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Dinosaur Tracks and Radial Cracks: Unusual Footprint Features

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Abstract Dinosaur tracks with radial crack features are unusual examples of preservation among fossil footprints. In some cases non footprint features may show radial cracks also. A description of some Cretaceous dinosaurian tracks that reveal radial cracks is given, and examples of other tracks and radial cracks are discussed.

Introduction

One of the major problems in the study of fossil footprints is the identification and recognition of indistinct traces. Textbooks often contain examples of well preserved dinosaur tracks, but such footprints represent only a small proportion of the millions that exist in the fossil record. Ichnologists recognize that tracks may be obscure because the original substrate on which the animal walked was too hard or too soft to allow the formation of well preserved tracks. Footprints may also leave obscure underprints and infillings which are hard to interpret.

The purpose of this report is to discuss some unusual footprint features characterized by radial cracks. Because cracks are typical of brittle deformation they are not usually associated with footprints, which normally exhibit plastic deformation features. The examples discussed herein come from the Lower Cretaceous Sebayashi Formation of Japan and the "middle" Cretaceous Dakota Group of Colorado. In both examples the features exhibiting radial cracks are different. Their relationship to footprints and their interpretation are discussed.

A series of features on a Lower Aptian cliff surface at Sebayashi, near Tokyo, Japan were described by MATSUKAWA and OBATA (1985a, b). These features were referred to as "indentations" in some cases, and footprints in others. Marks high on the cliff (series A) are relatively deep and exhibit radial cracks, whereas those lower on the cliff (series B) are shallower and lack radial crack features. Dinosaur bone (ornithomimid vertebrae) has been discovered nearby, and the Sebayashi sedimentary facies is typical of track-bearing deposits in other regions. There are also a few other examples of Lower Cretaceous dinosaur tracks reported from Japan (MANABE *et al.*, 1989), as well as some undescribed bird tracks. Given these facts it is not unreasonable to explore the possibility that problematic indentations might be dinosaur tracks.

