—Natural Resources—

Application of New Technologies Supporting Paleontological Resource Inventory and Monitoring in Intermountain Region Parks

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Introduction

The Intermountain Region (IMR) of the National Park Service (NPS) preserves a diverse and scientifically important fossil record, which extends from the top of the Rocky Mountains in Glacier National Park to the cliffs along the Rio Grande Wild and Scenic River. Collectively, fossils documented within 73 parks in the region span more than a billion years of Earth's history and provide exceptional opportunities for scientific research and public education. The challenges associated with the management and protection of nonrenewable paleontological resources resulted in the development of innovative practices and collaborative partnerships within the IMR parks. The use of new and improved technologies, including digital photogrammetry and unmanned aviation systems, were utilized for inventory, monitoring, protection, and interpretation of fossils within IMR parks during 2014 and 2015 (Santucci and Koch 2003; Santucci et al. 2009).

Rapid advances and the increasing affordability of powerful computers, software, and advanced digital photography enable the creation of precise 3-D models. Among these advances is photogrammetry software that uses overlapping digital photographs to find the 3-D aspect of an object and then recreate an accurate virtual model (Wood and Santucci 2014). Photogrammetric imaging of *in situ* paleontological resources has been recently undertaken at several IMR parks including: Arches National Park, Capitol Reef National Park, Florissant Fossil Beds National Monument, Glen Canyon National Recreation Area, Grand Canyon National Park, White Sands National Monument, and Wupatki National Monument. The photogrammetric data support scientific evaluation and long-term monitoring of fossils.

The application of emerging technologies in IMR parks points the way to future advances in paleontological research, monitoring, and protection.

Arches National Park

Paleontological field inventories within Arches National Park, Utah, over the past decade have yielded several rare and important fossil discoveries (Madsen et al. 2012). An unusual series of trace fossils preserved at one locality in the Lower Cretaceous Cedar Mountain Formation in Arches National Park may represent evidence of vertebrate feeding behavior. A repeated pattern of parallel groups of 4–8 grooves are being interpreted (Martin et al. 2014) as semicircular feeding traces by a beaked vertebrate, such as a bird or pterosaur (figure 1). The biogenic features form semicircular patterns suggesting a small vertebrate standing or floating in shallow water and shifting laterally to systematically mine the surface for food. Photogrammetric

Figure 1. Vertebrate feeding traces preserved in the Early Cretaceous Cedar Mountain Formation at Arches National Park, Utah *(NPS Photo, 2002)*.

images of the feeding traces enhance the ability to remotely describe and precisely measure the morphological patterns preserved in these unusual features.

Capitol Reef National Park

Through a cooperative agreement between the NPS Geologic Resources Division and the Utah Geological Survey, paleontological field inventories were undertaken at Capitol Reef National Park, Utah, between 2013 and 2014 (Kirkland et al. 2014). During field evaluations of the Late Triassic Chinle Formation, a fossil plant locality with 8 to 10 *in situ* casts of the tree-like large horsetail known as *Equisetites* (sp.) was discovered in the Monitor Butte Member. These fossils are preserved in growth position and occur in three distinct sedimentary layers. This rare occurrence of standing fossil horsetails contributes to the understanding of these ancient plants and the paleoenvironment during deposition of the Chinle Formation at Capitol Reef National Park (Dubiel 1987).

The *Equisetites* forest is an unusual occurrence, with only a few locations known with this fossil in growth position outside of Capitol Reef National Park (Dubiel 1987). In response, staff from the NPS Geologic Resources Division traveled to the park to document the locality through photogrammetry (figure 2). The photogrammetric data are being used for scientific description of the paleontological locality and will be available for long-term monitoring of the stability and condition of the site (Kirkland et al. 2014).

Florissant Fossil Beds National Monument

In May 2014, photogrammetry specialists from the Bureau of Land Management and the National Park Service met with staff at Florissant Fossil Beds National Monument, Colorado, to document a trio of large Eocene sequoia (ancient redwood) fossil stumps. Although the *in situ* petrified stumps are beneath a protective open-sided structure, they are subjected to seasonal and often extreme temperature fluctuations and freeze-thaw

Figure 2. Photogrammetric documentation of *in situ Equisetites* casts in the Late Triassic Monitor Butte Member of the Chinle Formation at Capitol Reef National Park, Utah *(Source: UGS, 2014)*.

effects. Photogrammetric images were obtained to provide baseline data for the park paleontologist and staff in order to further enhance monitoring of the stability and condition of the petrified stumps (figure 3).

