Lockley, M.G. & Lucas, S.G., eds., 2014, Fossil footprints of western North America: NMMNHS Bulletin 62

NOTES ON A NEW ANKYLOSAUR TRACK FROM THE DAKOTA GROUP (CRETACEOUS) OF NORTHERN COLORADO

MARTIN G. LOCKLEY [1] and GERARD D. GIERLINSKI [2]

[1] Dinosaur Tracks Museum, University of Colorado at Denver, PO Box 173364, Denver, Colorado, 80217; e-mail: martin.lockley@UCDenver.edu;
[2] JuraPark, ul. Sandomierska 4, 27-400 Ostrowiec Swiztokrzyski, Polish Geological Institute, ul. Rakowiecka 4, 00-975 Warszawa, Poland; Poland;
e-mail: gierlinski@yahoo.com

Abstract—A new report of an isolated, but well-preserved ornithischian track from a not-in-situ locality in northern Colorado is confidently attributed to an ankylosaurid trackmaker from the Dakota Group. It is one of the largest and oldest tracks yet recovered from the Dakota Group, and appears to have originated from the lower part of the section, where tracks are typically rare.

INTRODUCTION

Many tracks preserved as large natural casts have been reported from Cretaceous siliciclastic facies in the Western Interior region of the western USA. Reports of such occurrences in the Dakota Group are almost too numerous to mention, as evidenced from a number of papers in this volume (and references therein). Likewise, many reports of similar occurrences are associated with the "MesaVerde Group," especially in coal mines (Parker and Balsley, 1989; Parker and Rowley, 1989). These track-rich deposits, loosely referred to as coal-bearing, coastal-plain facies (Lockley et al., 1994), consist of heterolithic (anisotropic) sequences of sandstone and mudstone, that appear to have been very conducive to the preservation of sandstone casts, especially in the coastal plain systems associated with the Western Interior Seaway.

Many of these casts represent the sandy infillings of deep tracks made in muddy substrates by large dinosaurs and, as a result, once they lithified, they become very large, heavy and bulbous natural casts. Once they weather out of outcrops they slide and roll down slopes, and are frequently found out of place: i.e., no longer *in situ*. Depending on the size and depth of these casts they may weigh anywhere from ~5 to ~200 kg. While this may make collecting of the smaller, less-heavy casts easy, determining the horizon(s) from which they originated may be difficult, especially in cases where there are multiple track-bearing layers in similar lithologies.

We report on a single, large natural cast of a track weighing ~75 kg that was discovered as a loose specimen from near Fort Collins, Colorado (Fig. 1), and donated to the CU Denver Dinosaur Tracks Museum in 2009. The specimen (UCM 209.149, formerly CU 29.149; Fig. 2) is a tetradactyl pes cast attributed to an ornithischian, specifically an ankylosaur, trackmaker. As the locality is under private ownership, revisiting the site to locate the track-bearing layer and look for other specimens has not been possible due to restricted access.

INSTITUTIONAL ABBREVIATIONS

CEUM, CEU Prehistoric Museum in Price, Utah; CU, University of Colorado at Denver, Colorado; CU-MWC, University of Colorado and Museum of Western Colorado joint collection; MOR, Museum of the Rockies in Bozeman, Montana; UCM University of Colorado Natural History Museum; YPM, Yale Peabody Museum in New Haven, Connecticut

GEOLOGICAL PROVENANCE

The track was found in a gully on private land (from which it was collected in 2009) at a site about 33 km north of Fort Collins, Colorado, before being donated to the University of Colorado Denver Dinosaur Tracks Museum. According to available geological maps (Courtright and Braddock, 1989) the track was found sitting on outcrops designated as belonging to the Triassic Lykins Formation (Fig. 1). Analysis of this map shows that the discovery site lies at the base of a slope capped by units of the Cretaceous Dakota Group (Fig. 1). The lower part of the slope designated as (TRlu) represents the Triassic upper Lykins Formation, which is overlain, in ascending order by the following mapped units: the undivided Triassic Jelm and Middle-Upper Jurassic Sundance formations (designated as JTRsj), the Jurassic Morrison Formation (Jm) and the Lytle Formation and Plainview Sandstone Member of the South Platte Formation (Kspl): see Fig.1. As noted below (Fig. 1), the nomenclature and inferred age of pre-Morrison units is of no direct interest in determining the provenance of the track described here, and for this reason they are not discussed further.

Based on the known distribution of large ornithischian tracks it seems impossible that the track could have originated from anywhere below the Morrison Formation, and it is more likely to have originated from the Dakota Group. Based on the topography (see the cross section shown in Fig. 1) it is most probable that the track was eroded from the aforementioned lower mapped unit of the Dakota Group (Kspl). If the track had been eroded from one of the higher units in the Dakota Group, such as the Middle Shale member (Ksm) or First Sandstone member (Ksf) exposed farther to the northeast, barring the possibility of glacial transport, it appears that it would have been impossible to have been transported to the location where it was found without having had to have moved "up" the Kspl dip slope! Assuming an origination point in the Morrison Formation or Dakota Group, it is possible to compare this track with other ornithischian tracks found in these units.

