Lucas, S. G. and Sullivan, R.M., eds., 2006, Late Cretaceous vertebrates from the Western Interior. New Mexico Museum of Natural History and Science Bulletin 35.

DINOSAUR TRACKS FROM THE UPPER CRETACEOUS IRON SPRINGS FORMATION, IRON COUNTY, UTAH

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Abstract—Several dinosaur track localities have been identified in the upper Cretaceous (upper Santonian-Lower Campanian) Iron Springs Formation in Iron County, Utah. All localities are in the upper portion of the formation in Parowan Gap and the mouth of Little Canyon near Paragonah. Most of the Parowan Gap tracks pertain to ornithopods, most likely hadrosaurs, although less common theropod tracks have been found. Rare ceratopsian prints are represented by a single manus-pes set. A single, *in situ* site in Little Canyon also produced a very large ornithopod track. These are the first vertebrate tracks described from the Iron Springs Formation. The ceratopsian tracks are the oldest known in North America, and possibly in the world.

INTRODUCTION

A sequence of upper Santonian-lower Campanian strata (Goldstrand, 1994; Eaton et al., 1999, 2002) consisting of sediments deposited in braided stream channels with associated overbank sediments on an upland floodplain are exposed in the uppermost 50 m of the Iron Springs Formation, Parowan Gap, Iron County, Utah (Locality 1, Fig. 1). The formation in Parowan Gap produces an extremely diverse and abundant array of plant fossils, a poor- to well-preserved assemblage of dinosaur tracks and associated invertebrate traces, bivalves, gastropods, and turtle, fish, and rare dinosaur bone fragments. Dinosaur tracks from the Parowan Gap localities have only been briefly mentioned previously (Vice et al., 2003a, 2003b, 2004). These are the first reported vertebrate tracks from the Iron Springs Formation, although invertebrate traces consisting of "insect burrows and nests" have been mentioned in passing from the Gunlock area of Utah (Eaton, 1999). Like the tracks, descriptions and interpretations of invertebrate traces and plants from the Iron Springs Formation are sorely needed.

The Parowan Gap vertebrate ichnoassemblage includes tracks produced by ornithopods (most likely hadrosaurs), theropods, and very rare ceratopsians. Nearly all specimens occur in talus blocks, although a few have been found *in situ* on at least five stratigraphic levels at Parowan Gap (Fig. 2). Since the majority of well-preserved tracks are on fallen blocks, their exact stratigraphic positions are uncertain. *In situ* tracks are preserved as natural casts formed in the bases of several light yellow-brown sandstone layers. Original track molds were formed in non-resistant, generally plant detritus-rich, gray mudstones and locally calcareous mudstones that have eroded away to expose track casts on the undersides of the ledges.

A second site in a smaller, 20 m thick outcrop, also in the upper Iron Springs Formation, is situated at the mouth of Little Canyon north of Paragonah, and east-northeast of Parowan Gap across Parowan Valley in the Hurricane Cliffs (Locality 2, Fig. 1). This locality was discovered by Steven Heath, formerly of Southern Utah University, and reported to the senior author by Steve and Sally Stephenson (Utah Friends of Paleontology)**.** The locality has a single identifiable *in situ* ornithopod track that appears to overlap another large, probably ornithopod track. These tracks are very large, the largest found in the Iron Springs Formation to date.

Previous paleontological work in the Iron Springs Formation has been very limited due to a lack of productive localities and limited exploration for new sites. However, Jeff Eaton (Weber State University, Ogden, Utah) began prospecting the Iron Springs in the late 1980s. Eaton and James Kirkland (Utah Geological Survey) made the first serious prospect in the formation in the fall of 1990, finding dinosaur remains and important microvertebrate localities in the Gunlock area and on the west side of the Pine Valley Mountains (Kirkland et al., 1998; Eaton, 1999). All of the specimens collected by Eaton and Kirkland from 1990-1992 are housed at the Museum of Northern Arizona in Flagstaff (Eaton, 1999).

Specimens recovered by these early prospects were recovered via screen-washing fine-grained deposits that did not necessarily show any vertebrate fossils weathering out on the surface. This work produced many important vertebrate microfossil sites in the Iron Springs Formation, and has increased our knowledge of its paleontology (Eaton, 1999, 2004). Table 1 shows all of the known vertebrate body fossils recovered thus far from the entire Iron Springs Formation. Specimens collected by Eaton from 1993 to present are reposited in the Utah Museum of Natural History, Salt Lake City, Utah.

In the summer of 1997, a partially articulated skeleton of a hadrosaur, consisting of the hips, hindlimbs, and a portion of the caudal vertebral column were discovered on private land in Gunlock, Utah (Ludwig, 1997; Kirkland et al., 1998). Unfortunately, the site was poorly excavated, and all of the bones are now unaccounted for.

Recent investigations by the authors in both Iron and Washington counties have resulted in the discovery of several new and potentially productive microsites as well as the remains of larger vertebrates, including dinosaur, crocodylian, turtle, and fish bones.

INSTITUTIONAL ABBREVIATIONS

CU, University of Colorado at Denver, Dinosaur Tracks Museum, Denver, Colorado; **SGDS**, St. George Dinosaur Discovery Site at Johnson Farm, St. George, Utah. Specimens not collected were assigned field numbers. These are the definitions for all cited prefixes: **APG**, "Andrew – Parowan Gap"; **LC04**, "Little Canyon 2004"; **PG03**, "Parowan Gap 2003"; **PG04**, "Parowan Gap 2004"**.**

METHODS

The localities of all identifiable and significant tracks, fossils, and sedimentary structures were recorded by Global Positioning System (GPS), including *in situ* and talus specimens. Locality data are available through the State Paleontologist's office at the Utah Geological Survey in Salt Lake City. All specimens are from Bureau of Land Management (BLM) land through the State Paleontologist's permit; collected specimens are housed at the UMNH. A detailed stratigraphic section was measured at Parowan Gap, and all fossil-bearing layers and sedimentary structures recorded (Fig. 2).

