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A review of dinosaur track occurrences from the Morrison Formation in the type area around Dinosaur Ridge

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ABSTRACT

Although the type section of the Morrison Formation, near Denver Colorado, now also well-known as Dinosaur Ridge, has since 1877 been world-famous as the source of iconic Late Jurassic dinosaurs like Stegosaurus, Apatosaurus and Diplodocus, little detailed information has been published on fossil footprints from the formation this area. Late Jurassic (Morrison) footprints were not reported from the type section at Dinosaur Ridge until the early 1990s. Since then other footprints have been reported, and their precise stratigraphic occurrences documented. To date diagnostic examples of theropod, sauropod and thyreophoran (stegosaur) tracks have been documented from at least three different locations. The quality of preservation of these tracks ranges from moderately good to quite poor. Nevertheless more than 25 individual footprints, including some undertracks, have been identified unequivocally, including several manus-pes sets of quadrupedal trackmakers. The track assemblage are typical of many small
Morrison Formation ichnofaunas and are consistent with what is known of the body fossil assemblages. The track assemblage is reviewed and compared with summary data from the 64 Morrison Formation tracksites currently known.

Key words: Dinosaurs, footprints, Morrison Formation, Upper Jurassic, Dinosaur Ridge.

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1. Introduction

The Morrison Formation is world famous as the source of some of the world’s iconic Late Jurassic dinosaurs, like Stegosaurus, the Colorado State fossil, and the sauropods Apatosaurus and Diplodocus. All these taxa were reported, beginning in 1877, from what was to become the type section near Morrison, Colorado. This type section was formally defined in the mid 1940s by Waldschmidt and LeRoy, (1944) based on outcrops along Alameda Parkway (Fig. 1), a road constructed in the 1930s, over what geologists then referred to informally as the Dakota Hogback. As noted below, this section was measured before the Interstate 70 (I 70) roadcut was excavated, thereby increasing the exposed area of accessible outcrops (Fig. 1). The type section of these Upper Jurassic Morrison outcrops occurs on the west side of the hogback, stratigraphically below the Cretaceous sandstones that cap the hogback and make up the dip slope on the east side (inclination ~40° east). In 1973 this area of the hogback was designated as the larger of two properties named the Morrison Fossil Area National Natural Landmark (MFANNL). At the time Jurassic dinosaur tracks had not been identified along Alameda
Parkway west of the hogback ridge within the boundary of this area. The Cretaceous tracks known from the Dakota Sandstones on the east side of the hogback and their history of discovery (Lockley, 1987) are unrelated to the Jurassic Morrison Formation track discoveries discussed here. Later in the 1990s, when the Jurassic tracks were first identified, the hogback or “ridge” between Morrison and Colorado Highway 40 (Colfax Avenue) was also formally designated, by the US Geological Survey, as Dinosaur Ridge. The section along Alameda Parkway was developed as a well-known interpretative trail, including a stop on the west side where the dinosaur tracks were explained by interpretative signs (Fig. 2). The creation of Dinosaur Ridge as a well-defined geographical area not only enclosed the two MFANNL properties but it also enclosed the large road cut along Interstate 70 (I 70), which, when excavated in the late 1960s, created continuous exposures of the Morrison Formation on both the north and south sides of the highway (LeRoy and Weimer, 1972; LeRoy, 1992), only 2.4 km north of the tracksite on Alameda Parkway. This roadcut area also falls within the boundaries of what is now Dinosaur Ridge. Moreover, the roadcut was designated as a Point of Geological Interest by the Colorado Geological Survey and was also developed as an interpretive trail by the Rocky Mountain Association of Geologists. As demonstrated by Houck (2001), LeRoy and Weimer (1972) and LeRoy (1992) the I-70 roadcut provides a valuable stratigraphic section to supplement the information derived from the nearby type section. While the I-70 roadcut is not the historical type section, found 2.4 km to the south, it provides a valuable series of outcrops correlated with the type section as shown by Houck (2001): Fig. 3. At that time, in the 1960s, dinosaur tracks had not been identified along I-70 roadcut. Nevertheless, even before this ichnological information was reported, in 2001, it was abundantly clear that the Morrison Formation outcrops in this area were of considerable historical and geological importance. They have, for more than 40 years, been designated by various state and national agencies as protected areas.
With one exception (Marsh, 1899), it was not until the 1930s that any convincing reports of dinosaur tracks were reported from the Morrison Formation. Most of these, in turn, were not described in detail until they appeared as a series of site reports the 1980s and 1990s (Lockley and Hunt, 1998; Lockley et al., 1986, 1997, 1998a,b,c). Subsequently Foster (2003) and Foster and Lockley (2006) reviewed the distribution of more than 50 dinosaur tracksites in the Morrison Formation throughout the Rocky Mountain region.

