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

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

INTRODUCTION

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

From the late 1930s through the early 1970s Alf took students on collecting trips, called peccary trips, traveling to sites in California, Utah, Wyoming, South Dakota, Nebraska and Arizona. Alf concentrated on recovery of fossil vertebrates and by the 1960s had amassed a large regional collection (45,000 specimens). Alf was especially interested in collecting tracks and trackways and obtained 800 specimens from the Avawatz, Barstow, Coconino, Moenkopi, Moenave, Muddy Creek, Tecopa and Wasatch formations (Fig.1); the largest collection in the western United States. By the 1960s the incredible amount of material Alf and his students had collected overwhelmed the small museum that Alf had established in the basement of a library on the Webb campus. By 1967 a new facility was built and it was dedicated to Alf in 1968.

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

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

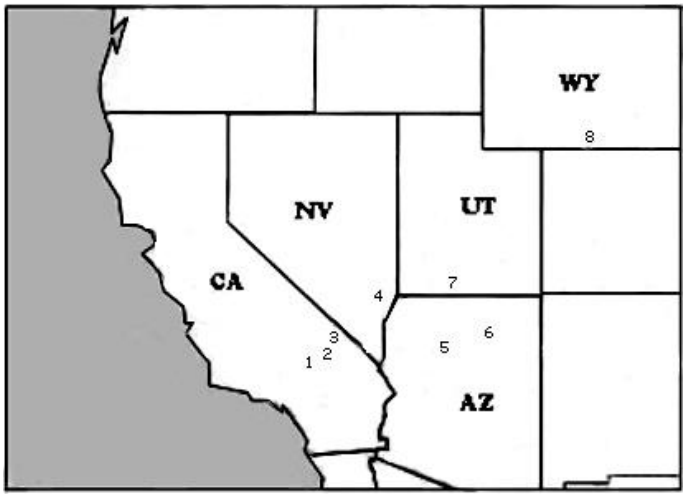

FIGURE 1. Map of the southwest United States showing location of Alf Museum fossil footprint collecting areas: (**1**) Barstow Formation; (**2**) Avawatz Formation; (**3**) Tecopa Formation; (**4**) Muddy Creek Formation; (**5**) Coconino Formation; (**6**) Moenkopi Formation; (**7**) Moenave Formation;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

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

COCONINO FORMATION (EARLY PERMIAN)

RAM Locality

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

Discussion

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

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

Alf and Webb students collected 142 track specimens that include ichnogenera *Laoporus* (over 120 specimens), *Agostopus* (RAM 128), *Octopodichnus* (RAM 139) and *Paleohelcura* (RAM 142). Over 90% of Coconino specimens exhibit one or multiple trackways of the vertebrate represented by *Laoporus.* Many large slabs have unidentified and poorly preserved invertebrate tracks on them in addition to *Laoporus.* Specimens range in size from 10 cm square, up to the massive slab (RAM 244) displayed in the museum's foyer (Fig. 3), which is about 5 m in length, 1.3 m in width, and 20 cm thick. The only Alf Museum Coconino holotype is RAM 139 (Fig. 4) representing *Octopodichnus raymondi* (Sadler, 1993; original specimen number JF 5905 was recatalogued as RAM 139). Alf compared modern spider tracks with RAM 139 and concluded the tracks preserved on RAM 139 represented a spider, but did not name it (Alf, 1968). Sadler's (1993) more extensive study supported Alf's original hypothesis and the species *O. raymondi* was named in his honor.

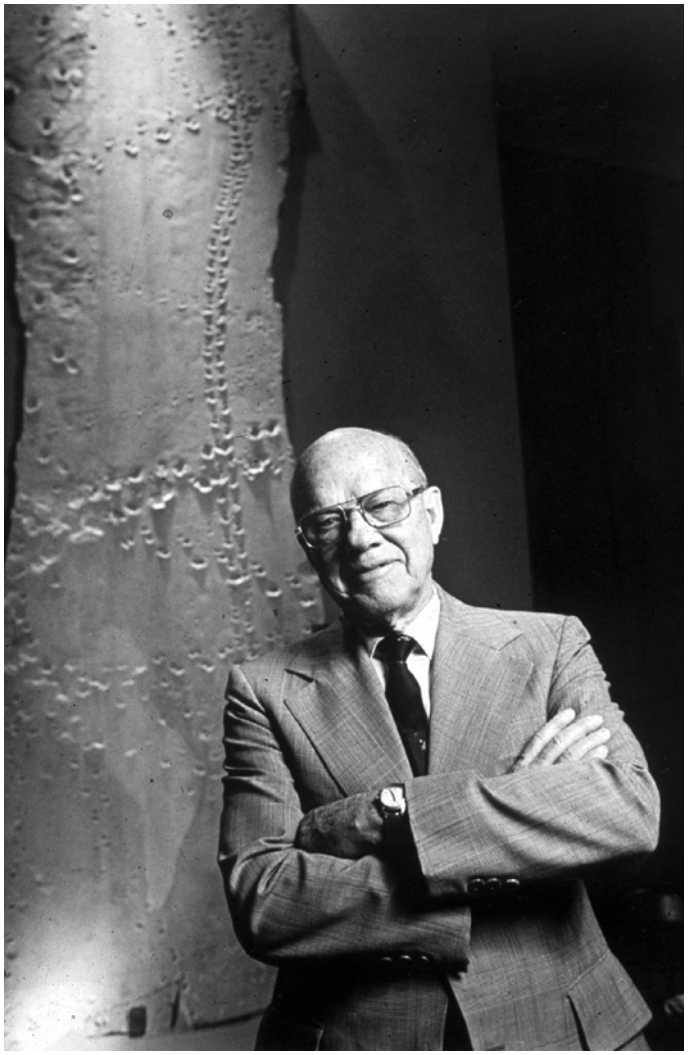

FIGURE 3. Ray Alf standing beside RAM 244 in the museum's foyer.