Track measurements were taken from the better preserved examples. The following measurements were taken for tridactyl tracks as illustrated in Figure 3: (1) track length (TL), measured from the "heel" to anterior tip of digit III, (2) maximum track width (TW), from the distal end of digit II to the distal end of digit IV, (3) divarication angles between digits II-III, III-IV, and II-IV (A, B, and C respectively), and (4) total track length (TTL), in-

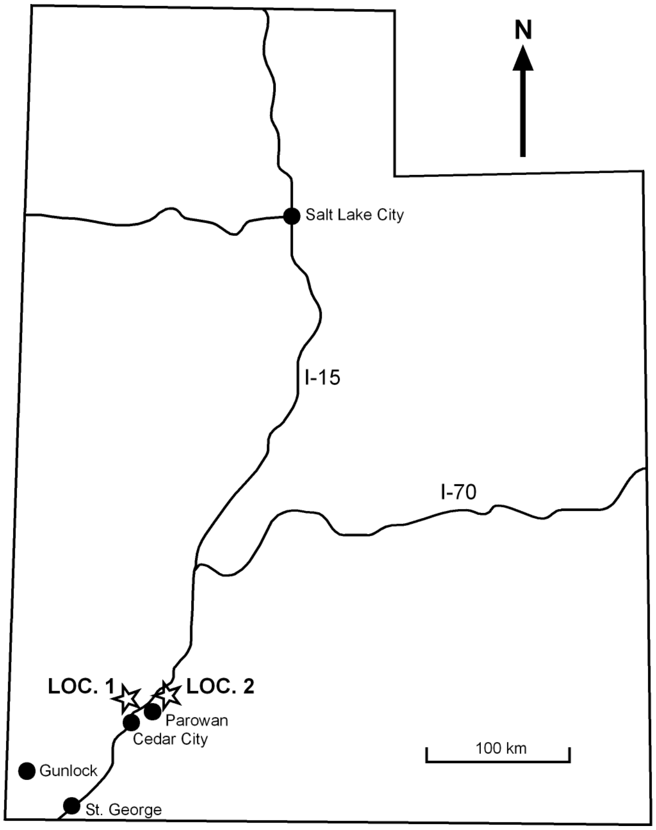

FIGURE 1. Map showing localities of two new dinosaur tracksites near the town of Parowan, Iron County, Utah. Locality 1 indicates Parowan Gap; locality 2 shows the approximate position of Little Canyon north of Paragonah.

cluding any metatarsal impression. Measurements were also taken of digit width and length, following Currie et al. (2003), and maximum track depth. For the theropod tracks, digit width, track width, total track length, divarication angle, and track depth measurements are the same ones used for ornithopod tracks described above. Measurements of the ceratopsian tracks are described below (Table 3), along with the detailed specimen description. Orientations of all *in situ* tracks were taken.

Photographs were taken with a Nikon Coolpix 8700 digital camera, and some of the better specimens were traced with acetate. All acetate tracings were then scanned and used in plates for comparison with corresponding photographs.

Two replicas taken from these latex peels are as follows: CU 227.1 for the ceratopsian manus pes set and CU 227.2 the best preserved ornithopod track. Duplicate replicas are also preserved at the St. George Discovery site as SGDS.824 and SGDS.825, respectively.

STRATIGRAPHY AND SEDIMENTOLOGY

The stratigraphic section measured spans the uppermost, approximately 90 m of the Iron Springs Formation in eastern Red Hills at Parowan Gap. The “upper” Iron Springs Formation in other areas is as much as 540 m thick (Fillmore, 1991). Maximum thickness of the Iron Springs Formation recorded at Gunlock is approximately 950 m (Johnson and Baer, 1984), although Willis and Higgins (1995) record a thickness of 1067-1220 m on the south side of the Pine Valley Mountains.

The Parowan Gap section is unconformably overlain by the lower conglomerate member of the Grand Castle Formation (Goldstrand and Mullett, 1997); the base of the Iron Springs Formation is not exposed in the Iron Springs thrust sheet (Maldonado and Williams, 1993), and the bottom of our measured is indiscernible due to talus blocks and other debris covering it (Fig. 2). The section is composed of alternating sandstone, conglomerate, siltstone, and mudstone deposits representing channel,

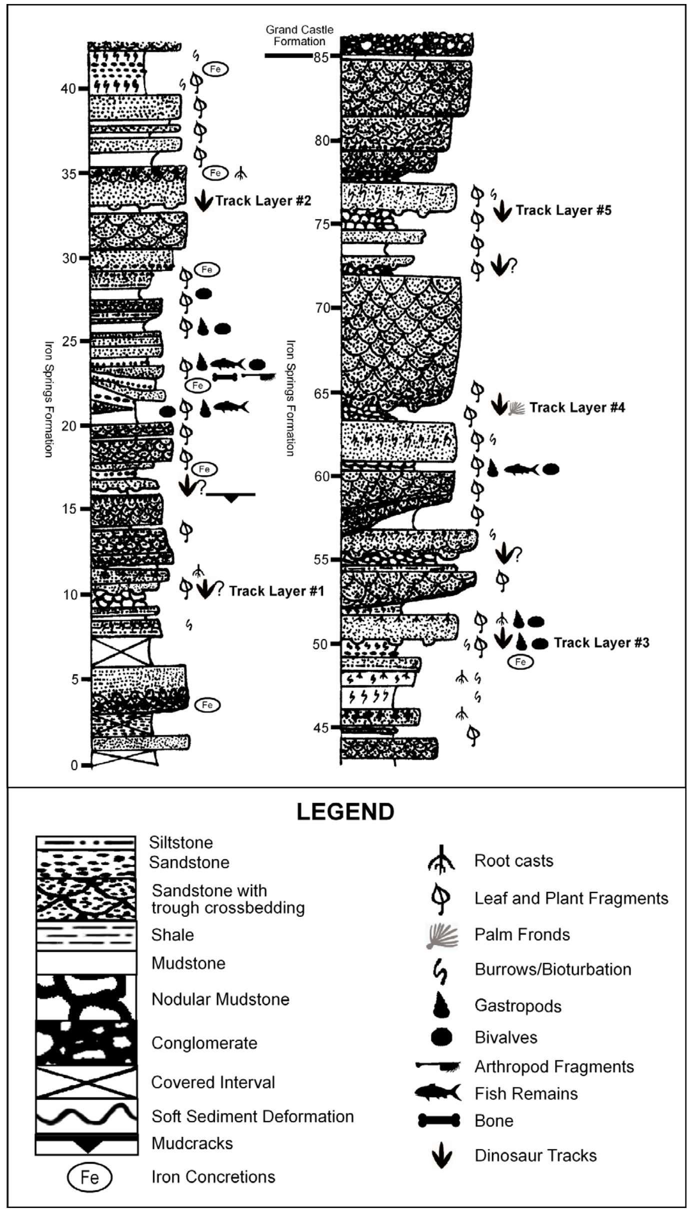

FIGURE 2. Generalized stratigraphic section at Parowan Gap showing the upper portion of the Iron Springs Formation and overlying Grand Castle Formation.

overbank, and floodplain deposits. Generally, the thick packages of tabular sandstones and thinner overbank-type mudstones and siltstones at Parowan Gap probably represent fine-grained, braid plain deposits (Goldstrand, 1994; Goldstrand and Mullett, 1997; Eaton et al., 2002).