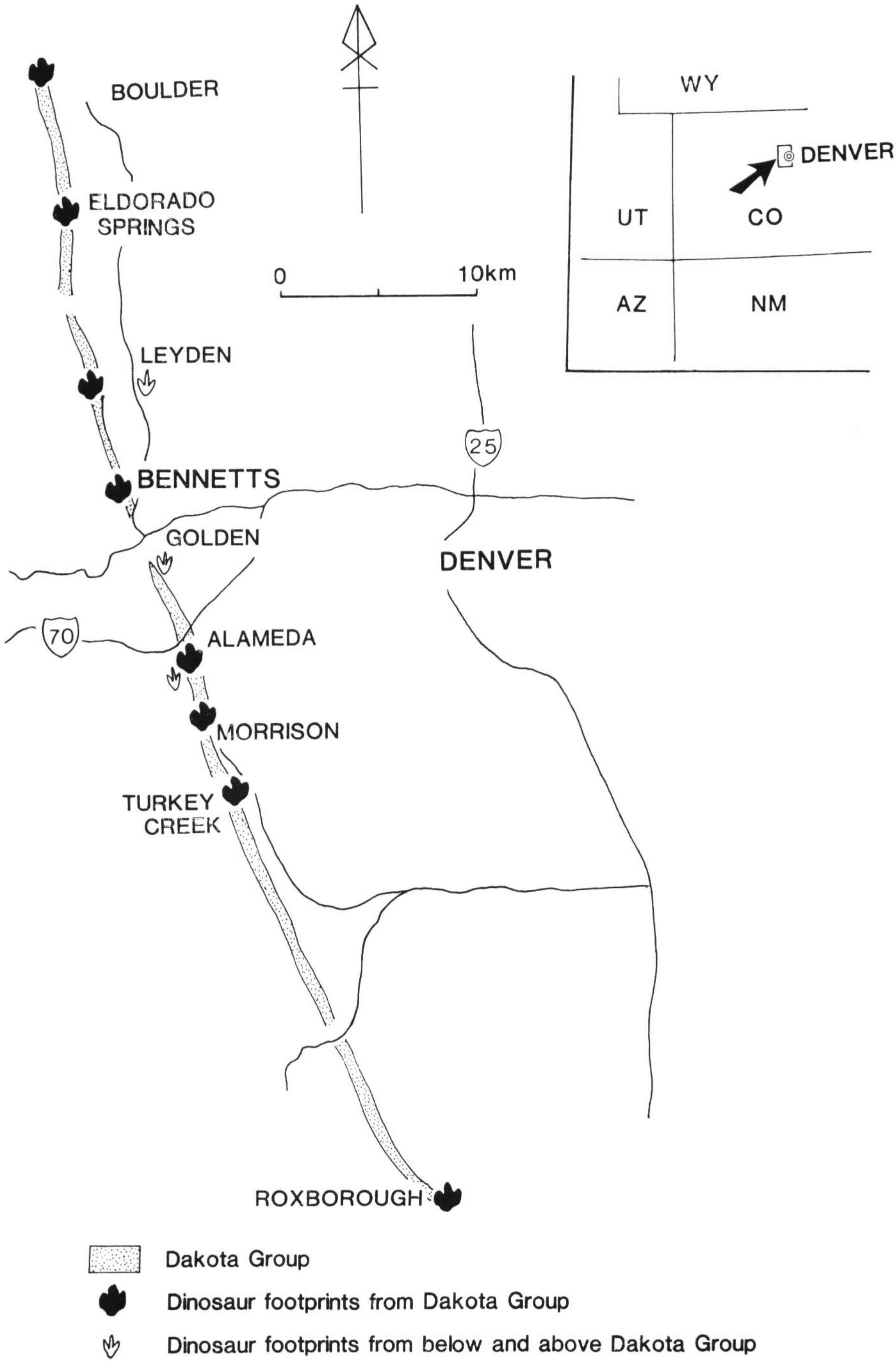

Fig. 1. Locality map of the dinosaur footprints from Dakota Group, near Denver, Colorado.

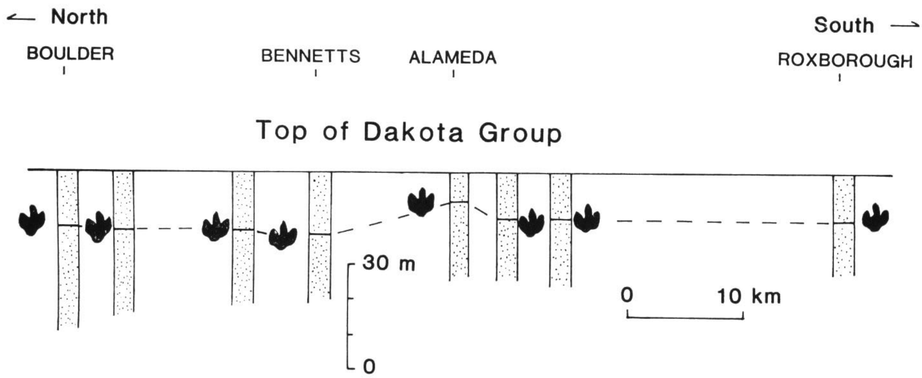

Fig. 2. Stratigraphic correlation of trackbearing beds, Dakota Group, Colorado (adapted from LOCKLEY, M., 1989).

MATSUKAWA and OBATA (1986) have already explored several possible interpretations and ruled out load casts, sand or mud volcanoes, sand/mud dykes, and meteorite impact craters.

In Colorado a somewhat similar situation exists. Although no dinosaur bones are known from the Dakota in this region, the deposits yield plant fossils, like the Sebayashi Formation, as well as bird tracks. Moreover the paleoenvironment represents a low lying clastic coastal plain comparable to the Sebayashi paleoneviron-ment. Such environments appear to have been the preferred habitats of Cretaceous ornithopods (OSTROM, 1964).