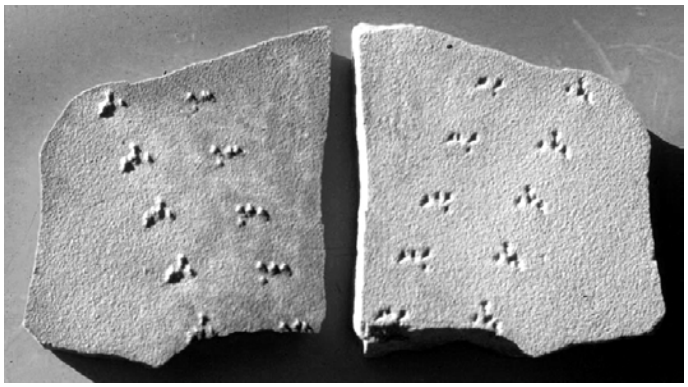

FIGURE 4. Holotype of *Octopodichnus raymondi* (RAM 139) from the Coconino Formation.

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

posits. However, a relatively recent challenge was presented by Brand and Tang (1991), who argued for a subaquaeous origin of the tracks. Using slabs on display at the Alf Museum (RAM 244 is figs. 2a and 2f, RAM 235 is figs. 2g and RAM 132 is fig. 2e in Brand and Tang, 1991) and other specimens, Brand and Tang (1991) noted that many *Laoporus* trackways displayed odd characteristics, such as abrupt starts and ends of track sets on undisturbed bedding planes and that individual tracks are often oriented perpendicular to the trend of the trackway. Tests performed with modern newts in shallow flowing water created tracks similar to those made in the Coconino Formation and formed the basis of the underwater hypothesis (Brand and Tang, 1991). However, the geology of the Coconino Formation supports an eolian hypothesis because the large scale bedforms, low angled cross stratification, abundance of well sorted quartz sandstone and the absence of ripple marks all indicate the probability of eolian deposition (for further discussion of this controversy see Brand, 1992; Lockley, 1992; Loope, 1992; Lockley and Hunt, 1995).

MOENKOPI FORMATION (EARLY-MIDDLE TRIASSIC)

RAM Locality

All specimens were collected from RAM V94005, a few miles southwest of Cameron, Arizona.

Discussion

The Moenkopi Formation is composed of sandstones, siltstones and mudstones of fluvial origin (McKee, 1954). As Alf became more interested in collecting fossil tracks, he developed an annual Webb spring break trip that was organized into a general Arizona-Utah-Nevada loop route with stops at Seligman, Grand Canyon National Park, Cameron Junction (where he encountered the Moenkopi Formation), Kanab and Zion National Park. On these trips Alf and students collected track specimens at Seligman (Coconino Formation) and Kanab (Moenave Formation) in addition to those from the Moenkopi near Cameron Junction. Alf's spring break trips ran for nearly 35 years and collections were made in the Moenkopi from around 1950 to 1970. As with many Alf Museum track localities, V94005 has not yet been precisely relocated. There are only a few photos in the museum's archives showing collecting activities in the Moenkopi Formation, but they probably would provide adequate information for site relocation.

The Alf Museum collection from the Moenkopi consists of 25 specimens, each in red siltstones with one or two tracks (usually one), which vary from moderately distinct to very faint. Ten specimens are referred to *Chirotherium* in the Alf Museum catalog, with the remaining 15 unidentified. However, all tracks are of similar size and shape and thus appear to represent a single ichnotaxon. *Chirotherium* has distinctive five digit impressions that superficially resemble human handprints, with the fifth digit on the pes remarkably similar to a thumb imprint (Lockley and Hunt, 1995). *Chirotherium* tracks from the Moenkopi Formation show a wide variety of sizes and probably represent various types of quadrapedal archosaurs (Lockley and Hunt, 1995).

MOENAVE FORMATION (EARLY JURASSIC)

RAM Locality

All specimens were collected from RAM V94277, in a canyon north of Kanab, Utah.

Discussion

The Moenave Formation, confined mainly to northern Arizona and southern Utah, is composed of the Dinosaur Canyon Member, the Whitmore Point Member and the Springdale Sandstone Member (Harshbarger et al., 1957; Miller et al., 1989). On Webb spring break trips, Alf and students would often collect north of Kanab in the Dinosaur Canyon Member (V94277 was relocated in 2000). These trips yielded 69 specimens of small to large three toed tracks attributed to bipedal dinosaurs (Fig. 5). The Alf Museum catalog lists 22 specimens of *Eubrontes*, 15 of *Grallator* and 13 of *Anchisauripus*. These identifications, made by Webb students, are based on size and may not be entirely accurate, as according to Lockley and Hunt (1995), *Anchisauripus* has not been identified in the western United States. The Alf Museum has 19 other specimens identified only as dinosaur tracks. Of the 69 Moenave specimens, only one (RAM 176) has more than two tracks. RAM 176, catalogued as *Grallator*, has 11 full or partial tracks oriented in various directions (Fig. 6), which indicates they may represent more than one individual.

