amia sp.	8
Order Lepisosteiformes	
Lepisosteus sp.	98
Order Siluriformes	14
Class Amphibia	
Amphibia undet.	4
Order Anura	
Anura undet.	4
Class Reptilia	
Order Chelonia	
Chelonia undet.	5
Trionychidae undet.	1
Echmatemys sp.	1
Palaeotheca sp.	2
Order Squamata	
Lacertilia undet.	117
Iguanidae undet.	3
Tinosaurus sp.	1
Saniwa sp.	1
Serpentes undet.	2
Order Crocodilia	
Allognathosuchus sp.	34
Crocodilia undet.	4
Class Aves	
Order Ciconiiformes	
Juncitarsus gracillimus	4
ANIMALIA, Chordata, Aves	
Order Falconiformes	
Accipitridae (2 species)	7
Order Charadriiformes	
Burhinidae	5
Order Gruiformes	
Rallidae	5
Geranoididae	8
Total Aves	
includes undet. specimens not listed above	(191)
Class Mammalia	
Mammalia undet.	150
Order Marsupialia	
Peratherium sp.	13
Peradectes sp.	1
Order Rodentia	
Rodentia undet.	13
Paramys sp.	1
Thisbemys sp.	1
Microparamys sp.	1
Ischyromyidae undet.	1
Sciuravus sp.	9
Pauromys sp.	2
Sciuravidae undet.	6
Order Apatemyida	
Apatemys sp.	1
Order Lipotyphla	
Lipotyphlan undet.	28
Scenopagus sp.	2
Entomolestes sp.	7
Centetodon sp.	6
Apternodontidae undet.	1
Nyctitherium sp.	4
Order Plesiadapiformes	
Uintasorex sp.	1
Order Primates	
Notharctus sp.	2
Omomys sp. nov.	214
Order Condylarthra	
Hyopsodus sp.	22
Order Cetartiodactyla	
Cetartiodactyla undet.	1
Homacodon sp.	1
Order Perissodactyla	
Hyrachyus sp.	1
TOTAL	**1,183**

3) an attritional accumulation consisting primarily of bird bones and eggshell formed in close proximity to a nesting area; and 4) a predator accumulation dominated by *Omomys* but probably including other vertebrates formed by owls in close proximity to a nest, day roost or night feeding station. The fauna and flora of the Omomys Quarry is listed in Table 3.

The same pattern of fossil distribution observed in the Hickey Mountain limestone occurs throughout the upper Bridger Formation (see Fig. 10). Most fossils are found in association with lacustrine deposits, although stream channels are also productive. Least productive are the volcaniclastic mudstone and claystone beds that were deposited on low relief floodplains; together with stream channel deposits, they comprise 95% of the total thickness of the upper Bridger. Examples of the floodplain deposits, here consisting of green and gray mudstone and claystone beds, are well exposed at this stop above and below the Soap Holes and Hickey Mountain limestones. Both the Soap Holes and Hickey Mountain limestones are better exposed, with some minor faulting, on the east side of the highway just to the north of this location.

Continue south on Highway 414 for 1.1 miles and turn east onto the gas well road. Follow this road to the east and it will bend to the north for a total distance of 1.6 miles from Stop 6. Park on the north side of the Henry #10 well pad. The Henrys Fork limestone (type locality of this unit) and the underlying Henrys Fork tuff are exposed above the well pad on the badland hill just to your north. Look for the gray weathered bed near the top of the badland slope and an overlying thin light gray marlstone. Bring a shovel to examine the tuff.