Despite the growing evidence that dinosaur tracksites, and those registering tracks of other tetrapods, are fairly abundant throughout the areas of Morrison Formation outcrop, there have been relatively few reports of well-preserved dinosaur tracks from the type area. As noted above, the type section, defined by Waldschmidt and LeRoy (1944) along Alameda Parkway on the west side of the Dakota Hogback is well-known known today as Dinosaur Ridge. It is from here that Lockley (1990) first reported Morrison dinosaur tracks, seen in cross section. As reported by Houck (2001, p. 98), exposures of the Morrison Formation “about 2.4 km north of the type section” on both sides of the Interstate 70 roadcut, provide better quality exposures, and have also yielded a few documented tracks from the south side (Fig. 4). This locality is referred to by Foster (2003, p. 74) as the “Interstate 70 Roadcut” (see also Foster and Lockley, 2006).

In the present paper we review what is known of the track record in the Morrison Formation in the area officially known as Dinosaur Ridge, situated between the town of Morrison, in the Bear Creek water gap, and the north end of Dinosaur Ridge situated at Lena Gulch and Colorado State Highway 40 (Fig. 1). This area includes the Morrison Formation type section (Waldschmidt and LeRoy, 1944) and locally correlative exposures. Despite the relatively sparse track record, and indifferent quality of track preservation at most sites in this area, there have, to date, as detailed below, been a number of brief references to at least four separate track occurrences, both at in situ sites, and on loose blocks. The track assemblages from the Morrison Formation at Dinosaur Ridge are shown to be quite typical of the formation throughout the region.
2. Methods

The methods used to obtain a record of the tracks examined and collected during this study were as follows. Selected tracks were collected, others were molded in latex and replicated in plaster, and others were traced on clear acetate film. Most original track casts and replicas are preserved in the University of Colorado Museum of Natural History (UCM) as specimens UCM 190.14 to UCM 190.17 (illustrated below (Figs 4-6). In addition a large block with stegosaur tracks (Fig. 7) is preserved in the Morrison Museum of Natural History with a replica (UCM 189.11) in the University of Colorado Museum of Natural History.

All were tracks were photographed to obtain standard 2D images. High resolution 3D photogrammetric images, also presented below (Figs. 5 and 6) were obtained using multiple images (sets of 89, 100 and 54 photographs, respectively, were used to compile Figures 5B, 6A and 6B) from a Canon EOS 70D camera (Focal Length 18mm, resolution 5472 x 3648, pixel size 0.00417183 mm). The photographs were processed by Agisoft Photoscan Professional (v.1.0.4) with all models having an error of less than 0.15 pix. These models were converted to colour topographic profile images using CloudCompare (v.2.5.3). Photogrammetric imaging was selected over field laser scanning as it was the most expedient and in terms of convenience, affordability and time-efficiency (Petti et al., 2008; Belvedere and Falkingham, 2012).

3. Previous work

The following reports of Morrison Formation dinosaur tracks from the Dinosaur Ridge area have appeared in the literature since 1990:
Lockley (1990), in the first edition of the Dinosaur Ridge Field Guide, reported tracks seen in cross section at Dinosaur Ridge, and inferred that the largest of these were attributable to sauropods (Fig. 2 and 3). Reports of this same occurrence were repeated in subsequent Dinosaur Ridge publications (Lockley and Hunt, 1994a) including the second (Lockley and Marquardt, 1995), third (Lockley 2001) and fourth (Lockley and Marshall, 2014) editions of the guide. Foster and Lockley (2006, p. 204) also referred to this as the “Dinosaur Ridge” locality. Because most of the tracks are seen in cross section, and might not immediately be recognizable to a non-ichnologist as footprint, they have been referred to in the aforementioned field guide editions and interpretative signs as “brontosaur bulges.” The brontosaur label is justified by the morphology of the largest tracks cast (bulge) which is ~75 cm long and ~60 cm wide, and thus too large to be attributed to any Late Jurassic dinosaurian trackmaker other than a sauropod.