This report is of interest because a smaller tetradactyl track was observed by the senior author at an *in situ* outcrop at the top of the Lytle-Plainview Formation near Bellvue, Colorado about

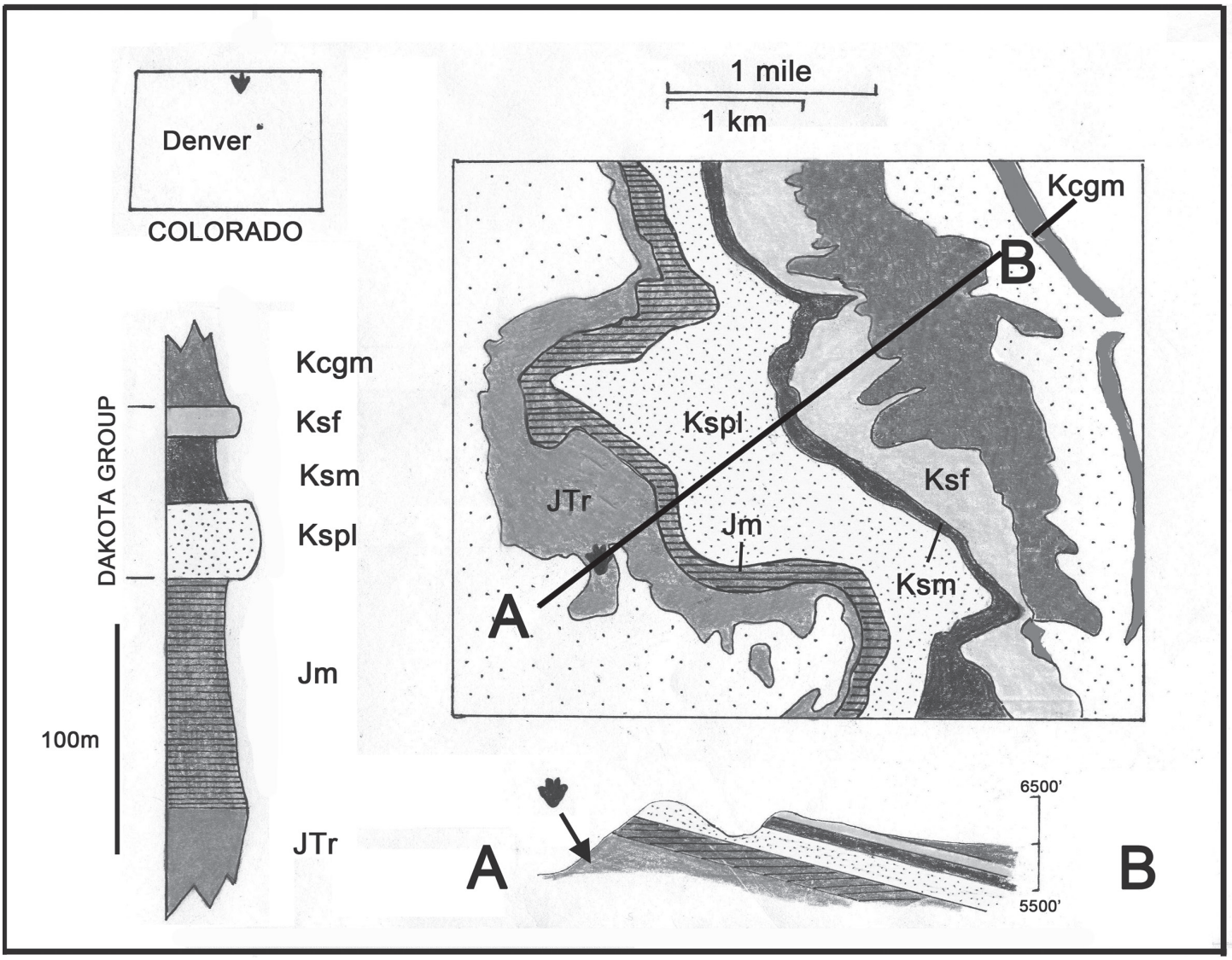

FIGURE 1. Locality map showing ankylosaur track locality discussed in this paper. Top left: location of site in northern Colorado. Bottom left: stratigraphic units after Courtright and Braddock (1989). See text for details. Top right and lower right: map and corresponding cross section showing where track was found at base of slope capped by Cretaceous rocks. See text for details.