STOP 7

Type locality of the Henrys Fork Limestone
(1.6 miles from Stop 6, cumulative 99.2 miles)

The Henrys Fork limestone (and associated shore margin deposits) is another highly fossiliferous unit and has produced hundreds of fossil mollusks and vertebrates across its distribution. It is quite widespread, covering an area of approximately 402 kilometers^2 (250 miles^2), and was deposited in an elongate east-west trending basin which formed in the downwarp along the Uinta Mountain front. At this location, which is near the western edge of ancient Henrys Fork Lake, the deposit is only 3 centimeters (1.2 inches) thick, but it attains a maximum thickness of 1.65 meters (5.4 feet) on the south side of Cedar Mountain near the center of its depositional basin. It is of taphonomic interest that the upper Bridger Formation with its abundant vertebrate fossils preserved in lacustrine and associated shore margin deposits contains few articulated skeletons or even partially articulated vertebrate remains, most of which have been collected in the Bridger B (see Alexander and Burger, 2001).

Immediately underlying the Henrys Fork limestone is the Henrys Fork tuff, a unit that was first discovered by Emmett Evanoff while conducting field work in the Sage Creek Mountain area in 1991. This ash fall tuff is the most analyzed tuff in the Bridger Formation, and it is beyond the scope of this paper to report the various ages that have been published. However, Murphey et al. (1999) and Murphey and Evanoff (2007) reported a 40Ar/39Ar age of 46.92±0.17 Ma based on single crystal laser fusion analysis of sanidine, plagioclase, and biotite. Recalculated using the current 28.201 Ma sanidine standard for the Fish Canyon Tuff (Renne et al., 1998), the age of the Henrys Fork tuff is 47.22 Ma. Ash fall tuff deposits comprise less than 1% of the total thickness of the upper Bridger Formation, and based on their mineralogy, are believed not to have originated in the Absaroka volcanic field to the north like other volcaniclastic Bridger Formation sediments, but rather in the Challis volcanic field located in central Idaho. At its type locality on the south side of Cedar Mountain, the tuff is 0.95 meters (3.1 feet) thick (Murphey and Evanoff, 2007). The tuff is a blocky, non-calcareous, gray to white biotitic claystone with a distinct bottom contact and a diffuse top contact. It contains biotite, zircon, allanite, and apatite crystals. Plagioclase is the most abundant feldspar. It typically consists of a structureless lower unweathered portion with coarse euhedral biotite (up to 1.3 mm in diameter) which grades upward into a reworked portion with less coarse and less abundant biotite.

The base of the Henrys Fork tuff forms the base of the upper Bridger C, and is 121 meters (397 feet) above the base of the Sage Creek limestone in upper Bridger Formation reference section (Murphey and Evanoff, 2007). Weathered badland exposures of the Henrys Fork tuff form a distinctive dark gray weathering bed that is readily discernable from other Bridger lithologies, especially when wet.

Return to Highway 414 and drive south for 3.0 miles (note the exposures of Henrys Fork tuff which is visible as a subtle gray bed on both sides of the highway just above road level after turning back onto the highway). Then turn west onto the access road for Conoco Fed # 20-2 gas well pad. Proceed to the well pad and park (3.2 miles from Stop 7). The route you just drove continued up section through the upper Bridger C to the level of the Lonetree limestone (base of lower Bridger D) which is at the approximate level of the highway at the Lonetree Divide. This is the stratigraphically highest point that Highway 414 attains in the Bridger Formation.

STOP 8

The Lonetree Divide
(3.2 miles from Stop 7, cumulative 102.4 miles)

This area provides some excellent vistas of the upper Bridger Formation and its marker units, especially from the top of the ridge just to your north. The base of the lower Bridger D, the Lonetree limestone (Lonetree white layer of Matthew, 1909), is well exposed at the base of the badland slopes at road level. The base of the middle Bridger D, the Basal blue sheet sandstone, is exposed on the slopes of the prominent conical butte to your west as well as on parts of the ridges to your north and south. The prominent butte, called “Old Hat Mountain” by the locals,