Although dinosaur tracks are known from the Dakota Group over a wide area (Figs. 1 and 2) (LOCKLEY, 1987, 1988, 1989; LOCKLEY *et al.*, 1988; Jones, 1988), in many instances the tracks are indistinct. The outcrops also display large indentations caused by vandals who have extracted unprotected tracks. Other problematic indentations, with radial cracks, are the result of blasting during highway construction several decades ago. Elsewhere along the strike radial crack features are shown to be directly attributable to dinosaur footsteps.

It is not uncommon for visitors to the Dakota outcrops to identify ancient excavation craters and blast holes as dinosaur tracks. The purpose of this paper is therefore to alert readers to the characteristics of certain problematic tracks and features in order to help differentiate true tracks from artifacts.

The authors have had the opportunity to visit both tracksites. Matsukawa visited the Dakota site in 1986 and 1989 and Lockley visited the Sebayashi site in 1987 and 1988. In 1988 Lockley discovered radial crack features in the Dakota Group which are unequivocally attributable to dinosaur footprints (Figs. 3 and 4). These radial crack features occur at several locations but are best preserved on the large slab described below (Figs. 4 and 5). In 1989 Matsukawa visited Colorado and assisted in the excavation of this specimen, which was deposited at the new Morrison Museum

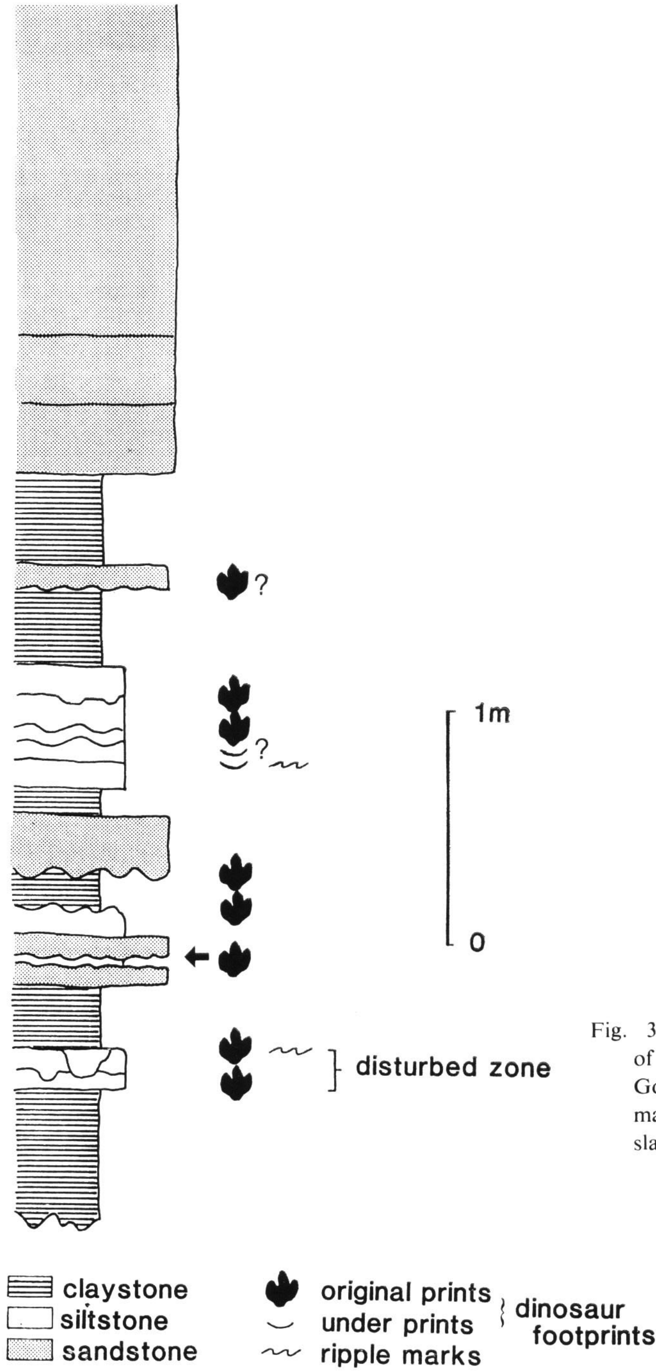

Fig. 3. Stratigraphic column of the Bennetts Ranch near Golden, Colorado. Arrow mark shows the horizon of slab described in this paper.