Sandstone is the dominant lithology in the upper Iron Springs Formation, and most beds represent braided stream channels. Individual sandstone beds in the Parowan Gap section range from 0.5-7 m thick, with the thicker deposits occurring higher in the section (Fig. 2). The majority of these sandstone beds contain low to moderately angled crossbeds composed of medium- to coarse-grained quartz, quartzite, feldspar and limestone lithics preserved as pebble stringers. Crossbeds in the sandstones range in height from about 0.5-12 cm and 3-50 cm in length, with size increasing toward the top of the section. Pebble stringers containing mostly quartzite pebbles about 0.5-1 cm in diameter occur parallel to the crossbeds. Stringers become more abundant and the pebbles larger up section.

Conglomerates composed of intra- and extrabasinal pebbles are abundant at the base of scoured sandstone beds represent channel lag deposits. The conglomeratic beds are from 10-40 cm thick and contain pebbles that

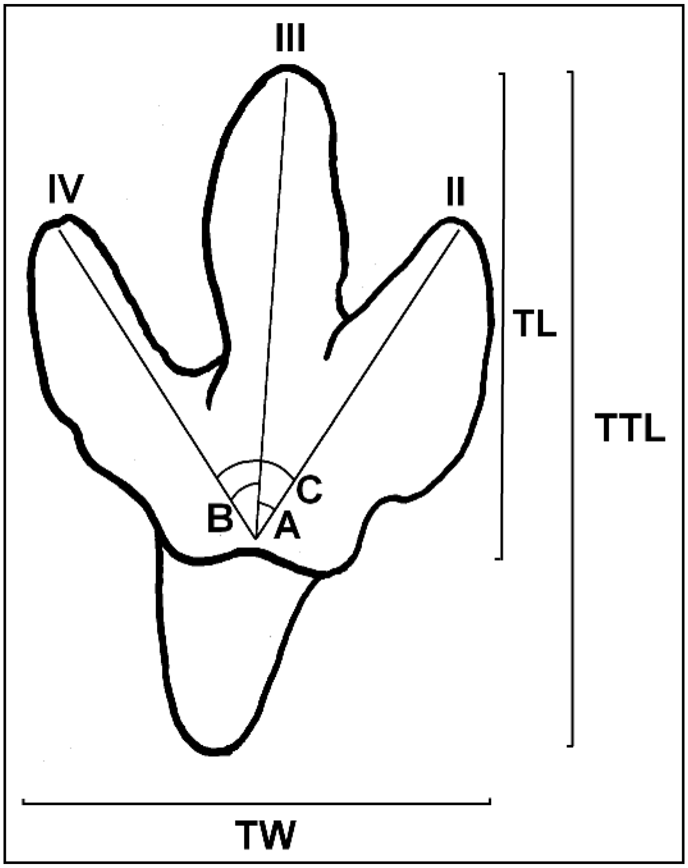

FIGURE 3. Diagram of an ornithopod track showing the kinds of measurements taken and a list of abbreviations used. **II**, **III**, **IV** = digits; **A** = divarication between II-III; **B** = divarication between III-IV; **C** = divarication between II-IV; **TL** = track length from anterior end of digit III to posterior border of "heel"; **TTL** = total track length; and **TW** = maximum track width.

range in size from 0.5-2 cm. Conglomeratic beds in other outcrops of the Iron Springs Formation in southwestern Utah can be tens of meters thick in places (Johnson and Baer, 1984).

Extrabasinal conglomerates occur throughout the Parowan Gap section, but only make up a small part of the deposited sequences overall. These pebble conglomerates are composed primarily of well-rounded quartzite up to 1 cm in diameter with minor occurrences of limestone (~5%). Goldstrand (1994) considered the rounding of these extrabasinal conglomerate pebbles to be primary in origin, with provenance of the conglomerates in the Wah Wah Mountains, Blue Mountain, and Iron Springs thrust sheets (Fillmore, 1991; Goldstrand, 1994; Goldstrand and Mullett, 1997), located between 1-30 km to the west (Goldstrand and Mullett, 1997). Several authors (Fillmore, 1991; Goldstrand, 1994; Goldstrand and Mullett, 1997) consider the Late Proterozoic-Early Cambrian Prospect Mountain Formation as the most likely origin of these quartzite pebbles. Limestone pebbles constitute about 5% of the extrabasinal clasts. These pebbles range in size from 0.5-0.7 cm in diameter and could be derived from a number of different Paleozoic limestone formations in the Wah Wah Mountains. Chert clasts are reportedly abundant in the Gunlock area (Johnson and Baer, 1984), but very few are recognized in the Parowan Gap section. Chert pebbles could have originated from a variety of sources including Paleozoic and/or Early Mesozoic formations.

Intrabasinal conglomerate clasts of sandstone and mudstone range in size from a few millimeters to 2 cm in diameter. The larger fragments are highly angular, and many were probably derived from the small Iron Springs thrust sheet located about 1 km to the west of the measured section. This thrust sheet overturned lower units of the Iron Springs atop upper portions of the formation (Goldstrand and Mullett, 1997).

TABLE 1. List of known vertebrate body fossils through the entire Iron Springs Formation of Washington and Iron counties, Utah (from Eaton, 1999).

Chondrichthyes
- Hybodontiformes
  - *Hybodus* sp.
  - ?*Lissodus* sp.
- Rhinobatoidea
  - Rhinobatoidea indet.
- Neoselachii
  - cf. *Cantioscyllium* sp.

Osteichthyes
- Osteichthyes indet.
- *Lepisosteus* sp.

Reptilia
- Testudines
  - cf. *Naomichelys* sp.
- Crocodylia
  - Crocodylia indet.
- Ornithischia
  - Neoceratopsia
    - Neoceratopsia indet.
  - Ornithopoda
    - Hadrosauridae indet.
  - Ankylosauria
    - Ankylosauria indet.
- Saurischia
  - Theropoda
    - Dromaeosauridae indet.
    - Troodontidae indet.