By 2001 dinosaur tracks had been recognized and illustrated from the south side of the I-70 roadcut (UCM locality 782) by Lockley (2001) and Houck (2001) who collaborated to illustrate a manus-pes set, preserved as natural sandstone casts (Houck 2001, figs 14 and 17) and Lockley (2001, p. 23) on the underside of a steeply inclined sandstone bed (Fig. 4A). The tracks showed a large elongate, sub triangular pes and small manus (Fig. 5A) identified as sauropodan. As noted by Houck (2001, p. 104) a full-sized tracing (T 477) of this manus pes set was preserved in the University of Colorado at Denver Track collections, now held at the University of Colorado Museum of Natural History (UCM). The diagram based on tracing T 477 was again reproduced by Lockley (2003, p. 18; Fig. 5A here). A portion of this wall and these two tracks subsequently fell down. The manus cast (Fig. 4B,C and Fig. 6A) was retrieved and added to the UCM collections as specimen UCM 190.15 (Tracing 1667). As shown in Figure 4 the fallen pes cast has been identified, but not collected, due to the damaged condition of the cast which renders the shape undiagnostic. However, the pre-fall morphology and outcrop configuration of both the manus and pes was recorded both as a photo and line drawing (Figures 4 A and 5A respectively). Despite the damage caused by the fall, the manus cast naturally separated from the outcrop as a
single, unbroken specimen, 13 cm long and 21 cm wide, with other morphological features, matching those seen in the 2001 photograph (Fig. 4A). Moreover these characteristics are typical of sauropod manus cast morphology.

Following the fall of these casts, the under surface of the sandstone bed more clearly revealed other track casts, including a pair of bulges, previously only partly exposed (Figs. 4 and 5B). This pair of bulges, now clearly visible, was first illustrated by Brandt et al., (2010), who referred to them as a probable sauropod manus pes set, re-illustrated here using photogrammetry (Fig. 5B). The photo published by Brandt et al., (2010, fig. 27) is dated 10/03/2010 and shows that by that date the previously-reported, manus-pes track set had already fallen, presumably as the result of natural erosion (mass wasting). As shown in Figure 5B the larger cast, to the right is reminiscent of sauropod pes morphology and the cast to the left can reasonably be inferred to represent an associated manus imprint. However, the casts are not particularly well preserved or unequivocally diagnostic of sauropods, even though we consider this interpretation the most parsimonious. It is also of interest that in comparison with the now-fallen manus pes set which had a great disparity in size between the manus and pes (high heteropody: ~ 1:10), the set presently exposed in the outcrop reveals much lower heteropody (~1:2). The ~1:10 value is exceptionally high and may be due to distortion of the shape of the pes cast.

Another cast, a large, semicircular sauropod manus (UCM 190.17) was found lower down the slope, directly below the in situ tracks; it is 30 cm wide and 22 cm long (Fig. 5C) with a convex anterior margin and slightly concave posterior margin. This morphology is quite different from the smaller, wider manus (UCM 190.15). These differences in size and morphology between two manus casts lend support to the inference that different-sized sauropod trackmakers, possibly different species, may have registered tracks on this same substrate.

A number of other tracks occur at the I 70 road cut locality, all preserved as natural casts. Most appear as rather indistinct and undiagnostic bulges on fallen blocks. However, one relatively-complete large track, replicated as UCM 190.16, is unusual for its mode of
preservation. As shown in the photogrammetric image (Fig. 6A), taken from the original track, the large size, oval shape, large elongate claw traces and sediment rim are all characteristic of a sauropod pes. The track is interpreted as a natural cast with a large claw trace (probably digit I) protruding from the underside of the bed in negative, convex hyporelief. It is also possible to identify the sediment rim situated as a concentric feature, partially encircling the main portion of the track cast. A concentric trough also encircles this rim feature. The large size of this track contrasts with the small sauropod manus (Fig. 6B) shown for comparison.