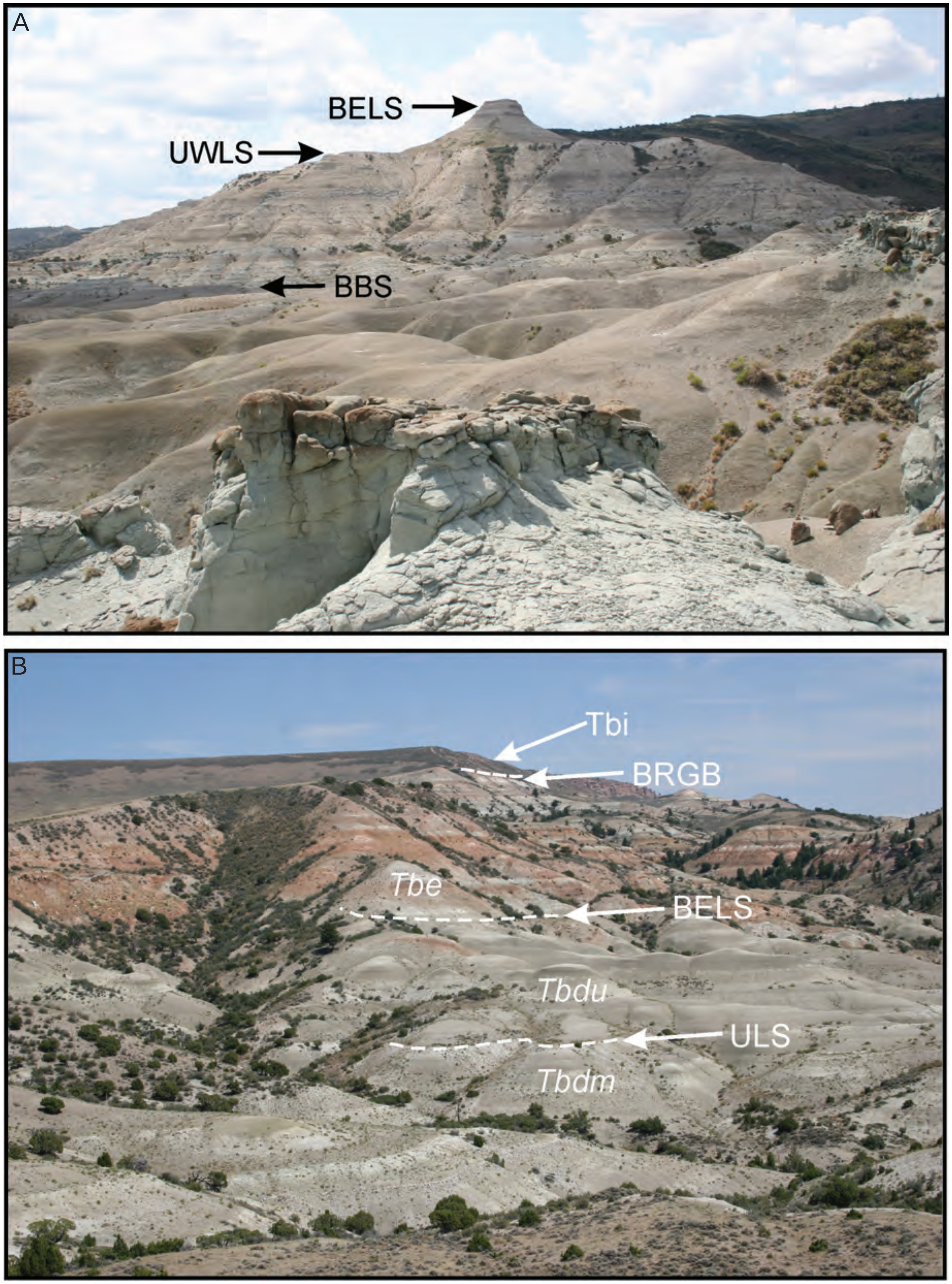

FIGURE 11. **A**, View of the Bridger D and E on “Old Hat Mountain,” a prominent butte on the southeast flank of Hickey Mountain, Uinta County, Wyoming. Photo taken looking southwest (BBS, Basal blue sheet sandstone; ULS, Upper White limestone; BELS, Basal Bridger E limestone); **B**, View of the Bridger D and Bridger E on the southwest flank of Cedar Mountain, Uinta County, Wyoming. Photo taken looking east (ULS, Upper White limestone; BELS, Basal Bridger E limestone; BRGB, Behunin Reservoir Gypsum bed; Tbdm, middle Bridger D; Tbdu, upper Bridger D, Tbe, Bridger E; Tbi, Bishop Conglomerate.

is an erosional remnant of Hickey Mountain (Fig. 11a) to which it is still attached. The 'rim of the hat' is the Upper White limestone (Upper white layer of Matthew, 1909). The butte is capped by a thin interval of red mudstone of the Turtle Bluff Member (Bridger E of Matthew, 1909). To your northeast is Sage Creek Mountain, with a thick sequence of Bridger E (red beds overlying gray beds of Bridger D) visible near its summit. The Basal Bridger E tuff (40Ar/39Ar age of 46.16±0.44 Ma, Murphey and Evanoff, 2007) occurs just below the base of the Bridger E on Sage Creek Mountain. O.C. Marsh called Sage Creek Mountain "Big Bone Butte" because of the abundance of uintathere bones found in the area. Visible to your east is Cedar Mountain, with the thickest and best exposed sequence of Turtle Bluff Member. All three of the mountains in this area (Hickey, Sage Creek, and Cedar) are capped by Oligocene Bishop Conglomerate.