Mammalia
- Marsupialia
  - *Alphadon* sp.
- Multituberculata
  - *Bryceomys* sp.
  - *Paracimexomys* cf. *priscus*

With channelized sandstone making up over half of the section, crossbeds are the dominant sedimentary feature. The crossbeds range in height from.5-12 cm and from approximately 3-50 cm in length. The paleocurrent orientations obtained from most of the Iron Springs are E-NE (Fillmore, 1991). In contrast, the Parowan Gap section shows paleocurrent directions with a more E-SE orientation. Crossbed orientations were used to determine paleocurrent directions.

Many of the overbank deposits contain an abundance of plant material. At least five paleosol horizons have been recognized in the Parowan Gap section, all containing abundant root casts replaced with concretionary iron. Iron staining is extremely common in the upper Iron Springs Formation, representing secondary replacement, staining, and Liesegang banding. Iron replacement is so pervasive that all root casts, much of the plant material, and even some gastropods have been replaced by iron. Iron staining occurs in all lithologic types and helps give the Iron Springs Formation its buff color. Liesegang bands range in diameter from a few cm to 0.5 m across. The bands are found almost exclusively in the sandstone layers, although some of the concentric patterns can be seen as more of a staining feature in mudstone layers containing paleosols.

GEOLOGICAL AGE

The age of the base of the Iron Springs Formation is considered to be early Turonian in Summit Canyon, located near Parowan Gap, based on oyster-rich beds of transgressive rock sequences (Eaton et al., 2002). Situ-

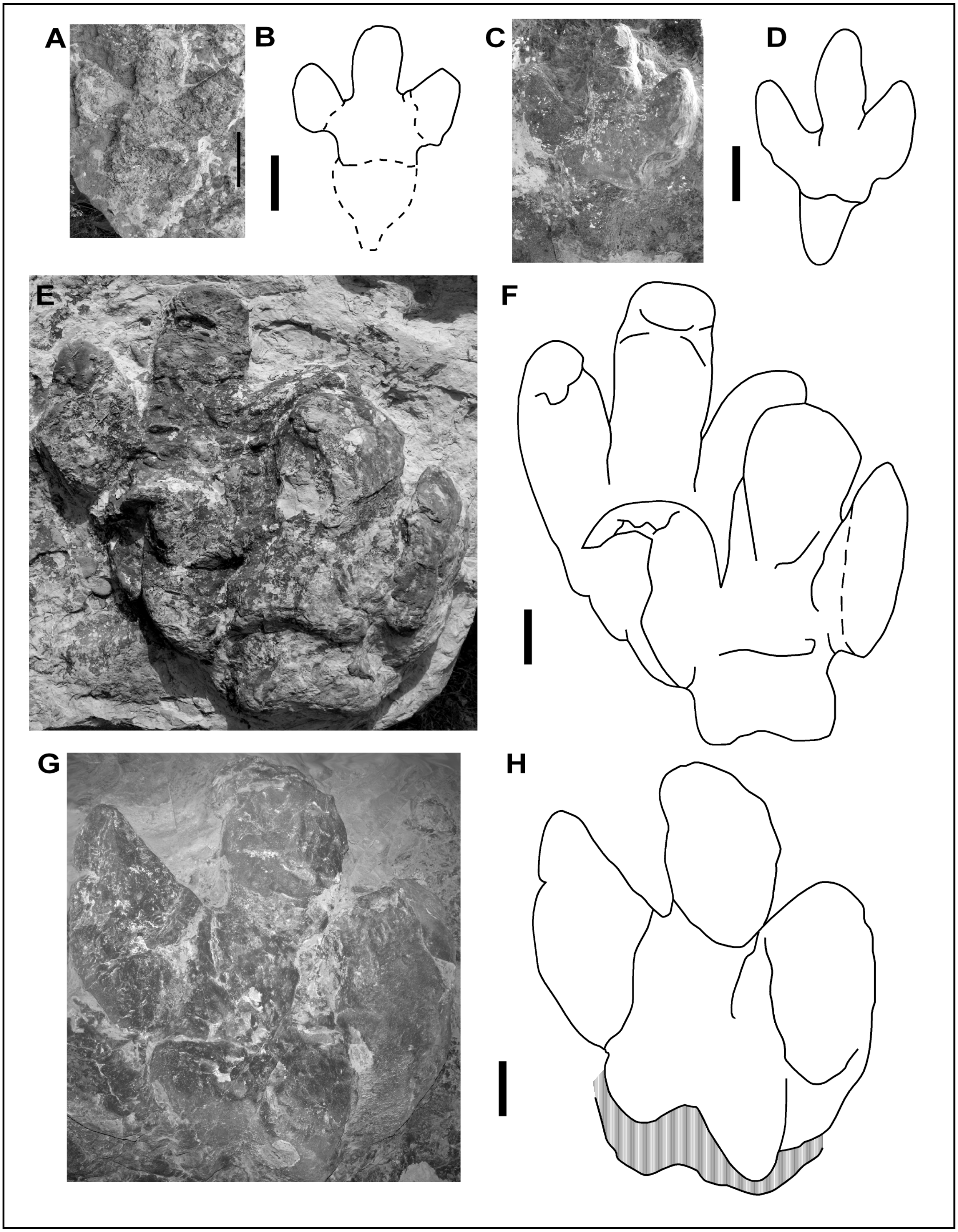

FIGURE 4. Photographs with corresponding outline tracings of representative ornithopod tracks (most likely hadrosaurs) from Parowan Gap (A-F) and Little Creek Canyon (G-H). **A-B,** Ornithopod track (PG04-11) showing possible "heel" and metatarsal impression. **C-D,** Right ornithopod pes track (SGDS.825) showing clear "heel" and metatarsal impressions. The bright white material on and around this track is plaster damage. **E-F,** Two large, overlapping ornithopod tracks. Specimen PG04-2.1 (lower right) overlaps PG04-2.2 (upper left). **G-H,** Little Canyon right ornithopod pes track (LC04-1) with "slip marks" (shaded) along the posterior margin. All specimens shown in this figure are preserved as natural casts, and all tracings are not reversed to show actual track orientation. Scale bars measure 10 cm.

TABLE 2. A selection of ornithopod (probably hadrosaur) track measurements from the Iron Springs Formation, Iron County, Utah. All measurements in cm.