FIGURE 5. Webb students with *Eubrontes* track (RAM 239) from the Moenave Formation.

WASATCH FORMATION (EARLY EOCENE; WASATCHIAN NALMA)

RAM Locality

All specimens were collected from RAM V94207, located in Carbon County, Wyoming.

Discussion

The exact location of V94207 is uncertain. However, excellent photos of the site are present in the museum archives and presumably the site could be relocated without great difficulty. What is known is that the site occurs north of Baggs in outcrops adjacent to Muddy Creek, which parallels State Highway 789 in south central Wyoming. Based on this general location, the site is probably within the main body of the Wasatch Formation, which would indicate that the Early Eocene-Wasatchian age determination is probably correct.

In 1969 and/or 1970, Raymond Alf and crew collected 24 specimens, seven of which represent birds of very small size that remain undescribed. The other 17 appear to represent tracks of a single mammalian taxon (some slabs with mammal tracks have small and faint bird tracks on them as well). Based on these 17 specimens, Sarjeant et al. (2002) described and named the ichnogenus and species *Quiritipes impendens*. The type is RAM 154, a set of tracks reconstructed from nine individual slabs arranged in their presumably original position and then set in cement. The paratype is RAM 267, a left pes. Sarjeant et al. (2002) thought the tracks of *Quiritipes impendens* belonged to a carnivore and noted the lack of claw impressions, which could indicate they represented a feloid. But their overall morphology was unlike any known feloid (Sarjeant et al., 2002) and the Early Eocene age of the site virtually precluded any alliance with the much younger feloid clade. Based on

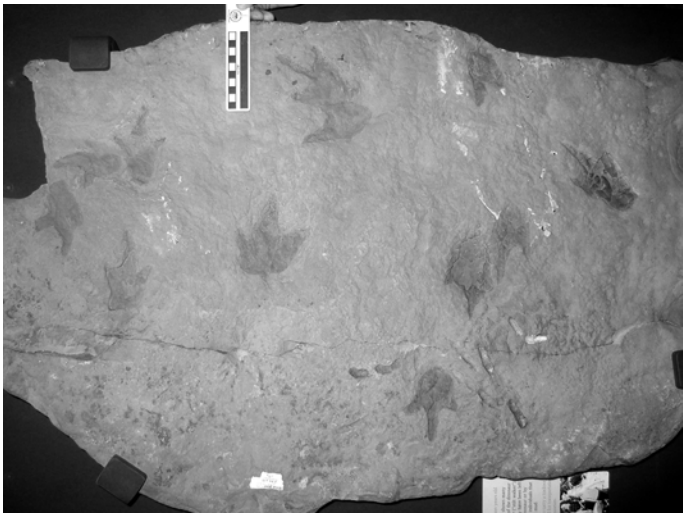

FIGURE 6. *Grallator* imprints (RAM 176), common tracks from the Moenave Formation.

their age and morphology, Sarjeant et al. (2002) surmised that the tracks were probably made by a creodont. In any case, the tracks of *Quiritipes impendens* housed at the Alf Museum represent a taxon not found in any other museum collection.

BARSTOW FORMATION (MIDDLE MIOCENE, BARSTOVIAN NALMA)

RAM Localities

Specimens were collected from RAM sites V94064, V94065, V94176, V94272, V94281, V94283, V94284 and V94293, in the Mud Hills, northwest of Barstow, California.

Discussion

The Barstow Formation is about 1,000 m thick and is composed of a sequence of fluviatile and lacustrine sediments and air-fall tuffs (Woodburne et al., 1990). The formation is subdivided into the Owl Conglomerate, Middle and Upper members (Woodburne et al., 1990). All the Barstow Formation tracks at the Alf Museum were collected in the Middle and Upper members. Alf first prospected for fossils in the Barstow Formation in 1935. After the discovery and publication of the new genus and species of peccary, *Dyseohyus fricki* by Stock (1937), Alf realized Barstow's great potential as a paleontological resource and the Barstow Formation became his main collecting area for the next 40 years. Exactly when Alf collected his first track from the Barstow Formation is unknown. But it could not have been before 1959 as in that year he described mammal tracks from the Avawatz Formation and claimed they were the first ever reported from the Mojave Desert (Alf, 1959). It is reasonable to assume that the success of finding tracks in the Avawatz Formation inspired Alf to expand his search to the Barstow Formation. Unfortunately, locality data for nearly the entire Alf Museum track collection from the Barstow Formation is very poor and stratigraphically unreliable. The only exceptions are the amphicyonid (RAM 100, V94272, Fig. 7) and proboscidean (RAM 187, V94176, Fig. 8) trackways which were relocated in 1994 using photos in the museum's archives.