Numerous fossil localities have been documented in the Lonetree Divide area. These include the classic Lonetree localities of Matthew (AMNH expeditions of 1903–1906) and Gazin (USNM expeditions between 1941 and 1969. This area was also worked by Robert M. West of the Milwaukee Public Museum during the 1970's, and by crews from the University of Colorado Museum during the 1990's. Channel sandstones in this area indicate paleocurrent directions to the southeast.

Turn south on Highway 414 for 1.9 miles and turn east onto Cedar Mountain Rim road (BLM Road # 4314). At 2.8 miles from Stop 8, the road bends to the north and travels stratigraphically through the upper Bridger C, crossing the Lonetree limestone, and continuing up through the lower and middle Bridger D. At the junction of Cedar Mountain Rim Road and Sage Creek Mountain Road (5.2 miles from Stop 8), turn south onto a two track road. Drive south on the two track, keeping straight at miles 6.2 and 6.3 where other tracks diverge, until you reach the Turtle Bluff Member overlook (6.4 miles from Stop 8). Note that if the ground is wet, it is not advisable to leave the paved highway (SH 414).

STOP 9

The Turtle Bluff Member on Cedar Mountain
(6.4 miles from Stop 8, cumulative 108.8 miles)

Looking east from this location affords an excellent view of the upper Bridger D, the highest sub-unit in the Twin Buttes Member, overlain by the Turtle Bluff Member of the Bridger Formation (Matthew's Bridger E). The contact between the two members is shown on Figure 11b, and is defined on the basis of a limestone that occurs at the approximate level of the lowest red bed (note that some of the strata you see are slumped). The limestone that supports the bench that you are standing on is the Upper White limestone.

TABLE 4. Taxonomic Summary of the Turtle Bluff Member, Bridger Formation (Biochron Ui1a). LRD – lowest range datum; HRD = highest range datum.