Fig. 4. Photograph of track-bearing slab in the Dakota Formation, near Golden, Colorado, (Mus. W. Colorado spec. no. 203); currently undergoing reconstruction at the Morrison Museum (Dinosaur Ridge).

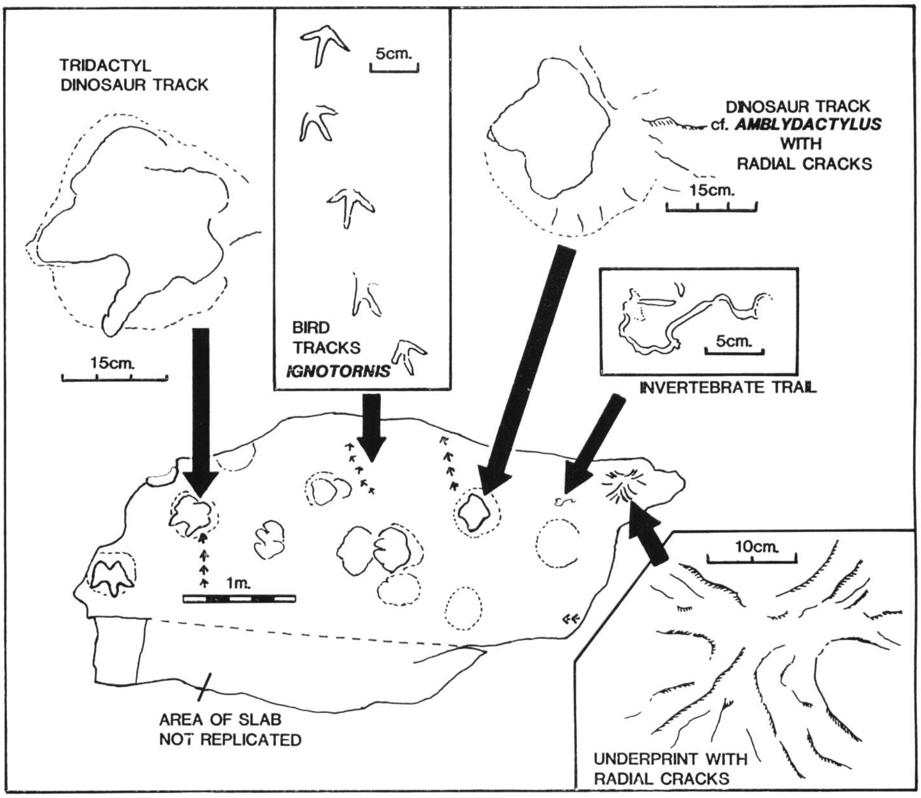

Fig. 5. Diagram (with details) of slab shown in Fig. 4. Note radial cracks associated with tracks left at right end of the slab; more radial crack features are known on the adjoining slab further to the right.

(Dinosaur Ridge). A detailed description of this slab is in preparation for publication elsewhere.

The Dakota Group track slab was excavated at a site north of Golden, Colorado. Although we have not disclosed the precise location, it is not far removed from the site from which Mehl (1931) described *Ignotornis mcconnelli*, the first bird tracks ever reported from the Mesozoic. The slab is unique because it exhibits both bird and dinosaur tracks as well as invertebrate trails. Although bird and dinosaur tracks have been reported from the same formations (Currie, 1981; Parker and Balsley, 1989) they have never previously been reported from the same bedding plane. The slab in question has been designated Museum of Western Colorado spec. no. 203 and replicas have been made from a latex mold for the National Science Museum in Tokyo and the Nakasato Dinosaur Center in Gunma Prefecture, Japan.