Glen Canyon National Recreation Area

Hundreds of fossil track localities are preserved in the Early Jurassic Navajo Sandstone and other Mesozoic strata along the shores of Lake Powell in Glen Canyon National Recreation Area, Utah. Most of the fossil localities preserve footprints of dinosaurs and occasionally tracks of early mammals or mammal-like reptiles and insects. Paleontological resource monitoring was established to evaluate the stability and condition of fossil track localities subject to periodic submersion and emergence with fluctuations in the water levels of the lake (Kirkland et al. 2011). Historically low water levels at Lake Powell has recently led to the discovery and documentation of several new and important fossil track localities during paleontological resource monitoring at Glen Canyon National Recreation Area.

In 2009, a team of paleontologists from the Utah Geological Survey and the National Park Service

Figure 3. Photogrammetric image of petrified redwood stumps at Florissant Fossil Beds National Monument, Colorado
Inset: NPS staff acquiring imagery for photogrammetric modeling *(NPS Photos, 2015*)

Figure 4A. The Megatrack Block at Glen Canyon National Recreation Area, Utah, contains a variety of dinosaur tracks within the Early Jurassic Navajo Sandstone *(Source: NPS, 2009)*

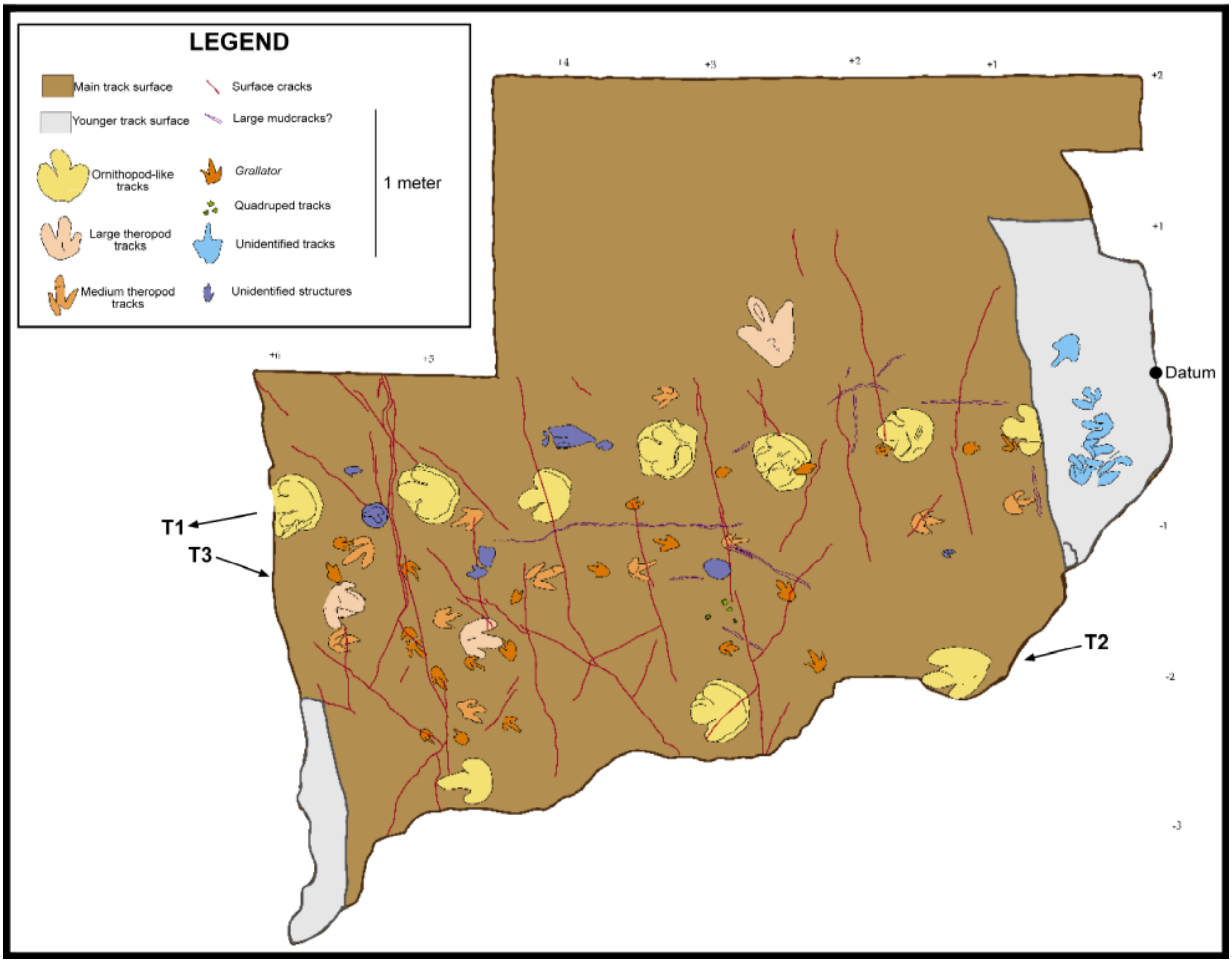

Figure 4B. Detailed surface mapping of the Megatrack Block reveals the occurence of seven distinct vertebrate track morphotypes *(Source: A. Milner, 2011).*

documented a large block of Navajo Sandstone containing dozens of individual footprints, representing at least seven different types of fossil tracks (known as morphotypes) (figures 4A–B). On the main track-bearing surface of the block is a prominent trackway consisting of what appear to be tracks made by a large bipedal ornithopod-like dinosaur. In order to facilitate the study of this megatrack block and to initiate long-term monitoring of the paleontological locality, photogrammetric documentation was undertaken in 2014.

Due to the low lake levels in 2014, another new and important fossil track locality was discovered and documented in the Navajo Sandstone at Glen Canyon National Recreation Area. The newly exposed locality preserves more than 100 fossil footprint impressions identified as *Brasilichnium*, which are believed to be associated with small early mammals or mammal-like reptiles (figure 5). Photogrammetric documentation of this fossil track locality during the period of low lake level will enable continued study when the site becomes resubmerged with a rise in the lake water level.