DESIGNATION	NUMBER	TAXA
Index Species	2	*Hemiacodon engardae*, Oromerycidae gen. and sp. nov.
Genus LRD	6	*Epihippus*, *Pareumys*, Oromerycidae gen. & sp. nov., Sespedectinae indet., *Metanoiamys*, *Triplopus*
Genus HRD	7	*Entomolestes, Paramys, Hemiacodon, Taxymys*, Oromerycidae gen. & sp.nov., *Uintasorex, Mysops*
Species LRD	3	*Epihippus gracilis, Triplopus cubitalis, Metanoiamys* sp.
Species HRD	8	*Entomolestes grangeri, Sciuravus nitidus, Paramys delicatior, Taxymys lucaris, Pauromys perditus, Thisbemys corrugatus, Pontifactor bestiola, Uintasorex parvulus*
Range-Through	36	*Apatemys* sp., *Nyctitherium* sp., *Antiacodon* sp., *Omomys carteri, Brontotheriidae* spp., *Orohippus sylvaticus, Centetodon bembicophagus, Pantolestes longicaudus,* Chiroptera indet., *Pantolestes natans, Copedelphys innominatum, Pantolestes* sp., *Dilophodon minusculus, Pauromys* sp., *Harpagolestes* sp., *Peradectes chesteri, Helohyus* sp., *Scenopagus priscus, Herpetotherium knighti, Thisbemys corrugatus, Herpetotherium marsupium, Tillomys senex, Hyopsodus* sp., *Trogolemur* sp., *Hyrachyus eximius, Uintacyon vorax, Isectolophus* sp., *Uintaparamys bridgerensis, Mesonyx obtusidens, Uintaparamys caryophilus, Microparamys minutus, Uintatherium anceps, Microsyops annectens, Viverravus minutus, Notharctus robustior, Washakius* sp.

Consisting primarily of banded red, gray, and tan beds of gypsiferous claystone and mudstone, rocks of the Turtle Bluff Member are the least volcaniclastic in the Bridger Formation. Lithologically, the Turtle Bluff Member is somewhat distinct from the rest of the formation, being similar in appearance to the red and brown sandstone, mudstone, and claystone beds of parts of the Washakie and Uinta Formations of similar age. The Turtle Bluff member occurs only on Hickey Mountain, Sage Creek Mountain, the south end of Black Mountain, and Twin Buttes, but by far the most extensive and thickest exposures occur here on the southwest side of Cedar Mountain. The type section for the Turtle Bluff Member on Cedar Mountain is a 131.5 meter (431 feet) thick sequence of reddish-brown and gray claystone beds with a high gypsum content. This gypsum is both primary and secondary. Secondary gypsum consists of selenite and satin spar crystals which are abundant on the upper slopes of Cedar Mountain. Primary gypsum occurs in thin beds, but the Turtle Bluff Member on Cedar Mountain is capped by a thick and laterally extensive gypsum bed. The mostly fine-grained reddish Turtle Bluff sediments were probably derived from the adjacent Uinta Mountains based on their color, unlike those of the Bridger A–D, which were largely derived from more distal volcanic sources.

The Turtle Bluff Member contains two markers: The Basal Bridger E limestone, which marks the base of the member (base of Matthew's Bridger E), and the Behunin Reservoir Gypsum Bed, which is the youngest and stratigraphically highest well exposed rock unit in the Bridger Formation (note that Behunin is pronounced "Buhannan" by locals). Here on southwest Cedar Mountain, the Turtle Bluff Member contains four additional unnamed limestone bed, and on Twin Buttes there are three. A 2.3 meter (7.5 feet) thick laterally extensive, quartz arenite bed that lies 75 meters (246 feet) above the base of the member on Cedar Mountain is the only sandstone bed. Similar sandstone beds in the Turtle Bluff Member also occur on the northwest flank of Hickey Mountain and the south flank of Sage Creek Mountain, and may be roughly stratigraphically equivalent.

The Behunin Reservoir Gypsum Bed is lithologically unique for the Bridger Formation. Although other gypsum beds occur in the Turtle Bluff Member, they are much thinner. Restricted to just below the southwest rim of Cedar Mountain (below the Bishop Conglomerate), this unit consists of a 7 meter (23 feet) thick sequence of gray and tan unfossiliferous bedded gypsum beds interbedded with gypsiferous mudstones and marlstones. It is visible from a great distance as a prominent white bed high on Cedar Mountain. This bed is interpreted as an evaporitic playa lacustrine deposit, and may indicate changing climatic conditions near the end of Bridger Formation deposition.

