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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 in 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 assemblages 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.

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 roadcut 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, 1971; 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 (1971) and LeRoy (1992), the I-70 roadcut provides an important 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 the 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

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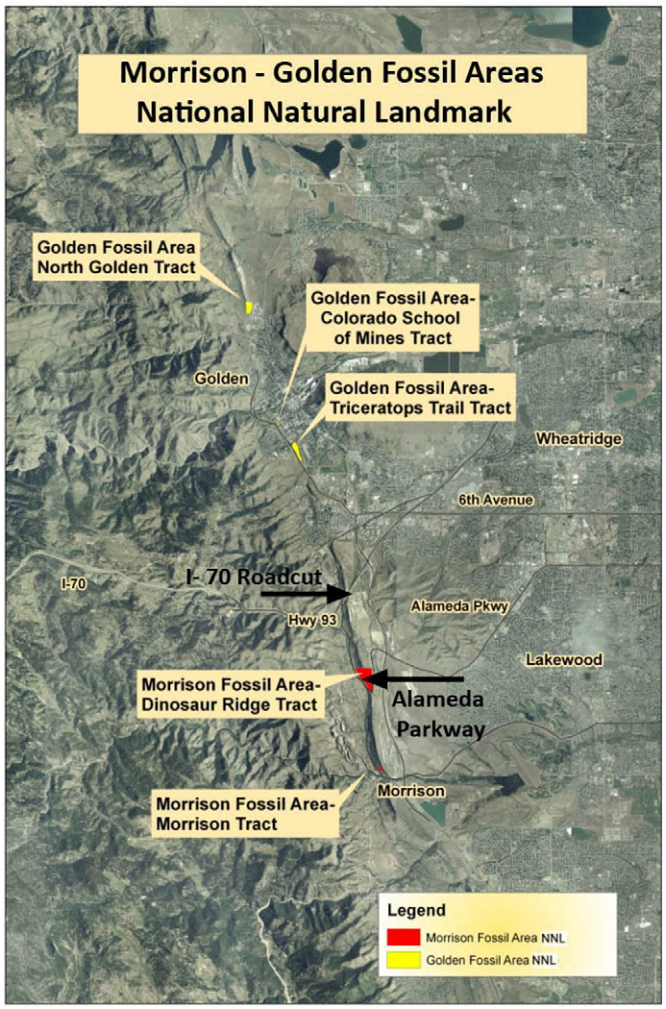

Fig. 1. Locality map for the Morrison Formation type area on Dinosaur Ridge showing *in situ* tracksites (black arrows) in relation to boundaries of properties within the Morrison—Golden Fossil Areas National Natural Landmark.

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 et al., 1986, 1997, 1998a,b,c; Lockley and Hunt, 1998). 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 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 tracks were photographed to obtain standard 2D images. High-resolution 3D photogrammetric images, also presented here (Figs. 5 and 6), were obtained using multiple images (sets of 89, 100, and 54 photographs, respectively, were used to compile Figs. 5B, 6A, and B) from a Canon EOS 70D camera (Focal Length 18 mm, resolution 5472 × 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 color 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 (Figs. 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; Lockley, 2001, p. 23) on the underside of a steeply inclined sandstone bed (Fig. 4A). The tracks showed a large elongate, subtriangular 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