Parameter	SGDS.825.	PG04-2.1.	PG04-2.2.	PG04-2-4.	PG04-3.	PG04-6.	PG04-10.	PG04-11.	LC04-1.
Track Length	29	57	55	~18	~37	~35	38	27	73
Total Track Width	29	55	50	21	37.5	~32	30	30	64
II-IV divarication	70°	55°	55°	105°	75°	70°	77°	89°	62
Left-III divarication	38°	25°	33°	55°	35°	42°	37°	48°	25
III-Right divarication	32°	30°	25°	50°	42°	45°	36°	45°	34°
Left Digit Length	23	34	~34	9	27	9	20	19	54
Digit III Length	~24	46	~39.5	~11	29	~25	21	20	62
Right Digit Length	23	38	~36	10	28	-	16	18	51
Left Digit Width	7	13	7.5	9	~8	10	14	9	28
Digit III Width	8	21	16	9	12	10	10	9	21
Right Digit Width	10	13	-	8	11	10	-	9	2
Anterior Depth	7	95	7.5	4	5	2.5	2.5	3	11
Posterior Depth	8.5	11	5.5	4	4	5.5	5	4	18

ated farther to the west, and closer to the Parowan Gap track localities, R. Mark Leckie (University of Massachusetts, Amherst) recovered a specimen of the bivalve *Mytiloides kossmati*, indicating the presence of normal marine deposits of early Turonian age (Eaton et al., 2002; J. Kirkland, personal commun., 2004). Other localities near the base of the Iron Springs Formation on the eastern side of the Pine Valley Mountains produce a high diversity, brackish water molluscan fauna. Eaton et al. (1997) and Eaton (1999) suggests that these brackish deposits are probably associated with the maximum transgression of the Greenhorn Sea, and indicate a late Cenomanian or early Turonian age.

Goldstrand (1994) considered the upper part of the Iron Springs Formation to be upper Santonian-lower Campanian(?) in age, representing fluvial deposition of sediments that originated from the Wah Wah and Blue Mountain thrust sheets located farther to the west along the Utah-Nevada border. The overlying Grand Castle Formation (Fig. 2) is considered to be Lower Paleocene and represents an east to southeast flow of braided river systems with the same source lithics as the underlying Iron Springs Formation (Goldstrand, 1994; Goldstrand and Mullett, 1997). We concur with these interpretations. Furthermore, a biotite-rich ash located 231 m below the upper contact of the Iron Springs Formation in Parowan Canyon has produced an $^{40}Ar/^{39}Ar$ age of 83±1.1 Ma (Eaton et al., 1999; Eaton et al., 2002), suggesting a Santonian-Campanian age for the upper part of the unit at both the Parowan Gap and Little Canyon track localities. The Santonian-Campanian boundary is 83.5 Ma (Gradstein et al., 2004).

As mentioned above, vertebrate body fossils from the Iron Springs Formation are uncommon, yet they have been recovered over a majority of the geographic extent of the formation. A specimen attributed to the turtle *Naomichelys* has been found in brackish water deposits near the bottom of the Iron Springs sequence exposed in Parowan Canyon (Eaton, 1999; Eaton et al., 2002). *Naomichelys* is commonly found in the Santonian age John Henry Member of the Straight Cliffs Formation located to the southeast of Parowan on the Colorado Plateau. Eaton et al. (2002) thus suggested a possible correlation between the John Henry Member of the Straight Cliffs and the lower portion of the Iron Springs Formation in Parowan Canyon.

DINOSAUR TRACK DESCRIPTIONS

The majority of vertebrate ichnites are those of ornithopods, most likely hadrosaurs, with less common theropod tracks, and only a single manus-pes set representing a ceratopsian. Nearly all specimens from the Parowan Gap localities have been found on fallen blocks, because no large bedding plane surfaces are exposed.

Ornithopod Footprints

Approximately 80 ornithopod ichnites have been recognized at all Iron Springs localities both in Parowan Gap and Little Canyon (Fig. 4). All are pes tracks, although some conspicuous natural casts may be manus traces, though better specimens are needed to confirm this. Pes prints range in size from 18 to 73 cm in total length (distal end of digit III to the back of the "heel") and 21 to 64 cm in width (Table 2).

Ornithopod tracks from the Parowan Gap localities range in size from 18-57 cm in total length to 21-55 cm at maximum width (Table 2). Several specimens show posterior traces interpreted as heel drag marks or metatarsal impressions (Figs. 4A-D). The majority of the easily recognizable tracks are isolated footprints, and some specimens are composed of overlapping tracks (Figs. 4E-H). These overlapping tracks, as well as others not figured here, show possible "hoof" or ungual impressions. Orientations of *in situ* dinosaur tracks indicate trends in a more or less N-NW and NW trend at Parowan Gap. Paleocurrent data collected in close association with the tracks in the upper Iron Springs Formation indicates flow toward the E-SE. This does not appear to correspond with dinosaurs paralleling river or stream channels.

One, and possibly second, ornithopod trackways have been located thus far. The first is a measurable example of a possible trackway on a fallen talus block that consists of three footprints with a stride of 60 cm with track lengths and widths averaging 28 and 29 cm, respectively. The second is a definite ornithopod trackway, located at track layer 4 (Fig. 2), comprises footprints preserved as casts on the underside of a ledge located high up on the cliff face. Because of its precarious position, trackway or footprint metrics cannot be obtained. Footprints in this trackway appear to be comparable in size with others for which measurements were obtained (Figs. 4C-D). Several isolated ornithopod ichnites have been located *in situ* on track layers 2, 3, 4 and 5 (Fig. 2).

The Little Canyon specimen (Figs. 4G-H) appears to consist of two large, overlapping tracks; the remainder of the surface shows heavy dinoturbation. Possible ornithopod manus impressions are present at this site. This locality preserves only a single identifiable, *in situ* ornithopod track, but it is very large (73 cm long and 64 cm at maximum width). This track is oriented in a N-NW direction. Though large, this specimen still does not approach the enormous size of ornithopod tracks from the Upper Cretaceous "Mesaverde" Group of Utah, Colorado, and Wyoming, which measure between 81 and 97 cm in width (Lockley et al., 1983; Carpenter, 1992).

The following ichnotaxonomic characteristics are noted for most of the better preserved Iron Springs Formation ornithopod tracks (Fig. 4): most specimens display weak to strong bilobed "heels"; tracks are slightly longer than wide; digit III is sometimes asymmetrical, being more rounded laterally than medially; digit II is sometimes more tapered distally and longer than digit IV, which is slightly shorter and more rounded; ungual impressions sometimes present; and "heel" drag marks and/or metatarsal impressions are sometimes present.

The overall ichnotaxonomy of large ornithopod tracks has certainly been confused until recently (Lockley et al., 2003). Even though

TABLE 3. Measurements of manus and pes ceratopsian tracks from the Iron Springs Formation, Iron County, Utah. All measurements in cm.