Because of its sparse fossils and steep, limited exposures, the biochronologic affinity of the Turtle Bluff Member has been difficult to determine. Matthew was the first worker to comment on the age of the member, saying that its few mammal fossils prove sufficiently that it "belongs to the Bridger Age" (Matthew, 1909, p. 296). Osborn (1929) correlated the Bridger E with the Washakie B and Uinta B, although he cited no evidence to support this correlation. Simpson (1933), Wood et al. (1941), and Gazin (1976) also regarded the Bridger E as Uintan, although this was apparently not based on fossil evidence. Based on eight isolated rodent teeth identified as *Paramys* cf. *P. delicatior*, and "several" bone fragments identified as brontothere, West and Hutchison (1981) concluded that the Bridger E (their Cedar Mountain Member) was Bridgerian. Subsequent work during the 1990's by crews from the University of Colorado Museum (Evanoff et al., 1994; Murphey and Evanoff, 2007) and in the 2000's by crews from the San Diego Natural History Museum (Walsh and Murphey, 2007) have now documented a much more diverse faunal assemblage from multiple stratigraphic levels within the Turtle Bluff Member (Table 4). Donna's locality (UCM Loc. 92189) is located near the base of the member, and is the only locality thus far to produce specimens of the newly described species of omomyid primate *Hemiacodon engardae* (Murphey and Dunn, 2009). Located 105 meters (344 feet) above the base of the member, Roll the Bones (SDSNH Loc. 5844) and Red Lenses (SDSNH Loc. 5844) are the stratigraphically highest localities to yield identifiable fossils in the member. Hundreds of fossils have now been collected from these and other localities mostly via screenwashing of sedimentary matrix. Non-Bridgerian taxa include *Epihippus, Metanoiamys, Pareumys, Triplopus, Sespedectinae indet.*, and *Oromerycidae gen*. and sp. nov. The faunal assemblage of the Turtle Bluff Member is now considered to be earliest Uintan in age (biochron Ui1a of Gunnell et al., 2009), although efforts to obtain additional fossils from this biochronologically important interval member on Cedar Mountain and other locations within the Bridger basin are ongoing.

The Bridger Formation is unconformably overlain by the Bishop Conglomerate, which is visible from this stop capping Cedar Mountain. To the east of this location it forms massive cliffs and spectacular columns. This unit is a very coarse conglomerate composed primarily of arkosic cobbles and boulders derived from the Proterozoic Uinta Mountain Group, with locally common cobbles and boulders of Paleozoic limestone (Bradley, 1964). It is as much as 40 meters (131 feet) thick. The Bishop Conglomerate is unfossiliferous, but currently believed to be Oligocene in age (K/Ar 29.50 ±1.08 Ma, biotite) based on isotopic ages obtained from a tuff that occurs within it on the south side of the Uinta Mountains (Hansen, 1986).

Return to Wyoming State Highway 414, and continue south. The highway crosses the Henrys Fork of the Green River, passes by the hamlet of Lonetree, and bends to the east. There is an excellent view of the Henrys Fork tuff and Henrys Fork limestone on the north side of the highway at SH 414 milepost 128. The Henrys Fork tuff is the prominent gray bed exposed low on the slopes of Cedar Mountain not far above road level, and the Henrys Fork limestone is a prominent white bed immediately overlying the tuff. Continuing east, the highway passes through the hamlet of Burntfork. At highway milepost 130.6 there is a point of historic interest on the south side of the highway. This location is near the site of the first (1825) mountain man fur trading "rendezvous" led by General William Ashley and attended by a then "green" Jim Bridger and Jedediah Smith. At the McKinnon

Junction (16.6 miles from Stop 9), turn north onto Sweetwater County Highway 1. Proceed to 18.8 miles from Stop 9 and pull over on the east shoulder next to the road cut.