The exact stratigraphic position of the slab is known. It originates from a series of alternating shales and thin sandstones in the Van Bibber Shale Member of the

"J" Sand Formation (Dakota Group). The exposed track bearing surface of the slab represents the underside of a 10 cm sandstone bed (Figs. 4 and 5) exhibiting bird tracks, tridactyl dinosaur tracks and radial crack features which are essentially underprints. All these footprint features appear in positive relief as natural casts.

Description and interpretation of the Dakota tracks were written by M. Lockley in cooperation with M. Matsukawa. Description of features in the Sebayashi Formation was mainly written by M. Matsukawa and I. Obata in cooperation with M. Lockely (MATSUKAWA, OBATA and LOCKLEY, 1989).

Description and Interpretation of the Dakota Tracks

The tracks on this slab fall into three categories, bird tracks, natural casts of dinosaur tracks and natural casts of underprints. Both the latter features exhibit radial cracks.

The bird tracks are of variable quality but include a few very well preserved natural casts of *Ignotornis mcconnelli* (Fig. 6). Some of the better preserved tracks occur in recognizable, parallel, trackway sequences (Fig. 5). The casts exhibit about 0.5 cm of relief suggesting that this was the original depth of the footprint impression at the time they were made in the mud immediately below the sandstone. In some places

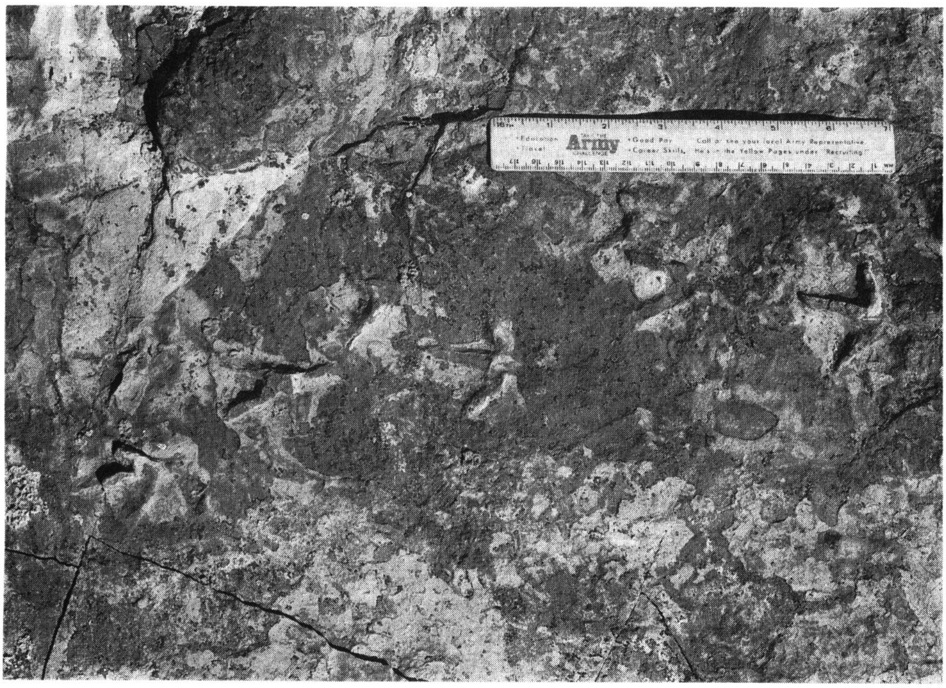

Fig. 6. Photograph of *Ignotornis mcconnelli* trackway shown in Fig. 5 (inset). Note that this locality is near to the type locality for this ichnospecies (see MEHL, 1931 for further details).

irregular casts appear showing greater relief; these suggest areas of wetter substrate where the bird's feet sank in deeper. However in these areas the tracks did not retain clear outlines, and the surrounding mud must have flowed back towards the tracks slightly, after it had been displaced. In other instances, very faint casts suggest lightly impressed tracks where the original substrate was firmer.