Figure 5. NPS geologist photogrammetrically document a partially submerged *Brasilichnium* trackway along the lake shore at Glen Canyon National Recreation Area, Utah *(Source: NPS, 2014)*.

Grand Canyon National Park

Grand Canyon National Park, Arizona, preserves one of the greatest concentrations of Late Paleozoic tetrapod (four-legged [quadrupedal] animal) tracks in the world. During the 1920s, Smithsonian paleontologist Charles Gilmore studied and made extensive collections of fossil tracks and trackways from the Early Permian Coconino Sandstone within the park (Gilmore 1926, 1927, 1928). Since Gilmore's research at the Grand Canyon, new fossil track localities have been documented in park strata. A massive detached block of Coconino Sandstone, discovered during 2013 by paleontology intern Cassandra Knight, preserves one of the most important fossil track localities known in the park. On one surface of the block, several exceptionally preserved trackways of large tetrapod footprints occur and are identified as *Chelichnus* (figure 6A).

Photogrammetric documentation of *Cassi's Fossil Track Locality* was accomplished in September 2014. Digital 3-D models were generated using the photogrammetric images to enhance scientific analysis and description of the Paleozoic tetrapod trackways (figure 6B). The photogrammetric images also yield baseline data for long-term monitoring of this important paleontological locality.

White Sands National Monument

An extensive Late Pleistocene fossil megatrack site has recently been documented within and around White Sands National Monument,

Figure 6A. *Chelichnus* trackways exposed on the surface of a block of Permian Coconino Sandstone in Grand Canyon National Park, Arizona *(Source: C. Knight, 2013).*

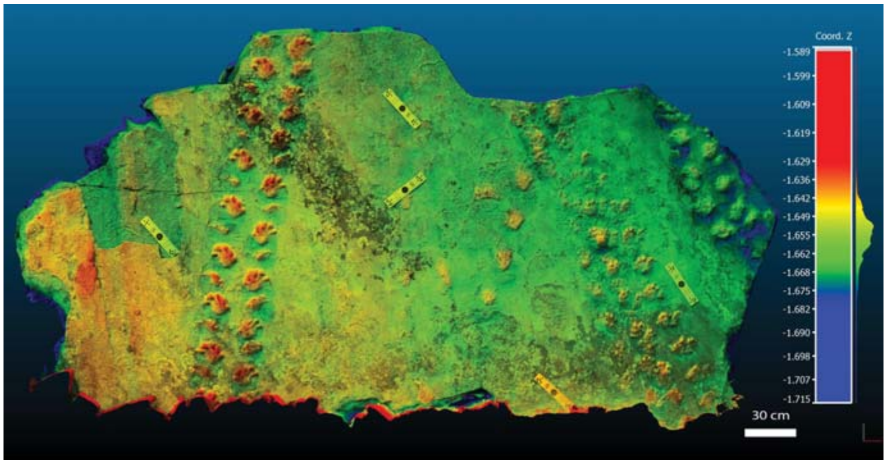

Figure 6B. Photogrammetric image of the same *Chelichnus* trackway block where color variation is based upon the depth of surficial features including the fossil footprints *(Source: NPS, 2015)*

Figure 7. Photogrammetric image of a large felid track preserved in Pleistocene sediments at White Sands National Monument, New Mexico *(Source: NPS, 2013)*.