Tracks have also been reported from surfaces on blocks of sandstone that have fallen from various levels in the Morrison Formation along Alameda Parkway. These originate from near the main bone site, now considered to be close to the location of Lake’s quarry 8 (Simmons and Ghist, 2014) not quarry 5 as previously inferred (Ostrom and McIntosh, 1966). This is simply the Dinosaur Ridge tracksite of Foster and Lockley (2006). These tracks include a probable manus-pes set attributed to a large stegosaur (Mossbrucker et al., 2008). This specimen is exhibited in the Morrison Museum of Natural History with a replica (UCM 189.11) also preserved in the UCM collections (Fig. 7). Another small, but poorly-preserved tridactyl track reported from the surface of a block from this same vicinity was illustrated (Fig. 8), traced (UCM T 1572) replicated (UCM 190.14) and briefly described (Lockley 2012). Although not very well preserved the track is about 23 cm long and 14 cm wide with the middle toe trace the longest, and individual pad impressions faintly visible. The track-bearing block is part of an outdoor display at Dinosaur Ridge and comes from a known stratigraphic level (Fig. 3)

Rajewski (2008) and Mossbrucker et al., (2009a, b, 2010; 2014) have also reported other purported tracks from fallen blocks in the vicinity of Quarry 8. These blocks have also been put on display at the Morrison Museum. Reports of these tracks have proved controversial for a number of reasons, not least because they have not been illustrated or described in any detail. In addition these abstracts and popular articles claim a greater diversity of tracks and
trackmaker behavior than has been inferred from any other Morrison Formation tracksite (see discussion below).

4. Discussion

The track assemblages from the Morrison Formation of the Dinosaur Ridge area are fairly typical of the many sites known from around the Rocky Mountain region discussed in more detail by Foster and Lockley, (2006). As noted below, most have relatively small sites, and in many cases they are associated with outcrops that expose relatively limited bedding plane surfaces. The Dinosaur Ridge assemblages are also mainly composed of the large tracks of sauropods, with evidence of at least one theropod and one ornithischian. In short, the total diversity of trackmaker groups that have been hitherto described from Dinosaur Ridge on the basis of illustrated tracks is three, representing large sauropods (Figs 3-6), a large ornithischian, probably a stegosaur (Fig. 7) and a theropod (Fig. 8).

Many of the tracks exposed at the three localities described here are large and not very well preserved. This is fairly typical of the Morrison Formation track assemblages (Foster and Lockley, 2006). Given that about 10 tracks have been identified in a small area on the south side of I 70 (Figs. 2-6) one might expect that more tracks would be found on the north side of the highway only about 100 meters away. To date no natural casts have been found on the north side of the highway. However, one very irregular surface of a sandstone bed is “pock marked” by large indentations (up to 75 cm in diameter and at least 30 cm deep), which suggests a trampled or “dino-turbated” surface (Fig. 9). This layer is higher stratigraphically than the track-bearing unit on the south side of I 70 (Fig. 3).

Given that all these track types, especially those attributable to saurischians (theropods and sauropods) have been previously reported from the Morrison Formation, the combined
ichnofauna from Dinosaur Ridge is typical. Moreover, due to the relatively poor quality of preservation of many of the tracks, the assemblages cannot be said to be exceptional. For example, due to the large size of sauropod trackmakers, many sites preserve large track casts of variable quality (Xing et al., 2015).

However, we can place this fairly typical assemblage in a broad context. As outlined by Lockley (1991) and Lockley and Hunt (1994b) terrestrial, vertebrate bearing formations can be divided into five categories as follows:

1) Footprints constitute the only evidence of vertebrates

2) Footprints constitute the majority of evidence, skeletal remains a minority

3) Footprints and skeletal remains occur more or less in equal proportions

4) Footprints constitute a minority of evidence, skeletal remains a majority

5) Footprints unknown, skeletal remains the only evidence of vertebrates

In categories 2, 3 and 4 we may observe a) consistency or b) inconsistency between the track and the skeletal record. Generally the Morrison Formation is a type 3a or 4a deposit (sensu Lockley 1991; Lockley and Hunt, 1994b), with skeletal remains as abundant (type 3) or more abundant (type 4) than tracks, but representative of similar trackmakers.