STOP 10

The McKinnon Roadcut
(18.8 miles from Stop 9, cumulative 127.6 miles)

This roadcut features the thickest lacustrine sequence in the upper Bridger Formation. The Sage Creek limestone is the thick blocky limestone near the top of the cut. Underlying it are at least 30 meters (98 feet) of lacustrine shale, mudstone, marlstone, and limestone, and the total thickness of the lacustrine sequence is unknown. It has been postulated that this sequence and underlying lacustrine strata of unknown thickness represents a final transgressive phase of Lake Gosiute (Laney Shale Member of Green River Formation) (Brand, 2007), although there is little supporting evidence. Whatever the case, this sequence, combined with evidence provided by other upper Bridger lacustrine deposits (thicknesses and areal distribution), suggests that lacustrine deposition during upper Bridger deposition was most prevalent just to the north of the Uinta Mountain front.

Continue north on Sweetwater County Highway 1. You will be driving through rocks of the lower Bridger C and will descend into upper Bridger B strata at approximate Sweetwater County Highway 1 milepost 16.7 before climbing stratigraphically again lower Bridger C strata at highway milepost 15.8. At mile 11.5 from Stop 10, turn east onto a two track road towards the north end of Black Mountain. Twin Buttes is the conical peak to the south of Black Mountain. Bear right at mile 12.1. Take the left fork at mile 13.0 (look for the BLM Wilderness Study Area sign). Park at the base of Black Mountain at mile 13.8. Note that if the ground is wet, it is advisable to stay on the paved highway.

STOP 11

Twin Buttes and Black Mountain
(13.8 miles from Stop 10, cumulative 141.4 miles)

Although the classic Bridger badlands and collecting areas we have already visited are located far to the west, the Twin Buttes Member and the Twinbuttean land mammal subage was named for Twin Buttes. Because of this, Murphey and Evanoff (2007) designated their type section of the Twin Buttes Member for the upper Bridger sequence on the south side of Twin Buttes,