10 km northwest of Fort Collins. The stratigraphy of this locality is well known and sections have been published by Macke and Maughan (1985) and Weimer et al. (1990)

TRACK DESCRIPTION

The track cast (UCM 209.149) is of a tetradactyl ornithischian right pes with wide, blunt toes (Fig. 2). The cast is 57 cm long and 48 cm wide, and is broadly triangular in shape with the acute apex represented by the heel. As the posterior part of the heel trace may represent forward and downward movement into the substrate as the foot registered, these raw cast measurements may not exactly correspond to the original foot size. However, because the track is well-preserved, these measurements probably represent foot size with fair accuracy. The cast indicates a footprint at least 30 cm deep. However, because there are no indications on the cast as to where the original substrate surface may have been relative to the deepest part of the track, the depth estimate is imprecise. Nevertheless, as noted below, it is clear that the trackmaker was a large individual in comparison with any other reported from this time interval.

The toe casts are inferred to represent digits I-IV with digit I the shortest, and a digital length formula of II=III>IV>I. Measured between the hypicies, the toe casts are more or less equal in width (~11-12 cm wide), with those of digits II and III being longer (~17-18 cm from hypex to toe tip) than digit IV (~ 14 cm) and digit I (~9-10 cm). Thus, the longest toes measured between toe tips and the hypicies on either side of digit III represent about 31-32% of the overall length of the cast. The distal part of the cast of toe II shows what appears to be the cast of an ungual protruding from the cast of the fleshy part of the foot that surrounds it. Such traces, which appear to differentiate distinct morphological features of the foot, are rare but have been reported in the case of ornithopods (Lockley et al., 2006a, fig. 19) and theropods (Huerta Hurtado, 2001; Torcida Fernandez-Baldor et al., 2007).

DISCUSSION

We divide the following discussion into two parts; the first dealing with the age and occurrence of presumed ankylosaur tracks, and the second dealing with their morphological characteristics and implications for trackmaker identity.