The Barstow Formation has yielded more track specimens, about 322, than any other formation from which Alf and Webb students collected. The majority of these specimens were collected in the 1960s and early 1970s and include 295 tracks/trackways of camels, 22 of felids, one set of canid prints (RAM 183) and the amphicyonid (RAM 100) and proboscidean (RAM 187) trackways. There are seven holotype, syntype or paratype specimens from the Barstow Formation in the Alf Museum

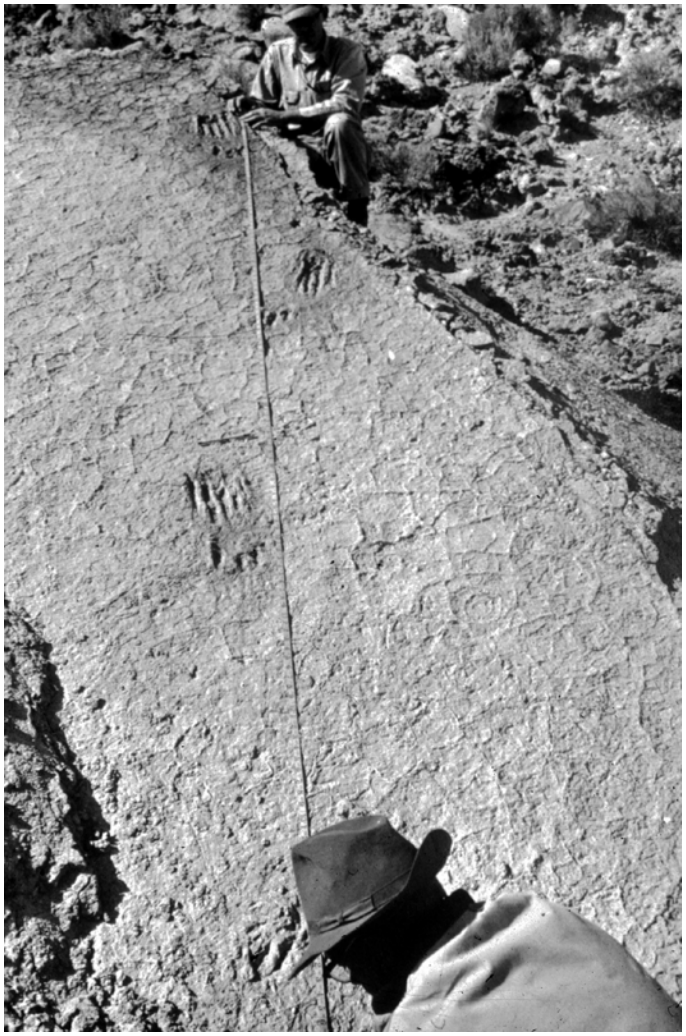

FIGURE 7. Ray Alf (bottom) and Richard Tedford (top) measure the amphicyonid trackway (RAM 100, holotype of *Hirpexipes alfi*) prior to its excavation from the Barstow Formation.

FIGURE 8. Webb students pose with the partially excavated proboscidean trackway (RAM 187) from the Barstow Formation.

collection.

One of the most important Barstow specimens is the amphicyonid trackway (RAM 100, Fig. 7), which Alf (1966) briefly described and identified as representing an amphicyonid. The trackway was collected in 1964 and reassembled for exhibit in the Hall of Footprints in the late 1960s. RAM 100 is the holotype of *Hirpexipes alfi* (Sarjeant et al., 2002). The large size, five digits and rake-like claw marks of *H. alfi* strongly support the interpretation that the tracks represent an amphicyonid (Alf, 1966; Sarjeant et al., 2002). Their very large size and stratigraphic position in the Middle Member of the Barstow Formation suggest they were made by *Amphicyon ingens* (Sarjeant et al., 2002). Based on RAM 100, *A. ingens* had a stride of 245 cm and a pace of 120 cm (Sarjeant et al., 2002).

The Alf Museum collection includes two other reconstructed trackways from the Barstow Formation, both of which are on display in the Hall of Footprints. One is a set of four proboscidean tracks (RAM 187, Fig. 8) from the Upper Member that were removed in large slabs (around 1969) and reconstructed at the museum. The other is a large slab (RAM 166, Fig. 9) containing two sets of camel prints that were broken into blocks (date unknown) and later reassembled at the museum. These camel prints (RAM 166) were designated as a syntype of *Lamaichnum alfi* by Sarjeant and Reynolds (1999). The other syntypes were RAM 159 (a right pes) and RAM 182 (a right manus). RAM 166 is particularly important because it clearly shows the gaits of at least two camels. The majority of Barstow camel prints in the Alf Museum collection are similar in morphology to *L. alfi* (Sarjeant and Reynolds, 1999).

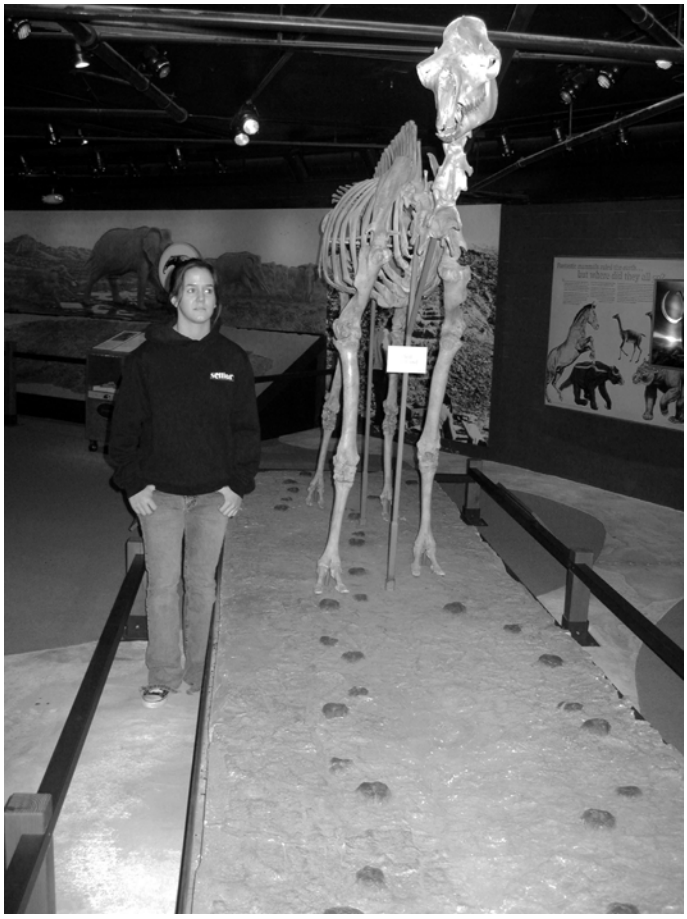

FIGURE 9. Multiple camel trackways (RAM 166, syntype of *Lamaichnum alfi*) from the Barstow Formation on display with a camel skeleton mounted above.