The tracks from the type area present various interpretative challenges, not least of which involve their preservation. As noted above with the exception of the inferred stegosaurian and theropodan tracks (Figs. 7 and 8 respectively) all other tracks are either of inferred sauropod or indeterminate affinity. The tracks at the so-called brontosaur bulges site along Alameda Parkway (Figs 2 and 3) are particularly difficult to interpret, and only the largest can be inferred to be diagnostic of sauropods. Several are simply, sand filled concave-down impressions appearing in outcrop as cross sections of cylindrical plugs (Fig. 3A), some more than 30 cm deep. Others are unequivocal shallow undertracks, with no more than 2-3 cms of relief, showing radial crack features (sensu Lockley et al., 1989) typical of surfaces below those on which large trackmakers registered their footprints.
At this site a package of laterally-extensive, planar-bedded sandstone beds range in thickness from ~3-~30 cm, and comprise a sequence about 5 meters thick (Fig. 3). The sandstone beds are separated by very thin, laminae or drapes of finer siltstone or mudstone. Indicating a somewhat cyclic, or rhythmic, pattern of deposition, with a thickening upwards of beds that suggest increased high energy deposition into the area. Tracks or undertracks have been recognized on at least five surfaces, but, unlike the I 70 outcrops, not on the lower sandstone surface at the interface with underlying mudstones. In some cases, especially in the track-rich zone about 1 meter above the base, we see both deep sand filled tracks and shallow underprints with radial cracks on the same surface. The latter indicate track making activity on higher surfaces not exposed in the present outcrop. A total of at least 14 tracks and undertracks have been identified, but the number of trackways or individual trackmakers is impossible to assess beyond assuming that at least one trackmaker registered tracks at each stratigraphic level. Given the presence of large trackmakers, on substrates characterized by depositional cycles that laid down many thin, laterally extensive-sandstones, separated by very thin mud silt units (drapes), indicating periods of lower energy deposition, it is very difficult to determine how many surfaces registered true tracks and how many registered transmitted underprints. We may however infer multiple episodes of track making activity.

The multiple track-bearing layers seen in cross section at the Dinosaur Ridge site are somewhat atypical of Morrison tracksites. Foster and Lockley (2006) reported 55 tracksites known from the Morrison and recorded a total of 294 trackway occurrences, each assumed to represent an individual trackmaker. These trackways were assigned to five broad taxonomic trackmaker categories: theropod, sauropod, ornithopod, stegosaurs and miscellaneous. The latter category contains 53 trackways of which 43 are undiagnostic tridactyls, probably mostly theropods, and 10 are identified as pterosaur, crocodilian, turtle and possible lacertilian tracks (Table 1). Since 2006 this total has been increased by reports of at least nine new sites, of which
seven have been reported briefly in the literature, bringing the grand total to at least 64 sites (Table 1). These newly reported sites include the aforementioned reports of a stegosaur manus- pes set (Mossbrucker et al., 2008), and the small theropod track (Lockley 2012), which constitute finds at a second site on Alameda Parkway separate from the Brontosaur Bulges site (Fig. 2) already recorded by Foster and Lockley (2006), a new report of a large thyrophan track (Hups et al., 2008; Lockley et al., 2014) occurring close to two other tracksites with small tridactyl tracks (Lockley et al., 2014), two theropod tracksites (Gierlinski et al., 2008) and two other hitherto unpublished sites (Lockley unpublished data; see acknowledgements).

These new reports allow modest updates of the data given by Foster and Lockley (2006). As shown in Table 1, to date, a total of 311 identifiable tetrapod trackways have been reported from the Morrison Formation from a total of 64 localites, of which 62 are documented. If we assign the miscellaneous tridactyl tracks reported by Foster and Lockley (2006) to dinosaurs, probably mostly theropods, the vast majority (96.8%) are attributable to dinosaurs. Of these theropod trackways, including the miscellaneous tridactyls, comprise a total of 58.2% and sauropods 27.0% giving a total for all saurischians of 85.2%. Only 11.5% are attributable to ornithischians, mainly ornithopods (10.3%), and only 3.2% to minor non-dinosaurian groups. Similar proportions are observed when we plot the number of sites at which the different track types occur, with theropod tracks, including tridactyls, occurring at 56.3% of sites and sauropod tracks at 39.1%; see Table 1 for proportions of other groups. The former measure, based on trackway count, is a generalized measure of relative abundance of different taxonomic groups in the fauna as a whole. The latter measure gives a generalized indication of the geographic distribution of taxa throughout the sample area, in this case the whole area of Morrison outcrops. In both cases there may be biases against preservation of small tracks, but these cannot be quantified. Nevertheless, the relative abundance and frequency of occurrence (geographic distribution) patterns are clear. Both measures indicate an ichnofauna in which theropods were the most abundant and widespread trackmakers with sauropods registering as the second most
abundant and widespread trackmakers. Given that the new reports adjust the whole data set only slightly it is not surprising that his result is in close agreement with the data presented by Foster and Lockley (2006, fig. 9B) for total trackway counts.