New Mexico (Santucci et al. 2014). Thousands of fossil tracks and trackways produced by extinct ice age animals, including mammoths, camels, carnivores, and possibly giant ground sloths, are preserved in the gypsum-rich sands associated with dry lake beds (figure 7). The nature of the loosely compacted gypsiferous sediments, in which the fragile footprints are preserved, results in their rapid weathering by wind and storms. Once exposed at the surface, tracks are ephemeral and temporary geologic features. Processes which erode the tracks will also help to exhume new ones from the subsurface as the sand shifts and abrades the underlying fossiliferous deposits.

Monitoring of the ephemeral fossil tracks preserved within the monument continuously reveals new fossil track occurrences, as well as documents the rapid deterioration of previously recorded fossil tracks. Traditional ground level monitoring and photogrammetry of fossil trackways require close proximity to the fossil tracks by the photographer. This approach to photodocumenting the tracks generates disturbance to the adjacent soft sediments and fossils at or near the surface.

Collaboration between the Department of Defense, Bureau of Land Management, United States Geological Survey, and the National Park Service during 2014 enabled the use of an unmanned aviation system, specifically an RQ-16 Tarantula-Hawk (T-Hawk), to be employed in restricted airspace to obtain aerial photography and videography of portions of the Late Pleistocene megatrack site at White Sands National Monument (figure 8). This proof of concept project represents the first time a T-Hawk platform has been used to support paleontological research and resource management. The aerial photography and videography enabled centimeter-scale resolution and geospatial data collection while minimizing impacts and ground disturbances to the fragile paleontological resources.

Figure 8. Interagency team, consisting of staff from the NPS, BLM, USGS, DOD and the RQ-16 Tarantula-Hawk, during documentation of ice age fossil tracks at White Sands National Monument, New Mexico *(Source: NPS, 2014)*.

Wupatki National Monument

A fossil vertebrate track with skin impressions was discovered in 2004 at Wupatki National Monument, Arizona. This rare preservation exhibiting early reptilian skin was associated with a fossil track identified as *Chirotherium* from the Lower–Middle Triassic Moenkopi Formation (figure 9). *Chirotherium* is a five-toed (pentadactyl) footprint believed to be produced by an unidentified early reptile (pseudosuchian). To date, several footprint specimens that preserve skin impressions have been collected at Wupatki National Monument and are maintained within the collections at the Museum of Northern Arizona.

Figure 9. *Chirotherium* track with skin impressions from the Triassic Moenkopi Formation at Wupatki National Monument, Arizona *(Source: NPS, 2014)*.

During September 2014, photogrammetric images were obtained of the Wupatki *Chirotherium* tracks with skin impressions. The high resolution 3-D images enhance the ability to view the morphological features of the ancient reptilian skin. The photogrammetric models will be available for use by researchers and for public interpretation of this rare evidence of early reptile skin.

Conclusion

The use of photogrammetry and unmanned aviation systems have increased opportunities for inventory and monitoring of paleontological resources in Intermountain Region parks. In some instances, the innovative applications of these new technologies have been employed to reduce potential impacts to fragile resources while enhancing paleontological resource management activities (Wood and Santucci 2014). The NPS Geologic Resources Division website includes some examples of paleontological resource photogrammetry projects.

The extreme precision of the ground-based and aerial photogrammetry enables documentation, monitoring, and subsequent remote scientific study of *in situ* paleontological resources. The acquisition of high resolution images provides a methodology for evaluating changes in the stability and condition of fossils and fossil localities due to either natural processes, such as weathering, or human impacts.

Digital photogrammetric data can be used to generate mathematically precise 3-D models, which are able to be printed or electronically shared for public education or scientific study. The 3-D models will allow millions to enjoy the fossils virtually or in person with no resource damage, truly leaving no trace and protecting the actual location of sensitive fossil localities. The use of photogrammetry will likely yield opportunities for other resource management and interpretation applications, support long-term resource preservation, and expand analysis of paleontological resources.

For Additional Information Please Visit:

http://www.nature.nps.gov/geology/monitoring/photogrammetry/

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