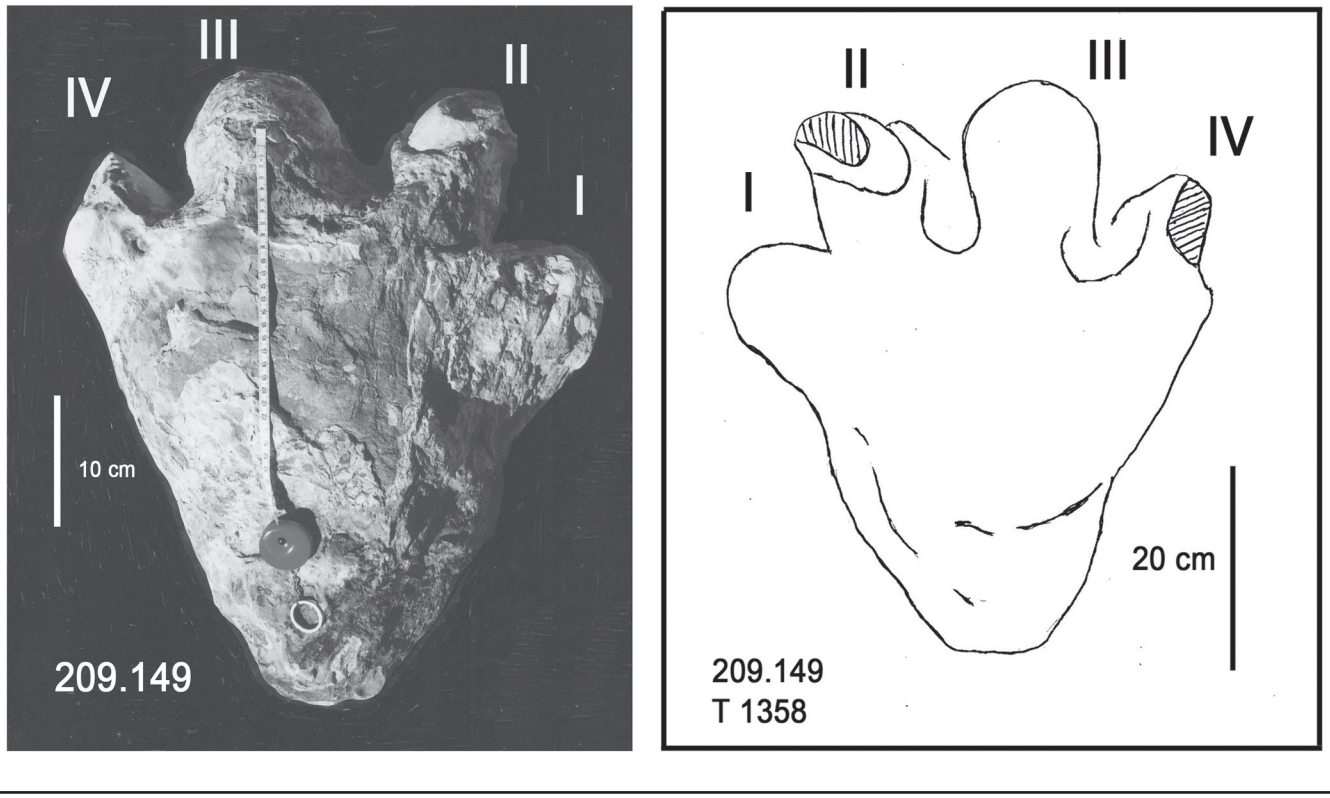

FIGURE 2. The reported specimen: cf. *Tetrapodosaurus* sp. (UCM 209.149, formerly CU 209.149), presumed to be from the Dakota Group of northern Colorado. Photograph (left) shows natural cast of presumed right footprint. Line drawing (right) is a reversed tracing showing presumed ungual traces on digits II and IV.

Age and Occurrence of Dakota Group Ankylosaur Tracks

Although ornithischian dinosaur tracks are common in the Dakota Group, especially in the upper part (Sequence 3 sensu Weimer, 1989; Lockley et al., 1992, 2006b), most of these tracks have been attributed to ornithopods (ichnogenus *Caririchnium*). Ankylosaur tracks are relatively rare in the Dakota Group of eastern Colorado. The first significant report (Kurtz et al., 2011) dealt with an assemblage of large tracks inferred to be from Sequence 2 (Plainview Formation) near Cañon City, Colorado. This report documents large pes tracks up to 48 cm long and 52 cm wide. The only other documented occurrences in eastern Colorado deal with specimens from Sequence 3 that are much smaller (Lockley et al., 2006) and include specimens about 27.5- 32.0 cm long and 24.0-27.0 cm wide (Fig. 4g) that are more gracile than the specimen reported herein. These are only about half the linear dimensions of the northern Colorado specimen (UCM 209.149) and the specimens from Skyline Drive (Kurtz et al., 2001). Therefore, it is of stratigraphic significance that the only two reports of well-preserved ornithischian tracks from the Dakota Group of eastern Colorado appear to be from the lower part of the Dakota Group (Sequence 2 and the lower part of Sequence 3). As reported elsewhere in this volume, ankylosaur tracks are common at some recently-found sites in western Colorado (Lockley et al., 2014), but these are smaller than the Fort Collins and Skyline Drive specimens, and their relationship to the stratigraphic sequences of eastern Colorado has yet to be determined.

Morphological Characteristics

It is difficult to infer the identity or taxonomic affinity of track makers responsible for making tracks and trackways that appear attributable to the broad category of quadrupedal ornithischian. In a recent review of all ornithischian track morphotypes (Lockley et al., 2012), six categories were recognized, including those of small basal ornithischians with tridactyl pes footprints and large ornithopods (iguanodontids and hadrosaurs), also with tridactyl pes footprints. In this discussion we deal only with trackmakers with a tetradactyl pes. This reduces the categories to four morphotypes, most of which are of ornithischian affinity. However, as noted below, one category, containing the ichnogenus *Marcropodosaurus*, may be attributable to a non-ornithischian trackmaker. The specimen UCM 209.149 described here (Fig. 2) is a clearly semiplantigrade footprint with four well-defined toes. Among the four main morphotypes (A-D) of semiplantigrade and plantigrade tracks from the Cretaceous of North America (Fig. 3), we refer UCM 209.149 to morphotype D.

Morphotype Categories

Morphotype "A" (Fig. 3A) has been recently recorded in North America (Gierlinski and Lockley, in press) and represents an elongate footprint with four slender, tapering and narrowly divaricated digits. This type closely resembles the Eurasian ichnotaxon named *Macropodosaurus* by Zhakarov (1964) and is identified as