Given that the bird tracks are about the size of those of modern waders (Order Charadriiformes), such as the sandpiper (Genus *Tringa*) or the killdeer (Genus *Charadrius*), which are light weight animals weighing only a few hundred grams at most, we can infer a relatively moist and receptive substrate to permit track formation. We can also infer that the birds would not have left tracks if there had been any standing water in excess of a modest wading depth of a few centimeters. This establishes that the water table was at or just above the sediment surface at the time of track formation. This sheds some doubt on the interpretation of the sediments as "well drained" levee deposits (LINDSTROM, 1976).

The dinosaur footprint casts exhibit up to 10 cm of relief, and several features which suggest they were made on the upper surface of the sand bed before being pressed through to the point where they made contact with the underlying mud. The base or sole of the casts shows a relatively clear outline, at least in one case indicating an identification of the ornithopod ichnogenus *Amblydactylus*. However the sides of the casts do not show the relatively steep sides and striations typical of tracks made in cohesive muddy substrates. Instead the sides of the casts show that the base of the sandstone layer bent uniformly down towards the point of maximum foot penetration, thus indicating pressure exerted from a point above the base of the sandstone before the feet finally penetrated to the underlying sand/shale contact. These uniformly inclined sides of the sandstone casts show a number of radial "crack" features which resemble small scale normal faults (i.e. small scarp features on the order of about 1 cm radiate outward between up and down thrown sectors: Fig. 5). Such "Crack" features support the interpretation of footprint pressure from above the sandstone bed because they suggest some degree of competence or strength in the impacted sediment.

In addition to the bird and dinosaur track features there are a number of casts of underprints which exhibit radial cracks. These features consist of broad, oval convex casts, exhibiting low relief (1–2 cms) and distinctive radiating cracks similar to those described above. Typically these dish-shaped casts are between 25 and 35 cms in diameter and display about 20 radiating cracks (Fig. 5). They are interpreted as underprints of tracks made on the upper surface of the sandstone. In some instances they appear to be along the trend of the trackway, made by the more prominent casts.

The radially cracked underprints predominate at one end of the slab (especially on an adjoining section, to the right of the slab shown in Fig. 5), whereas the high relief casts predominate at the other end, along with a greater abundance of bird tracks. These differences possibly indicate slight differences in the sediment saturation levels or the substrate consistency across this small area. We consider it unlikely that the radial crack features would be interpreted as fossil footprints by most geolgists unless they were found in association with clearly defined tracks, as in this case.

Description of Features in the Sebayashi Formation

Indentations and features interpreted as tracks on the cliff at Sebayashi have been described elsewhere in some detail (MATSUKAWA and OBATA, 1985a, b, 1989; MATSUKAWA, OBATA and LOCKLEY, 1989). It is clear from these studies that the features or tracks in series A and series B are very different. Only series A exhibits radial cracks.

Unlike the Dakota tracks described above, the features of Sebayashi Series A are preserved as indentations or impressions, in normal relief, rather than as inverted or negative casts. They occur in the top of a sandstone bed overlain by shale, and the cracks appear to radiate further from the indentations than those observed in the Dakota. In many respects the mode of preservation at the two sites is very different or opposite, but there are some similarities. Like the Dakota tracks the series A indentations are deep. They also occur at a distinct lithological boundary, though this is a very common ichnological observation. Series A also shows rapid size and depth variation and is in close proximity to other features (series B) which have been interpreted as tracks also. It is also worth noting that the Sebayashi features have been interpreted as underprints, like those in the Dakota Group.

The discovery of radial cracks in association with dinosaur footprints in the Dakota Group of Colorado does not allow us to make an indisputable interpretation of the radial crack features at Sebayashi. However, it does permit us to conclude that footprints may cause unusual indentations and deformation features in sedimentary successions.

Conclusions

(1) Dinosaur tracks can generate radial crack features. These features are sometimes associated with underlayers where the foot impacts slightly compacted sandy layers in contact with an underlying muddy layer.

(2) Different types of track preservation often appear at the same geological horizon. The Dakota example shows bird tracks and two different types of dinosaur track expression, representing at least two different episodes of track making. The Sebayashi example also shows two distinctly different features in Series A and Series B; their origin is still problematic, but the original interpretation of footprint related indentations can not be ruled out.

Acknowledgements

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