Other types in the Alf Museum collection from the Barstow Formation include the felids *Felipeda bottjeri* and *Felipeda scriverni* described by Sarjeant et al. (2002). The holotype of *F. bottjeri* is RAM 103 (right pes?) and the paratype is RAM 104 (right manus?); figured specimens of *F. bottjeri* also include RAM 181 and RAM 275 (Sarjeant et al., 2002). The holotype of *F. scriverni* is RAM 242 (now part of the collections at Death Valley National Park) and the paratype is RAM 105 (left manus?). *Felipeda bottjeri* differs from *F. scriverni* in its more elongate shape and lesser digital span (Sarjeant et al., 2002). Specimens of *F. bottjeri* are more numerous in the Alf Museum collection than *F. scriverni*. *Felipeda* tracks may represent those of *Pseudaelurus* (Alf, 1966; Sarjeant and et al., 2002).

Other specimens of particular interest include RAM 183, a small canid print referred to *Canipeda* species "A" that may represent the track of *Tomarctus* (Sarjeant et al., 2002) and a bird print on the amphicyonid trackway slab (RAM 100) that was used to emend the diagnosis of *Gruipeda becassi* Panin and Avram (1962) (Sarjeant and Reynolds, 2001).

AVAWATZ FORMATION (LATE MIOCENE, CLARENDONIAN NALMA)

RAM Localities

Specimens were collected from RAM sites V94021, V94134, V94135 and V94136, in the southern part of the Avawatz Mountains,

FIGURE 10. Ray Alf on ladder collecting trackway slabs (RAM 215 and 216) from the Avawatz Formation.

north of Baker, California.

Discussion

The upper part of the Avawatz Formation yields vertebrate fossils and is composed of coarse to fine grained tuffaceous sedimentary rocks interbedded with distinct white to buff colored volcanic ashes that can be over a meter thick (Henshaw, 1939; Alf, 1959). While on a trip with Alf in February of 1957, student Robert Baum discovered mammal footprints on steeply dipping bedding planes, high on the side of a steep canyon in the Avawatz Formation. Two more trips were made soon thereafter to remove the tracks, which had to be excavated while standing on a ladder (Fig. 10). These were the first mammal tracks described from the Mojave Desert (Alf, 1959). The Avawatz Formation proved to be an untapped treasure trove of tracks as nearly 140 specimens were collected by Alf and Webb students following Baum's original discovery. These Avawatz specimens include 81 bird, 49 camel, 4 felid and 7 unidentified vertebrate tracks. All of these specimens were assigned to the general Avawatz locality V94021 because the locations of the three main Avawatz collecting sites (V94134, V94135 and V94136) were unknown. In 1994, Robert Baum led an Alf Museum crew back to the Avawatz Formation and precisely relocated two (V94134 and V94135) of the original collecting sites. Reassignment of specimens from V94021 to V94134 and V94135 was completed in 2005.

Eight holotype, syntype or paratype specimens from the Avawatz Formation are housed at the Alf Museum. The birds, all described by Sarjeant and Reynolds (2001), include: RAM 110, the holotype of *Avipeda gryponyx,* a series of seven prints with partial impressions of others that probably represent a small wading bird (Sarjeant and Reynolds, 2001); the holotype (RAM 115, left pes) and paratype (RAM 269, right pes) of *Anatipeda californica*, webbed footprints of small to moderate size with three digits directed forward and a fourth backwards; the holotype (RAM 111, right and left pedes) of *Anatipeda alfi*, a web-footed species named in honor of Raymond Alf (specimens figured by Sarjeant and Reynolds (2001), also include RAM 113, Fig. 11, a left pes and RAM 112, left and right pedes) and ?*Anatipeda* sp. based on RAM 274, a left pes, which is like others of the genus but is larger in size. Footprints

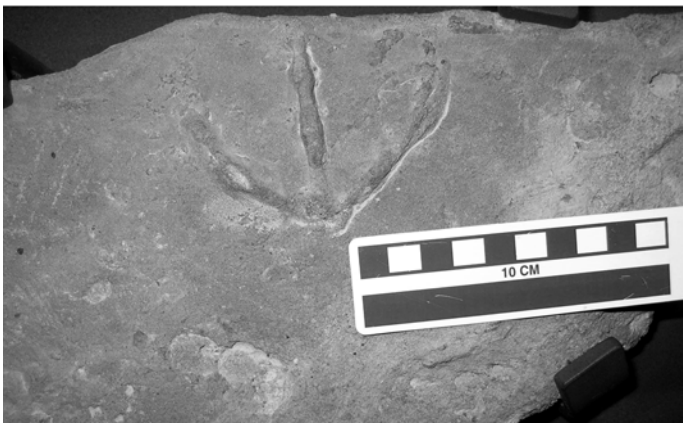

FIGURE 11. Left pes of *Anaipeda alfi* (RAM 113) from the Avawatz Formation.

of *Anatipeda* were probably made by pelicans, flamingos, ducks, geese, swan or other similar birds (Sarjeant and Reynolds, 2001). Also, Sarjeant and Reynolds (2001) used RAM 272 and 278 to emend the diagnosis of *Aviadactyla vialovi* Kordos and Prakfali, 1990, and RAM 270 to emend the diagnosis of *Charadriipeda recurvirostrioidea* Panin and Avram (1962).