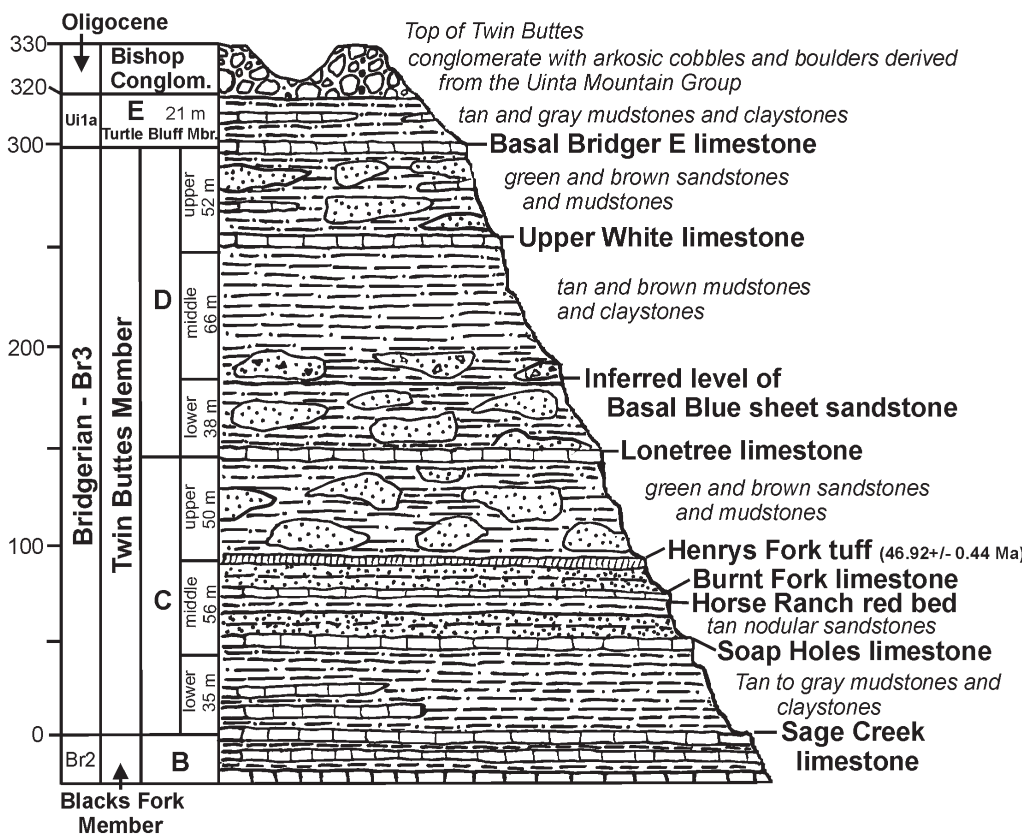

FIGURE 12. Generalized stratigraphic section of the upper Bridger Formation in the Twin Buttes area, Sweetwater County, Wyoming. The diagram shows widespread and more localized markers, as well as informal submembers of Matthew (1909). Thicknesses taken from the type section of the Twin Buttes Member, which includes the Turtle Bluff Member on Twin Buttes (from Murphey and Evanoff, 2007).

and established their Twin Buttes Member reference section of the upper Bridger for the sequence in the Sage Creek and Hickey Mountain area. However, the reference section is thicker and contains more marker units. The major stratigraphic features of the upper Bridger in the Twin Buttes and Black Mountain area are shown in Figure 12.

You are standing in front of another upper Bridger marker bed. The Horse Ranch red bed occurs only in the eastern part of the basin (east side of Twin Buttes [Mass Mountain], Black Mountain and Twin Buttes). It is an approximately 4 meter (13 feet) thick sequence of non-calcareous brick red, greenish-gray, and light brown claystone, blocky mudstone, and blocky fine-grained muddy sandstone (Murphey and Evanoff, 2007). It is locally fossiliferous.

For many years, paleontologists were vexed by the difficulty of correlating between Twin Buttes and Cedar Mountain to the west, especially considering the classic "layer cake geology" of the Bridger with very low dips and laterally persistent marker units. This was because the stratigraphic positions of the "white layers" did not align as expected when using the Sage Creek limestone as a datum. This problem was finally solved by locating the mineralogically diagnostic Henrys Fork tuff not far from here on Black Mountain, and using it as a stratigraphic datum. The reason that earlier workers had difficulties establishing a correlation between the Twin Buttes and Black Mountain area with exposures to the west using the "white layers" is that the lower Bridger C thins dramatically from the west to the east as evidenced on Twin Buttes, where the thickness between the Sage Creek limestone and Soap Holes limestone is 21 meters (69 feet) less than in the nearest correlative sequence to the west.

You are stratigraphically located within the middle Bridger C, and the Henrys Fork tuff is located 42 meters (138 feet above this level). In fact, all of the major marker units present in the Twin Buttes reference section are present in the Twin Buttes type section except for the Basal blue sheet sandstone (base of middle Bridger D). The Lonetree limestone is very well exposed in the saddle between Black Mountain and Twin Buttes, and the Upper white limestone is exposed near the top of Twin Buttes. Only 21 meters (69 feet) of Turtle Bluffs Member occurs at Twin Buttes, which is capped by a thin remnant of Bishop Conglomerate. The hike from this stop to the saddle between Twin Buttes and Black Mountain is well worth the effort if you have the time.

This is the end of the Bridger basin portion of the field trip. From here we will head south to Manila, Utah, via Sweetwater County Highway 1 and Wyoming State Highway 414, and then continue south over the Uinta Mountains to Vernal and the Uinta basin.

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