Parameter	CU 227.1 or SGDS.824
Manus Length	17
Manus Width	23
Pes Length	25
Pes Width	28.5
Pes divarication angles:	
I-IV	95°
I-II	50°
II-III	30°
III-IV	37°
Pes Digit Lengths:	
I	10
II	13
III	15
IV	12
Pes Digit Widths	
I	5
II	6
III	6
IV	5
Manus-Pes Distance (center to center)	35
Manus Depth	8
Pes Depth	7

ichnotaxonomy should not be based on presumed trackmaker identity, the problem has been compounded by the fact that large ornithopod tracks from the Cretaceous could represent either iguanodontian or hadrosaurian track producers, with a temporal overlap of both groups during the mid-Cretaceous. Lockley et al. (2003) systematically assessed each ichnotaxon, reducing the number of valid ichnogenera of large ornithopod tracks and naming *Hadrosauropodus langstoni* based on well-preserved ornithopod tracks from the St. Mary River Formation (?Campanian-Maastrichtian) of Alberta. These tracks show skin impressions and are described as true hadrosaur tracks.

Although some Iron Springs ornithopod tracks exhibit good morphology, including scale scratch marks, too few tracks, trackways, and/or manus impressions are preserved to attempt to place these ornithopod tracks ichnotaxonomically at this time. However, we can infer with confidence that the Iron Springs ornithopod tracks were made by hadrosaurs based on their late Santonian-early Campanian age.

CERATOPSIAN FOOTPRINTS

A single, left manus-pes set of ceratopsian tracks, preserved as natural casts (Fig. 5; Table 3), was discovered on a fallen block by Jim Kirkland (Utah Geological Survey) in 2002 at one of the Parowan Gap localities. The pes appears to have four, somewhat blunt digits. Digits II and III appear sharp in Figure 5B, but this is only an artifact of low quality preservation, since digits II-IV are broken distally (Fig. 5A). Furthermore, the broken toes have oxidized, as has digit I on the manus, and have a darker appearance resembling the surrounding, iron-replaced plant fragments (Fig. 5B).

The left manus track clearly displays digits I and II in a more anterior position with faint bulges representing digits III and IV (Fig. 5B). The distance from the midpoint of the manus to that of the pes measures 35 cm. The relative position of the manus appears to be turned outward from the midline of the pes by about 45° and being placed more laterally. Digit I and II of the manus are projected in a more anterior direction.

The Parowan Gap specimen has the appropriate arrangement of digits, overall foot and manus shapes, and distance between the manus and pes to represent small ceratopsian tracks. Lockley and Hunt (1995) eliminated any possibility of the tracks from latest Cretaceous Laramie Formation of Colorado as being attributable to saurischians, ornithopods, stego-

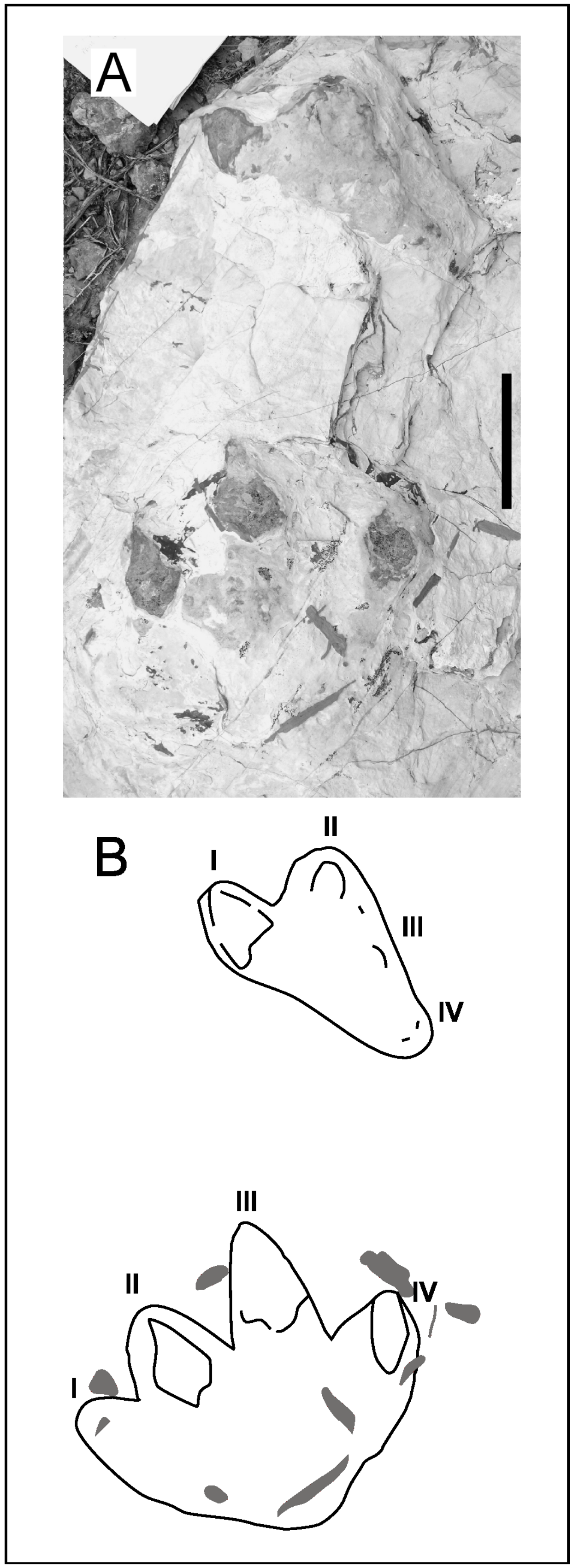

FIGURE 5. A ceratopsian left manus and pes set (CU 227.1 and SGDS.824.) preserved as natural casts from Parowan Gap. Note abundant oxidized plant fragments associated with the pes track (grey on B). **A,** Photograph of natural cast. **B,** Tracing of natural cast in negative relief. Scale bar measures 10 cm.

TABLE 4. A selection of theropod and theropod–like (indicated with *) track measurements from the Iron Springs Formation, Iron County, Utah. All measurements in cm.