Other important specimens include: RAM 205, a small slab with two cat prints (right manus and left pes?) that was described as the holotype of a new genus and species, *Pycnodactylopus achras*, by Sarjeant et al. (2002); RAM 197 (manus) and RAM 209 (left pes), syntypes of *Dizyogopodium dorydium*, a camel of moderate size (Sarjeant and Reynolds, 1999) and RAM 216 (slab with left manus and right pes), the syntype of *Dizygopodium quadracordatum,* another camel of moderate size (Sarjeant and Reynolds, 1999).

TECOPA FORMATION OR "CHINA WASH BEDS" (LATE MIOCENE, CLARENDONIAN NALMA)

RAM Locality

All specimens were collected from RAM V94215, a few miles south of Tecopa, California.

FIGURE 12. Print of *Lamaichnum macropodum* (RAM 165, syntype) from the Tecopa Formation made by a very large camel.

Discussion

The Tecopa Formation is comprised of a series of tuffaceous sedimentary rocks that outcrop south of Tecopa in the Sperry Hills; these same rocks are informally referred to as the "China Wash Beds" by Sarjeant and Reynolds (1999). This collecting area was only visited by Alf and Webb students a few times in the late 1960s. Photos of locality V94215 are housed in the museum's archives and were used to relocate the site in March 2006.

Thirteen specimens were recovered from locality V94215, all of which represent camels. Most slabs preserve the tracks of a very large camel. Sarjeant and Reynolds (1999) assigned these specimens to *Lamaichnum macropodum* and designated RAM 146 (manus) and RAM 165 (pes, Fig. 12) as syntypes. These tracks measure about 20 cm in length and width and probably were made by either *Aepycamelus* or *Megatylopus* (Sarjeant and Reynolds, 1999), the largest known camels of the late Miocene.

MUDDY CREEK FORMATION (LATE MIOCENE, HEMPHILLIAN NALMA)

RAM Localities

Specimens were collected from RAM sites V94163, V94164, and V94286, a few miles north of Glendale, Nevada.

Discussion

The Muddy Creek Formation is comprised of a thick series of sandstone, siltstone and mudstone with lesser amounts of conglomerate and tuff (Stock, 1921) that was deposited in a series of small basins in southern Nevada that coalesced into a single large basin (Reynolds and

Lindsay, 1999). Photos in the museum's archives of the Alf Museum track sites from the Muddy Creek Formation are not labeled as to which site number they represent. Thus, it is doubtful that even if the Muddy Creek Formation sites could be relocated, specific specimens could be assigned to specific localities.

In the late 1960s Alf and Webb students collected about 53 track specimens and one large trackway slab from the Muddy Creek Formation. They represent camels and 2 types of carnivores, an ursid and a canid. This ursid formed the basis of the new genus and species, *Platykopus ilycalcator*, which was described by Sarjeant et al. (2002). RAM 277 (manus) was designated as the holotype and RAM 232 (pes) the paratype. Because of its large size and the presence of five digits, *P. ilycalcator* was interpreted to represent a large bear (Sarjeant et al., 2002). There are other specimens of this large ursid in the Alf Museum collection including a large trackway (RAM 218) comprised of multiple slabs preserving 10 tracks which were numbered in the field and then reconstructed for display at the museum (RAM 218 was removed from exhibit in 2002). Another example of this large ursid is RAM 327, which has two tracks.

RESOURCE MANAGEMENT

Fossils are present on public lands in the western United States, sometimes in vast numbers. Effective management of paleontological resources can pose special challenges, especially tracks and trackways. For instance, to collect vertebrate fossils from public lands a permit is required because vertebrate fossils are considered rare and worthy of special protection. A permit is not required to collect invertebrate fossils on public lands unless they occur in a specially protected area (such as a national park or monument). However, invertebrate tracks and trackways are usually much rarer than those of vertebrates in rock units where fossil tracks are present. Managers of paleontological resources on public lands where trackways occur should take this into consideration when drafting plans for managing the resource. Unlike other public land management agencies, the National Park Service (NPS) requires research permits for collection of any material, including all fossil specimens, in an NPS unit.

"Float" Tracks and Trackways

Tracks and trackways occur in two types of settings based on how they have been exposed by erosion. The first is float, a term that describes fossils that are lying loose on the ground. In the case of tracks, specimens are chunks of rock with tracks (Fig. 13) or multiple tracks (Fig. 5) that usually lie adjacent to the outcrop from which they eroded. Tracks found as float are usually preserved in well-indurated rock, otherwise they would have been destroyed as they eroded. A preserved track can be the imprint the animal made (mold), the cast of the imprint (sediment that later filled the imprint) or the undertrack of the imprint (impression preserved below original bedding plane of imprint). Unless extremely large, these float tracks can be simply picked up, given a field number and then transported to a suitable repository. Float tracks can often be traced to a specific layer in the outcrop from which they eroded and more tracks may be exposed on the same bedding plane. Other times the original bedding plane of the track float may have been completely removed by erosion. In either case, track float should always be collected as erosion will eventually destroy even the most indurated rock.