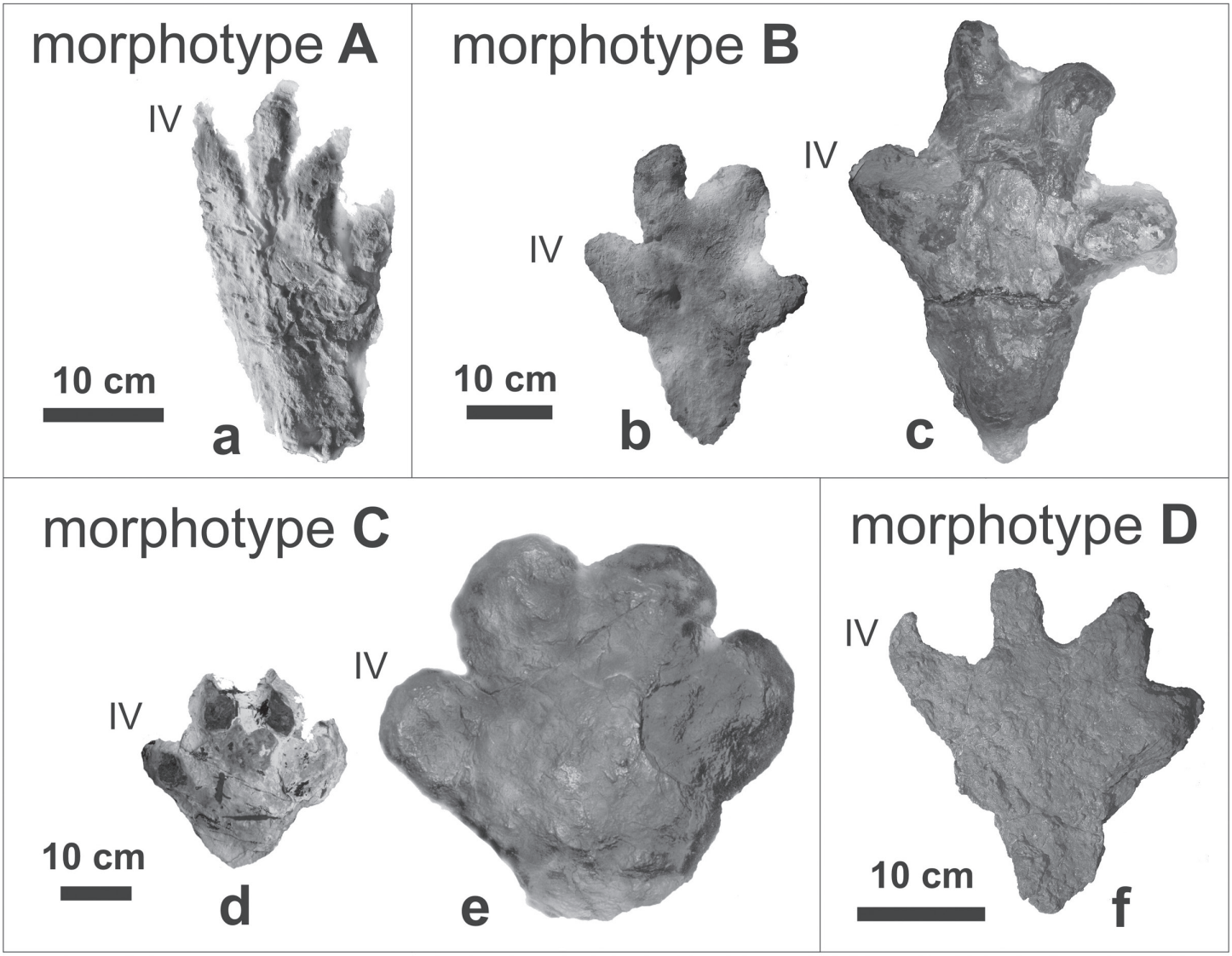

FIGURE 3. Four main morphotypes of dinosaurian tetradactyl semiplantigrade and plantigrade tracks from the Cretaceous of North America: **a** - cf. *Macropodosaurus* sp. (CU 219.3) from the Ferron Sandstone at Muddy Creek Canyon in Utah; **b** - ceratopsian track (uncatologued specimen) from the Castlegate Sandstone at Thompson Pass in Utah; **c** - ceratopsian track (CEUM 831) from the Blackhawk Formation near Price in Utah; **d** - ceratopsian track (CU 227) from the Iron Springs Formation at Parowan Gap in Utah; **e** - *Ceratopsipes goldenensis* Lockley and Hunt 1995b (CU-MWC 220.516) from the Laramie Formation at PArfet Clay Pit in Colorado; **f** - *Tetrapodosaurus* sp. (CU-MWC 209.33) from the Dakota Group near Walsh in Colorado.

belonging to a therizinosauroid track maker by Sennikov (2006). This type differs importantly from specimen UCM 209.149 in that it possesses long sharp digit traces and a relatively narrow U-shaped heel in comparison with other morphotypes.

Morphotype "B" (Fig. 3B-C) is characterized by a relatively narrow metapodium, but one that is V- rather than U-shaped posteriorly, and highly prominent (anteriorly projecting) traces of digits II and III. This kind of tetradactyl footprint is mainly known from the Upper Cretaceous coal mines near Price, Utah, and is generally inferred to be of ceratopsian origin (e.g., Parker and Rowley, 1989; Lockley and Hunt, 1995b). Its morphology fits a gracile ceratopsian foot pattern, possibly corresponding to the pedal morphology of *Cerasinops* (Fig. 4C). This is also clearly a different type of morphology from specimen UCM 209.149, which shows very short broad toes subequal in length.