Parameter	**PG04-5.1.**	***PG04-5.2.**	**PG04-9.**	**PG03-41.1.**	**PG03-41.2.**	**APG.11.1.**
Total Track Length	18	19	29	23	25	24
Total Track Width	11	19	20	17	19	18
II-IV divarication	65°	85°	60°	60°	60°	64°
II-III divarication	39°	45°	38°	35°	35°	36°
III-IV divarication	30°	42°	20°	25°	25°	37°
Digit IV Length	8	9	~16	14	17	14
Digit III Length	10	13	20	18	20	15
Digit II Length	8	9	17	15	15	10
Digit IV Width	3	5	4.5	4	4	1.5
Digit III Width	4	~3	8	6	5	3
Digit II Width	4	~3	4.5	3	3.5	2.5
Anterior Depth	1.5	1.5	-	5	2.5	2
Posterior Depth	2	2.5	-	5	-	3.5

saurs, psittacosaurs, or pachycephalosaurs. This leaves two potential candidates: ankylosaurs and ceratopsians.

Ceratopsians have five manual digits with digit V being greatly reduced. Ankylosaurs also have five digits on the manus, but some species may have fewer. Both ceratopsians and ankylosaurs have a tetradactyl pes. The manus is only slightly smaller than the pes in ankylosaurs, whereas the manus in ceratopsians is about two-thirds the size of the pes (Lockley and Hunt, 1995). *Tetrapodosaurus borealis* tracks from the Lower Cretaceous of British Columbia (Sternberg, 1932), typically attributed to an ankylosaur, have only slightly smaller manus than pes prints; their overall shape thus appears to more closely match ankylosaur than ceratopsian tracks. Size comparisons between the manus and pes are not reliable indicators of identity, and this can clearly demonstrated by tracks described and illustrated by Lockley et al. (this volume) from the Richardson Ranch Site in the Dakota Group of Colorado.

Since the position and orientation of the manus-pes in relationship to each other do compare well with other known ceratopsian tracks (Lockley and Hunt, 1995). Furthermore, the asymmetrical shape of the manus can also be considered distinct from those produced by ankylosaurs. Thus, we conclude that the Parowan Gap specimen was produced by a ceratopsian dinosaur. Lockley et al. (2001) have shown that new ceratopsian track discoveries from the Laramie Formation of Colorado indicate that digits I and II are larger than digits III-V and anteriorly directed.

We determine the Parowan Gap specimen represents the oldest recorded ceratopsian tracks in North America, and probably in the world. The previously oldest ceratopsian tracks are from the Campanian Blackhawk Formation near Price, Utah (Lockley et al., 1983; Carpenter, 1992). Kaufmann (1977) reports a radiometric age range for the Blackhawk Formation between 82-77.5 Ma, and the formation is estimated to span approximately 4.5 million years (Carpenter, 1992). Since the Parowan Gap tracks are late Santonian-early Campanian (83.5 Ma for the Santonian-Campanian boundary, Gradstein et al., 2004) in age, we consider them slightly older than the Blackhawk tracks.

THEROPOD FOOTPRINTS

A total of seven theropod footprints have been recognized to date, all occurring at Parowan Gap localities. A single theropod track was found *in situ* (Figs. 6A-B) with a S-SE orientation. This *in situ* track is very well-preserved and located on track layer 5 (Figs. 2, 6A-B). All remaining theropod tracks were found in talus blocks (Table 4).

One definite and two possible theropod track morphotypes can be recognized at Parowan Gap (Figs. 6-7). The most common theropod morphotype displays a more elongate and wider digit II than digit IV and a greater divarication angle between digits II and III (35°-39° range) than between III and IV (20°-37° range) (Table 4). Tracks of this type are relatively small, ranging in size from 18-29 cm long and 11-20 cm wide and

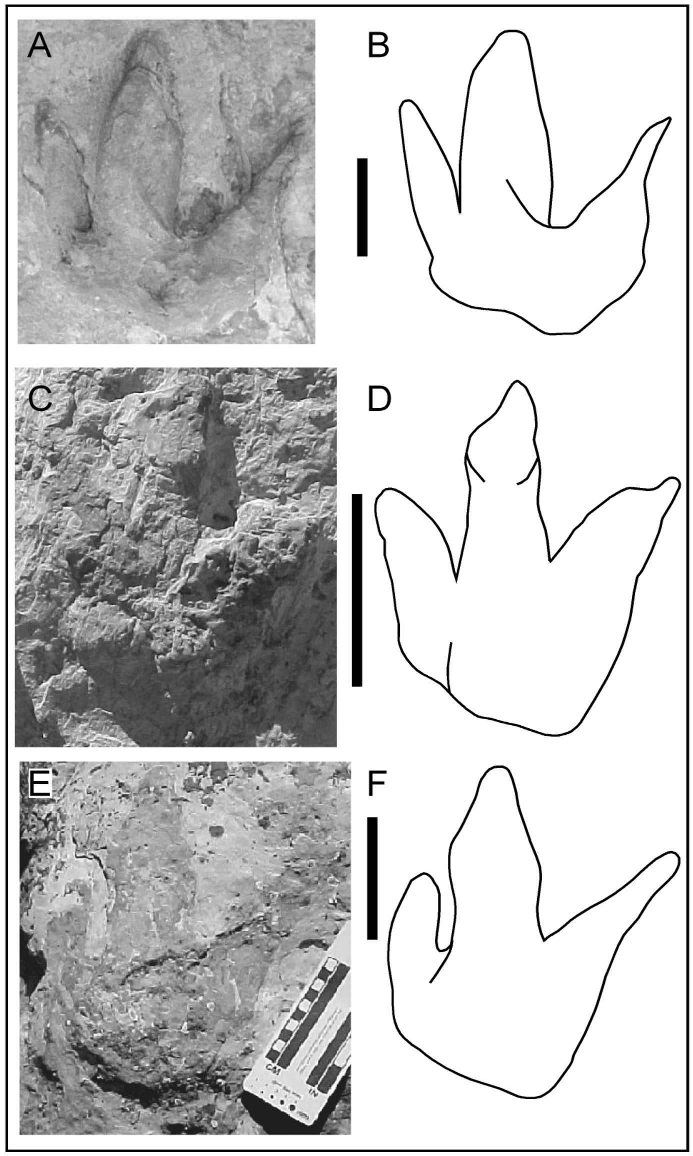

FIGURE 6. THEROPOD ICHNITES FROM PAROWAN GAP: **A-B**, *In situ* left theropod pes track (PG03-41.2). **C-D,** Left theropod pes track (PG04-5.1) on talus block. **E-F,** Largest theropod track from the Iron Springs Formation (PG04-9). All specimens shown are preserved as natural casts in negative relief. Scale bar measures 5 cm for A-B and 10 cm for C-F.