FIGURE 13. Ray Alf (standing far right) and students with trackway slabs from the Coconino Formation.

In situ Tracks and Trackways

In situ tracks and trackways on public lands are another matter as a decision must be made on whether to remove them, leave them *in situ* or perhaps do a combination of the two. Tracks exposed *in situ* are preserved on bedding planes that often contain both the molds (tracks themselves) and the casts (infilling of tracks) of one or multiple individuals. Thus, the tracks are still in their original position in relation to the sediments in which they were imprinted. The decision to be made is it in the best interest of the resource to collect the tracks or leave them in place? The main factor to consider in this regard is whether the trackway can be protected from erosion and theft or vandalism.

In situ trackways are exposed to the elements and even if treated with hardening agents will eventually be destroyed. If it is important that the trackway be left *in situ* or that the tracks can't be collected due to size, geographic setting or another factor, casts of representative tracks should be made and placed in a suitable repository so a permanent record of the trackway is preserved. Then a method must be employed to preserve the *in situ* trackway for as long as possible. In most cases, the trackway can be covered with loose sediment to slow the rate of erosion of the bedding plane preserving the tracks. Thus, the site is both protected from erosion and very difficult to find. Covering the site is important, even in remote areas on public lands, to minimize potential for theft or vandalism. Even if visitors are aware that collecting is illegal without a permit, it only takes one irresponsible person to try and excavate part or all of the trackway. The resource is then damaged in the unsuccessful process of removal and/or is excavated and lost (usually never recovered). Even in a specially protected area like a national park where sites are patrolled, the resource is still in danger from theft or vandalism. A protective covering of plastic or some other material would be desirable, but that could be counterproductive as it draws attention to the site. If feasible, important trackway sites should be covered by a permanent structure that can be secured and monitored. Examples of this would be Dinosaur National Monument (Utah) and Ichthyosaur State Park (Nevada) for vertebrate fossils and the new St. George Dinosaur Discovery Site at Johnson Farm (Utah) where trackways will be preserved *in situ*, housed within a large building. Although this option is extremely expensive, it does provide an exceptional setting for the public to view a unique resource.

Collecting Tracks and Trackways

If a trackway is to be collected then different approaches can be employed, based on the condition of the tracks and the lithology and degree of induration of the sedimentary rock in which the tracks are preserved. Slabs of thick indurated rock containing trackways can be collected in one piece if a natural break in the bedding plane can be located. A good example of this is the Coconino Formation, which is notable for its many bedding planes that contain well-preserved vertebrate and invertebrate trackways (Lockley and Hunt, 1995; and references therein). Once a productive interval of the formation is located, a slab can usually be separated from outcrop along natural breaks in the rock and then loaded for transport. Slabs can range from 10 cm square to over 5 m in length. Large specimens, like the latter, can weigh over two

tons. Unless machinery is employed, it takes a large crew to move large slabs into a vehicle for transport. Ray Alf was able to collect many large track-bearing slabs of the Coconino Formation, which are now housed at the Alf Museum, with the help of Webb students. Every spring Alf would lead a trip to RAM locality V94004 near Seligman, Arizona, where a large trackway-bearing slab would be located and readied for removal. A few weeks later, in early June, Alf would return with the entire Webb senior class (about 40 students) who were on their way to Grand Canyon National Park to hike the canyon before graduation. Using pry bars, Alf and students would manually elevate a large slab so that rollers could be placed beneath. The slab was then slowly moved downslope (Fig. 2) to a large flatbed truck. Because of Alf's interest in Coconino tracks and the availability of large numbers of Webb students, the Alf Museum now has a large and unique collection from the formation. Specimens such as RAM 244 (Fig. 2) are extremely large and difficult to store or exhibit. Alf placed RAM 244 on exhibit by mounting it on a reinforced wooden platform, lowering it by crane, and placing it in the foyer of the Alf Museum (Fig. 3) while the building was still under construction. This unique exhibit provides a breathtaking experience for the public as the resource is displayed in an unusual and dramatic fashion.

However, most trackways are not preserved in well indurated rock that often naturally breaks into large and thick slabs like the Coconino Formation. If the decision is to preserve a trackway by collecting it, then different approaches can be employed depending on the geographic setting of the site, hardness of the rock and other factors. For example, Ray Alf used a 20 ft ladder to collect the first mammal tracks from the Avawatz Formation in 1957 because the tracks were situated high on the side of a canyon (Fig. 10). Before removal is attempted, casts should always be made while the tracks are still *in situ*. This insures that the morphology of the tracks will be preserved even if the collecting process causes damage. Also, having casts will guide repair of a damaged track and aid in the process of reassembling the trackway at a later date. Although opinions vary on the issue, we recommend that if a trackway has significant scientific value and cannot be protected *in situ*, then all exposed tracks should be removed. Examples of partially exposed trackways from the Barstow Formation that were collected and are now housed at the Alf Museum are an amphicyonid trackway (*Hirpexipes alfi*; RAM 100; Fig. 7), a probocidean trackway (RAM 187; Fig. 8) and a multiple camel trackway (*Lamaichnum alfi*; RAM 166; Fig. 9).