Morphotype "C" (Fig. 3D-E) comprises ichnites such as *Ceratopsipes* (Lockley and Hunt, 1995b) and an unnamed ceratopsian track from the Iron Springs Formation of Utah (Milner et al., 2006), identified as the footprints of more derived ceratopsians. This morphotype corresponds with a more robust ceratopsian foot skeleton with shorter and wider phalanges, and metatarsals (Fig. 4F). However, Morphotype C is a wider form with shorter heel and slightly shorter digits than observed in track UCM 209.149.

Morphotype "D" (Fig. 3F), previously also supposed to be of ceratopsian affinity (Sternberg, 1932; Gierlinski and Sabath, 2008), seems to fit well the morphology of discussed specimen. However, this type is represented by the ichnogenus *Tetrapodosaurus* (Sternberg, 1932), is more likely attributed to an ankylosaurid trackmaker (McCrea et al., 2001). The type of *Tetrapodosaurus* has rather elongate and well-demarcated pes digit traces, in comparison with *Ceratopsipes* (Morphotype C). However, we recognize that the amount of flesh contained by and the separation of the pes digits and their corresponding traces may be variable and size related. Thus, large ankylosaur pes feet and tracks may be convergent with those of large ceratopsians. Conversely, there may also be convergence between the tracks and feet of the smaller members of these two clades.