The total track count for the Dinosaur Ridge assemblages is 27, as detailed in Table 2. As noted above it is difficult to estimate the total number of trackways, as a proxy for the number of individuals. Stegosaur and theropod tracks each represent a single trackway (Figs 7 and 8 respectively) and there are only about five sauropod tracks that can be inferred to unequivocally represent different individuals, one at the Brontosaur Bulges site (Fig. 2) and the others from the I 70 roadcut (Figs 5 and 6). Thus, a minimum of seven individuals can be inferred solely on the basis of identifiable track types, although as noted below additional individuals must have registered the unidentifiable tracks at other levels. This small sample suggests the presence of sauropods, theropods and stegosaurs. This assemblages of inferred trackmakers is entirely consistent with the trackmaker composition inferred on the basis of the entire sample of 64 sites outlined above (Table 1).

The presence of unidentifiable, poorly-preserved tracks points to the fact that many footprints in the track record are poorly preserved. Thus, counts of identifiable tracks, which omit hard-to-identify footprints, lead to conservative underestimates of the trackmaker numbers. Thus the total estimate of 311 trackways hitherto recorded from the Morrison Formation is conservative.

The problem of understanding track preservation is also highlighted by reports of tracks by Mossbrucker et al., (2009a,b, 2010). These authors claim to have identified tracks of both adult and juvenile stegosaurs and apatosauras, theropods, ornithopods, lepidosaurs and a “possible badger-sized mammal” originating from the Quarry 5 sandstone (Mossbrucker et al., 2010, p. 35). These sandstone blocks and the purported tracks inferred by these authors, are on display at the Morrison Natural History Museum. They originate from sandstone outcrops associated with
a coarse channel sandstone sequence, with poor sorting and mud clasts, at the main bone-bearing outcrops at one of the main Dinosaur Ridge tour stops along Alameda Parkway. Interpretative signs at this stop do not mention tracks, although the theropod track (Fig. 8) is interpreted at another stop not far away. According to recent research (Simmons and Ghist, 2014), the bone bearing outcrops are not the site of Quarry 5, as previously thought, (Ostrom and McIntosh, 1966) but are closer to the Quarry 8 outcrops. The large stegosaur manus pes set and the theropod track (Figs 7 and 8) may come from these outcrops. We have examined the other Morrison Natural History Museum blocks and have been unable to confirm the presence of any convincing or unequivocal tracks. Claims of as many as eight track morphotypes (sensu Mossbrucker et al., 2009,a,b, 2010) in such facies would be rather extraordinary if confirmed by detailed published accounts. In this regard, we note that whereas one abstract refers to “a stegosaur-rich track assemblage” (Mossbrucker et al., 2010, p. 355) another refers to “probable …. stegosaur tracks” (Mossbrucker et al., 2014, p. 73). From the latter we infer some uncertainty regarding the interpretation of this material. Pending further study, we conclude that the present report lists all the tracks presently known from the Morrison Formation at Dinosaur Ridge.

Acknowledgements

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illustrated in Fig 8. Was first reported to the Friends of Dinosaur Ridge (501 C. 3) by matt Mossbrucker (Morrison Museum of Natural History. History Colorado granted permission to make it the track-bearing block part of the Dinosaur Ridge outdoor trail.

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Fig. 2. Dinosaur tracks seen in cross section at Dinosaur Ridge. A: largest brontosaur “bulge” attributed unequivocally to a sauropod. Note interpretive sign also shown in general view (B) of site in 2014. C: original sketch from Lockley (1990) showing occurrence of tracks at same stratigraphic level. Compare with photograph (D) showing two other large dinosaur tracks of uncertain, but probable sauropod, affinity, in cross section.