The amphicyonid trackway was discovered in 1960 when a manus-pes track set was found exposed on a moderately dipping bedding plane. Excavation of the rock overlying this bedding plane revealed 4 additional manus-pes sets (Fig. 9). In 1964, the trackway bedding plane was carefully cut into square sections using a power rock saw with the sections aligned so that each manus-pes set was intact. Each section was numbered in the field and then transported to the Webb campus and stored in a shed. In the late 1960s the entire bedding plane was reassembled for exhibit in the Hall of Footprints.

The proboscidean trackway was a different situation as four large round tracks were exposed on a single bedding plane that was dipping at about 30 degrees and the tracks were already showing signs of damage from erosion. The tracks needed quick removal and Alf and students collected the tracks in 1969 by cutting the rock into sections (Fig. 8). The sections were reassembled a few weeks later and displayed in the Hall of Footprints.

The multiple camel trackway preserves two sets of tracks of mid-sized camels, which are now displayed on a large reconstructed bedding plane in the Hall of Footprints (Fig. 9). Details of where the trackways were collected and when this was done are obscure. However, in contrast to the amphicyonid and proboscidean trackways, the bedding plane preserving the camel trackways is a highly indurated limey mudstone. This unit was not cut, but was broken into sections and then reassembled for exhibit. Breaking the bedding plane into sections is a simple removal process compared to cutting the rock, but it should be employed rarely and only with great caution.

The amphicyonid, proboscidean and camel trackways from the Barstow Formation housed at the Alf Museum are unique and scientifically important specimens. The amphicyonid trackway is the only know example from North America, the proboscidean trackway is an early record of the migration of these animals from Asia into North America in the mid-Miocene and the camel trackways preserve evidence of two individuals walking in the same direction, perhaps side by side. By collecting and exhibiting these trackways, the Alf Museum has provided a valuable service to both the public and scientific community as the trackways are easily accessible.

For both the amphicyonid and proboscidean trackway sites, more tracks probably could be collected. Each trackway is situated in rock whose maximum bedding plane dip is oriented parallel to the direction of movement of the individual who left the tracks. Thus, it appears that both trackways extend underground and that if a major excavation was initiated it would likely result in recovery of more tracks. But before further excavation is attempted, it must be for good reason. If no additional information of scientific value will be gained or if more tracks are not needed for exhibit or other purposes, the unexposed portion of the trackway should remain undisturbed. All excavated, *in situ*, and float track sites should be mapped, photographed and inventoried so the sites can be revisited if required.

Limiting Site Information Access

Finally, to protect the proboscidean and amphicyonid trackway sites, or any track site, it is important to both severely limit access to site information and ensure that the site looks undisturbed. Site location information should only be available to researchers or resource management staff as wide distribution of site information could lead to harmful resource impacts including theft or vandalism (in this paper, we selected close-up photos of sites so the sites can't be relocated using the photos). The NPS, for example, has a Freedom of Information Act (FOIA) exemption for specific site, or locality, information (1998 NPS Omnibus Management Act, Section 207). This provision authorizes the NPS to withhold information from the public in response to a FOIA request concerning the nature and specific location of "mineral or paleontological objects" within units of the National Park System. Also, the area where the tracks were collected must be groomed so even though more tracks are not exposed, the site looks natural and does not attract inadvertent attention. In the Barstow Formation in the 1960s, there were many track sites that were exposed and not collected by legitimate entities. By the 1990s, theft or vandalism had destroyed virtually all of these sites.

SUMMARY

The fossil footprint collection at the Raymond M. Alf Museum of Paleontology consists of approximately 800 specimens and is one of the best in the world. These tracks and trackways were recovered from eight formations, with those from the Barstow (322 specimens), Coconino (142 specimens) and Avawatz (141 specimens) formations comprising the largest holdings. The collection includes 22 holotype, syntype or paratype specimens representing 14 ichnotaxa (Sadler, 1993; Sarjeant and Reynolds, 1999, 2001; Sarjeant et al., 2002). The Alf Museum once housed seven specimens from Tertiary rocks in Death Valley National Park, some of which represent the holotypes or syntypes of 4 ichnotaxa: *Hippipeda gyripeza* (equid, holotype RAM 204); *Lamaichnum etoromorphum* (camel, syntypes RAM 203 and RAM 200) (Sarjeant and Reynolds, 1999); *Alaripeda lofgreni* (bird, holotype RAM 201) (Sarjeant and Reynolds, 2001); and *Felipeda scrivneri* (felid, holotype RAM 242) (Sarjeant et al., 2002). These specimens were returned to the National Park Service in the late 1990s and presumably have been recatalogued.

The track collection at the Alf Museum is a testament to the life's work of museum founder Raymond Alf whose early interest in trace

fossils translated into a career-long search for fossil footprints throughout the western United States. Students and faculty at The Webb Schools assisted Alf in this endeavor that spanned nearly four decades (late 1930s to early 1970s). The stratigraphic utility of parts of the collection is limited by the lack of precise locality data for many specimens. However, there are many excellent photographs of Alf's collecting sites housed in the museum archives. These photos have been used to relocate specific sites in the Barstow, Avawatz, Moenave and Tecopa formations. This work needs to be expanded to all museum track sites.

Management of fossil tracks-trackways on public lands is a challenge as protection of sites from erosion and vandals is paramount as the paleontological information each site yields is usually unique. Float track should always be collected. Exposed *in situ* trackways are at risk and should be excavated if they can't be protected. Because each site is different in terms of the quality of track preservation, type of rock, geographic setting and other factors, removal of trackways can be easy to difficult depending on the site. Examples from the Alf Museum show that collecting trackways and reassembling them for exhibit makes the resource readily accessible to both the public and the scientific community.

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