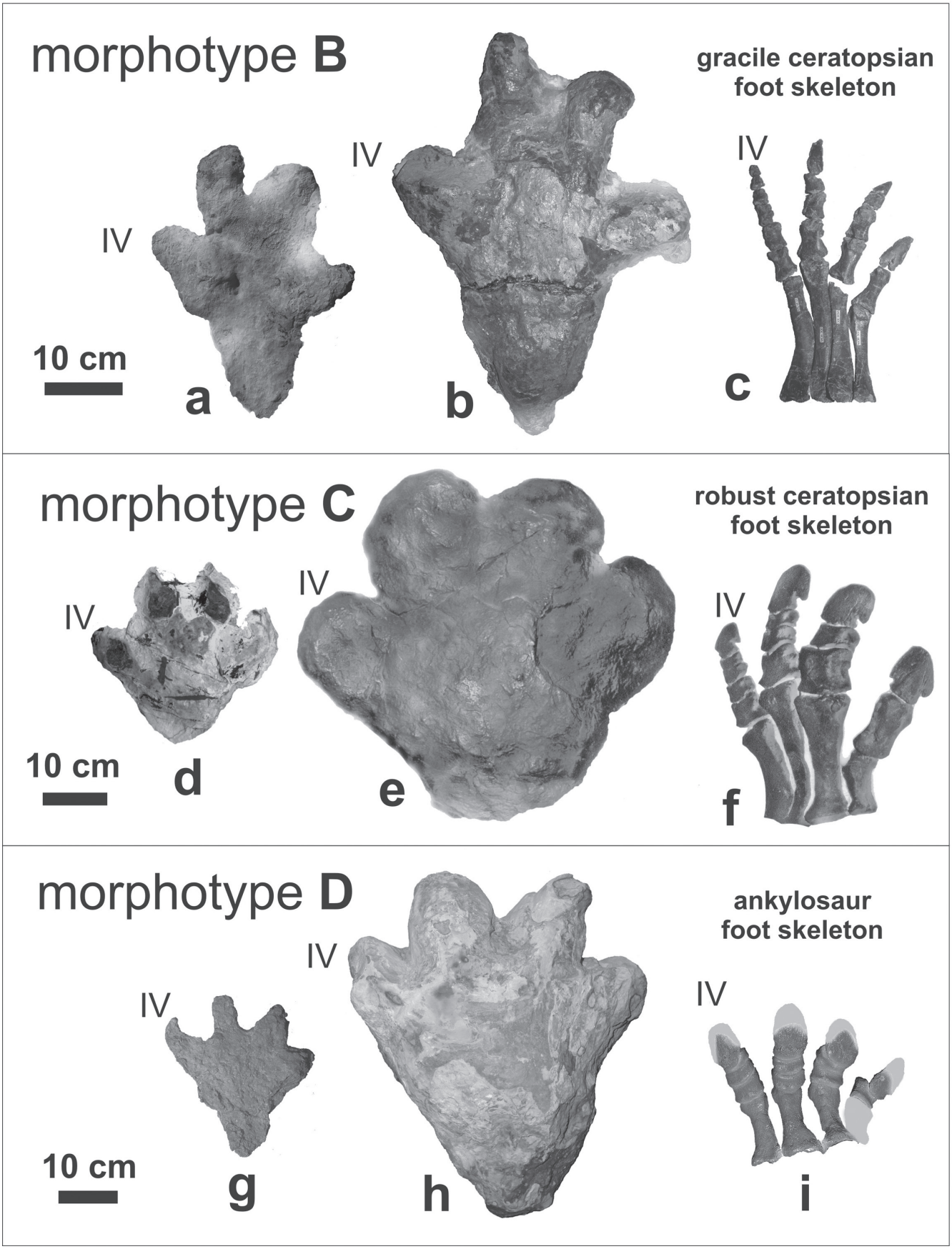

FIGURE 4. Three morphotypes of tetradactyl semiplantigrade and plantigrade ornithischian tracks in comparison with the foot skeletons of possible trackmakers: **a** - ceratopsian track (un-cataloged CEUM specimen) from the Castlegate Sandstone of Utah; **b** - ceratopsian track (CEUM 831) from the Blackhawk Formation of Utah; **c** - *Cerasinops* pes (MOR 300) from the Two Medicine Formation of Montana; **d** - ceratopsian track (CU 227) from the Iron Springs Formation of Utah; **e** - *Ceratopsipes goldenensis* Lockley & Hunt 1995b (CU-MWC 220.516) from the Laramie Formation of Colorado,; **f** - *Centrosaurus* pes (AMHN 5351) from the Dinosaur Park Formation of Alberta; **g** -*Tetrapodosaurus* sp. (CU-MWC 209.33) from the Dakota Group of Colorado; **h** – studied track CU 209 from the Platte Formation of Colorado; **i** - ankylosaur pes reconstructed on the basis of an *Nododosaurus* material YPM 1815 from the Frontier Formation of Wyoming.

CONCLUSIONS

The study of the tracks of ankylosaurs and related quadrupedal ornisthischians is still in flux (Lockley et al., 2012), and has been somewhat hampered by the lack of well-preserved and well-defined trackways. Although abundant trackways are known from some regions (McCrea et al., 2001, 2014), in many regions the sample of ankylosaur tracks is mainly composed of isolated casts. The present study provides a typical example of an intriguing footprint with a distinctive morphology that has an uncertain geological provenance.

Our tentative conclusion is that the track can be assigned to ichnogenus *Tetrapodosaurus*, herein assigned to Morphotype D. This inference suggests an ankylosaur track maker. The track likely originated from the lower part of the Dakota Group, locally mapped as the Lytle Formation and Plainview Sandstone Member of the South Platte Formation Lytle-Plainview (Fig. 1). This conclusion is of interest because previous reports of tracks from this unit are rare despite an abundance of reports from the upper part of the Dakota Group.

ACKNOWLEDGMENTS

We thank Denis Anderson of Fort Collins for collecting the specimen (CU 209.149) and donating it to the University of Colorado Denver Dinosaur Tracks Museum. Richard McCrea and Lisa Buckley, Peace Region Palaeontological Research Center, provided helpful reviews of this manuscript.

REFERENCES

Courtright, T.B. and Braddock, W.A., 1989, Geologic map of the Table Mountain Quadrangle and adjacent parts of the Round Butte and Buckeye Quadrangles, Larimer County Colorado, and Larimer County Wyoming: U. S. Geological Survey, Miscellaneous Investigation Series Map 1-1805.

Gierlinski, G. and Lockley M. G. 2013. First report of probable therizinosaur (cf. *Macropodosaurus*) tracks from North America, with notes on the neglected vertebrate ichnofauna of the Ferron Sandstone. Chapter 23, In Titus, A. L. and Loewen, M. A. (eds). At the Top of the Grand Staircase, Indiana University Press, p. 530-535.

Gierlinski, G. and Sabath, K., 2008, Stegosaurian footprints from the Morrison Formation of Utah and their implications for interpreting other ornithischian tracks: Oryctos, v. 8, p. 29-46.

Huerta Hurtado, P., 2001, Procesos de formacion de huellas en Costalomo (Salas de los Infantes, Burgos: Actas de las I Jornadas Internacionales sobre Paleontologia de Dinosaurios y su Entorno. Colectivo Archeologico-Paleontologico de Salas, p. 361-369.

Kurtz, B. Jr. Lockley, M.G. and Engard, D., 2001, Dinosaur tracks in the Plainview Formation, Dakota Group (Cretaceous, Albian) near Cañon City, Colorado: A preliminary report on another "dinosaur ridge:" Mountain Geologist, v. 38, p. 155-164.

Lockley, M.G., Cart, K. Martin, J., Prunty, R., Hups, K., Lim, J-D., Kim, K-S. Houck, K., Gierlinski, G. and Milner, A.R.C., 2014, A bonanza of new tetrapod tracksites from the Cretaceous Dakota Group, western Colorado: Implications for paleoecology: New Mexico Museum of Natural History and Science, Bulletin 62, this volume.

Lockley M.G., Gierlinski, G. McCrea, R.T, and Buckley, L., 2012, Tracking thyreophorans and related ornithischian dinosaurs: a review; *in* Lida, X. and Lockley, M.G., eds., Abstract Book of Qijiang International Dinosaur Tracks Symposium, Chongqing Municipality, China Nov 29-30th 2012, Boulder Publishing, p. 62-63.