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Figure 1
Figure 2
Figure 3
Figure 4
Figure 5
Figure 7
Figure 8
Table 1. Summary of the number of identifiable trackways of main track types (top row) reported from 63 Morrison Formation localities (middle row) with corresponding % of total trackway count. Lower row shows frequency of occurrence of track types across all sites (with corresponding % occurrence). Modified after Foster and Lockley (2006, table 1) with updates. Percentages less than 1% omitted. Thyreoph., ptero., croc., ?lac., and misc. refer to thyreophoran, pterosaurian, crocodylian, ?lacertiform, and miscellaneous tracks respectively. See text for details.

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<td>tways (%)</td>
<td>(44.4%)</td>
<td>(27.0%)</td>
<td>(10.3%)</td>
<td>(1.2%)</td>
<td>(1.0%)</td>
<td>(1.2%)</td>
<td>(6.2%)</td>
<td>(6.2%)</td>
<td>(13.8%)</td>
<td></td>
</tr>
<tr>
<td>Number</td>
<td>33</td>
<td>25</td>
<td>8</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>64</td>
</tr>
<tr>
<td>sites (%)</td>
<td>(56.3%)</td>
<td>(39.1%)</td>
<td>(12.5%)</td>
<td>(6.2%)</td>
<td>(4.7%)</td>
<td>(6.2%)</td>
<td>(6.2%)</td>
<td>(6.2%)</td>
<td>(13.8%)</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. List of tracks identified from the Morrison Formation at Dinosaur Ridge

Dinosaur Ridge: UCM refers to University of Colorado Natural History Museum.

<table>
<thead>
<tr>
<th>Locality name</th>
<th>Track types (and # tracks)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dinosaur Ridge (bulges site)</td>
<td>Sauropod pes (1)</td>
<td><em>in situ</em> at outcrop: Figs. 2 &amp; 3</td>
</tr>
<tr>
<td>Dinosaur Ridge (bulges site)</td>
<td>Indeterminate tracks (~13)</td>
<td><em>in situ</em> at outcrop: Figs. 2 &amp; 3</td>
</tr>
<tr>
<td>Dinosaur Ridge (stop 1 area)</td>
<td>Stegosaur manus pes set (2) replica UCM 189.11</td>
<td>Original at Morrison Museum of Natural History: Fig. 7.</td>
</tr>
<tr>
<td>Dinosaur Ridge (stop 1 area)</td>
<td>Theropod track: replica = UCM 190.14 (1)</td>
<td>Original on Dinosaur Ridge: Fig. 8.</td>
</tr>
<tr>
<td>Dinosaur Ridge (I 70 south)</td>
<td>Original manus cast = UCM 190.15 &amp; pes (2)</td>
<td>Manus cast collected: Figs 4 - 6</td>
</tr>
<tr>
<td>Dinosaur Ridge (I 70 south)</td>
<td>Pes replica = UCM 190.16 (1)</td>
<td>Mold and replica collected: original in field: Fig. 6.</td>
</tr>
<tr>
<td>Dinosaur Ridge (I 70 south)</td>
<td>Original manus cast = UCM 190.17 (2)</td>
<td>Original collected: Fig. 5.</td>
</tr>
<tr>
<td>Dinosaur Ridge (I 70 south)</td>
<td>Manus pes set (2)</td>
<td>Originals in field: Fig. 5</td>
</tr>
<tr>
<td>Dinosaur Ridge (I 70 south)</td>
<td>Indeterminate bulges/casts (3)</td>
<td>Originals in field: Fig. 2</td>
</tr>
<tr>
<td>Dinosaur Ridge (I 70 north)</td>
<td>Inferred trampling; probably sauropodan</td>
<td>No material collected: Fig. 9</td>
</tr>
</tbody>
</table>
HIGHLIGHTS Re: PALAEO8352.

New Morrison Formation dinosaur track reports from Dinosaur Ridge, Colorado
Dinosaur track erosion and rescue from Morrison Formation type section Dinosaur Ridge
Review of Late Jurassic dinosaur tracks known from Morrison Formation type section
Morrison Formation type section dinosaur tracks placed in regional context