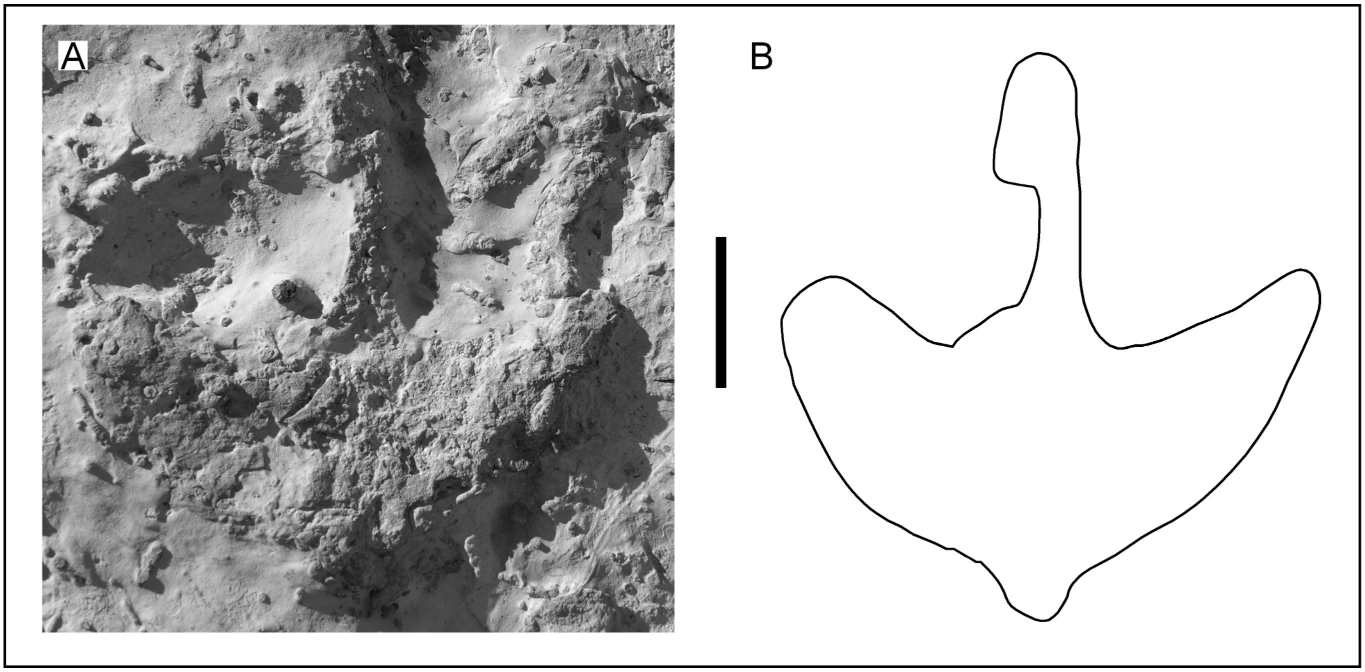

FIGURE 7. An unidentified theropod footprint type (PG04-5.2) preserved as a natural cast and surrounded by invertebrate burrows. This track was possibly produced by an ornithomimosaur; however the overall shape and wide divarication angle between the digits might be a relic of weathering and/or poor preservation. **A,** Photograph of natural cast. **B,** Tracing of natural cast in negative relief. Scale bar measures 5 cm.

ranging in depth from 1.5 to 5 cm (Table 4), but overall track shape remains the same. Thus far, only dromaeosaurid and troodontid body fossil remains have been found in the Iron Springs Formation (Table 1), taxa whose predominant size ranges correspond to the sizes of the tracks. We can rule out any deinonychosaurian theropod as a producer of the Iron Springs tracks since the usually have an abbreviated digit II given that this digit appears to be held up off the ground, creating functionally didactyl pes prints. Therefore we cannot speculate on the producer of these theropod tracks at this time.

A second possible theropod morphotype from Parowan Gap is represented by a poorly preserved and extensively weathered footprint (Fig. 7; Table 4). It has a wider divarication angle between digits II and IV than the aforementioned theropod morphotype (Table 4). We suggest that this track could have been made by an ornithomimosaur because of its wide divarication angle, but this is conjectural.

DISCUSSION

The Upper Cretaceous Iron Springs Formation is a terrestrial unit that crops out throughout much of southwestern Utah and was deposited by in an upland fluvial braided stream system. The southernmost outcrops were deposited in braided stream and lacustrine environments (Fillmore, 1991). The upper part of the formation measured in the study area was deposited in a meandering stream environment. This 90 m section was deposited on the eastern end of an alluvial plain that extended from Sevier Orogeny-derived highlands to the west to the western shores of the Cretaceous Western Interior Seaway to the E and SE.

Dinosaur tracks in the upper Iron Springs Formation actually appear to be quite abundant given that only two small and steep outcrop areas have produced over 80 footprints thus far. Its wide size range of ornithopod tracks may, in the future, contribute to an ability to distinguish non-hadrosaur iguanodontian and hadrosaur footprints. Theropod tracks of one, and possibly two, morphotypes have been found at localities in Parowan Gap. The most common form of theropod track displays an elongate digit II and a wider divarication angle between digits II-III than of digits III-IV. By far the most important track found in the upper Iron Springs Formation is a manus-pes set of ceratopsian tracks. This specimen is definitely the oldest known ceratopsian trace fossil in North America, if not in the world. However, older North American ceratopsian body fossils of Turonian age are known from the Moreno Hill Formation of New Mexico (Wolfe and Kirkland, 1998) and the Smoky Hollow Member of the Straight Cliffs Formation (Eaton, personal commun., 2006).

Future work on the Iron Springs Formation should include further exploration for dinosaur tracks and body fossils. Multiple micro-vertebrate sites are in need of collection, as are descriptions and interpretations of invertebrate body and trace fossils and diverse plants.

ACKNOWLEDGMENTS

Our special thanks go out to Steven Heath for bringing both the Parowan Gap and Little Creek Canyon track sites to our attention. Thanks to the many Utah Friends of Paleontology members for field assistance in locating and documenting further specimens. We thank Dr. James I. Kirkland (State Paleontologist, Utah Geological Survey) and Gardiner Daley (Regional Archaeologist for the Bureau of Land Management) for assisting with permits and field work. There help allowed for the location and data collection of many of the specimens discussed in this publication. Special thanks to the Faculty of Geology at Southern Utah University in Cedar City for use of their facilities and equipment during initial field work. Also thanks to Spencer G. Lucas, Jeffrey G. Eaton, and James I. Kirkland for reviewing the manuscripts at different phases of preparation.

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