Lockley, M.G., Holbrook, J. Kukihara, R., and Matsukawa, M., 2006b, An ankylosaur-dominated dinosaur tracksite in the Cretaceous Dakota Group of Colorado and its paleoenvironmental and sequence stratigraphic context: New Mexico Museum of Natural History and Science, Bulletin, 35, p. 95-104.

Lockley, M.G., Hunt, A.P., and Meyer, C., 1994, Vertebrate tracks and the ichnofacies concept: Implications for paleoecology and palichnostratigraphy; *in* Donovan, S., ed., The Paleobiology of Trace Fossils: Wiley and Sons, Inc., p. 241-268.

Lockley, M.G. and Hunt, A.P., 1995a, Dinosaur tracks and other fossil footprints of the western United States. Columbia University Press. New York, 338 p.

Lockley, M.G. and Hunt, A.P., 1995b, Ceratopsid tracks and associated ichnofauna from the Laramie Formation (Upper Cretaceous: Maastrichtian) of Colorado: Journal of Vertebrate Paleontology, v. 15, p. 592–614.

Lockley, M.G., Houck, K. Yang, S-Y., Matsukawa. M and Lim, S-K., 2006a, Dinosaur dominated footprint assemblages from the Cretaceous Jindong Formation, Hallayo Haesang National Park, Goseong County, South Korea: Evidence and implications: Cretaceous Research, v. 27, p. 70-101.

Macke, D.L. and Maughan, E.K., 1985, Rocky Mountain Section Field Trip Guide. Rocky Mountain Section America Association of Petroleum Geologists and Rocky Mountain Section Society of Economic Paleontologists and Mineralogists.

McCrea, R., Lockley, M.G. and Meyer, C.A., 2001, Global distribution of purported Ankylosaur track occurrences; *in* Carpenter, K., ed., The Armored Dinosaurs. Indiana University Press. p. 413-454.

McCrea, R.T., Buckley, L.G., Plint, A.G., Currie, P.J., Helm, C.W., Haggart, J.W., and Pemberton, S.G., 2104, A review of vertebrate track-bearing formations from the Mesozoic and earliest Cenozoic of western Canada with a description of a new theropod ichnospecies and reassignment of an avian ichnogenus: New Mexico Museum of Natural History and Science, Bulletin 62, this volume.

Milner, A.R.C., Vice, G.S., Harris, J.D**.** and Lockley, M.G., 2006, Dinosaur tracks from the Upper Cretaceous Iron Springs Formation, Iron County, Utah: New Mexico Museum of Natural History and Science, Bulletin 35**,** p. 105-113.

Parker, L.R. and Rowley, R.L. Jr., 1989, Dinosaur footprints from a coal mine in east-central Utah; *in* Gillette, D.D. and Lockley M.G., eds., Dinosaur Tracks and Traces. Cambridge University Press, Cambridge, p. 361-366.

Parker, L.R. and Balsley, J., 1989, Coal mines as localities for studying dinosaur trace fossils; *in* Gillette, D.D. and Lockley M.G., eds., Dinosaur Tracks and Traces. Cambridge University Press, Cambridge, p. 353-359.

Sennikov, A.G., 2006, Reading segnosaur tracks: Priroda, v. 5, p. 58-67 [in Russian].

Sternberg, C.M., 1932, Dinosaur tracks from Peace River, British Columbia: Bulletin of the National Museum of Canada**,** v. 68, p. 59–85.

Torcida Fernandez-Baldor, F.T., Izquierdo Montero, Huerta, P. Montero Huerta, D., Perez Martinez, G and Urien Montero, V., 2006, El Yacimiento de icnitas de dinosaurios de Costalomo (Salas de los Infantes, Burgos, España): Nuevos datos: III Jornadas Internacionales sobre Paleontologia de Dinosaurios y su Entorno, Salas de los Infantes, Burgos, p. 313-347.

Weimer, R.J., 1989, Sequence stratigraphy, Lower Cretaceous, Denver Basin, Colorado U.S.A.; *in* Ginsburg, R.D. and Beaudoin, B., eds., Cretaceous Resources, Events and Rhythms. NATO ASI Series, Kluwer, Dordrecht, p. 1-8.

Weimer, R.J., Dolson, J., Etheridge, F. and Warme, J., 1990, Sequence Stratigraphy-Lower K, Fort Collins-Boulder-Morrison Area. 2-Day Feld Trip (April 28-29). Rocky Mountain Section of the Society for Sedimentary Geology (Society of Economic Paleontologists and Mineralogists), 125 p.

Zhakharov, S.A., 1964, On footprints of a Cenomanian dinosaur whose tracks were found in the Shirkent River Valley; *in* Reiman, V. M., ed., Paleontology of Tadzikistan:Akademiya Nauk Tadzhikskoi SSR, Dushanbe, p. 31-5 [in Russian with English summary].