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Nicholas J. Minter and Spencer G. Lucas
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THE ARTHROPOD TRACE FOSSIL *CRUZIANA* AND ASSOCIATED ICHNOTAXA FROM THE LOWER PERMIAN ABO FORMATION, SOCORRO COUNTY, NEW MEXICO

NICHOLAS J. MINTER[1,2] AND SPENCER G. LUCAS[3]

[1]Department of Earth Sciences, University of Bristol, Wills Memorial Building, Queen's Road, Bristol, BS8 1RJ, UK
[2]School of Biological Sciences, University of Bristol, Woodland Road, Bristol, BS8 1UG, UK
[3]New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104, USA.

Abstract—A trace fossil assemblage consisting of *Cruziana problematica*, *Diplichnites gouldi*, *Diplichnites* isp., *Monomorphichnus* isp., *Palaeophycus tubularis*, *Rusophycus carbonarius, Striatichnium* cf. *S. Natalis* and compound traces of *C. problematica* × *R. carbonarius* is reported from the Lower Permian Abo Formation of the Joyita Hills in Socorro County, New Mexico. The assemblage is an example of the *Scoyenia* ichnofacies and indicates deposition under a continental regime during the last phase of Abo sedimentation in central New Mexico. It is atypical of Abo trace fossil assemblages in that it is dominated by striated bilobate traces whereas other assemblages from the Abo Formation are dominated by tetrapod and arthropod trackways. This reflects the production of this assemblage within a small ephemeral water body on a floodplain whereas other Abo assemblages formed during fleeting preservation windows on exposed surfaces after sheetfloods on the floodplain. The majority of trace fossils are attributed to notostracan branchiopod crustaceans, which are adapted to inhabit ephemeral water bodies.

INTRODUCTION

The Lower Permian Abo Formation and equivalent strata of the Hueco Group in central and southern New Mexico contain one of the world's most extensive records of nonmarine Permian red-bed trace fossils. These encompass well-studied, prolific assemblages of tetrapod footprints and, until recently, less well-studied but equally prolific assemblages of arthropod trace fossils. Here, we add to this arthropod trace fossil record of the Abo Formation the ichnogenera *Cruziana* and *Rusophycus*, well known, stratigraphically long ranging, and facies-crossing trace fossils. The paleoecological significance of the trace fossil assemblage is discussed. In this article, NMMNH refers to the New Mexico Museum of Natural History and Science, Albuquerque.

PROVENANCE

The *Cruziana* locality (NMMNH locality 6708) was discovered by Thomas Martens in October 2005 and we collected the site in August of 2006. The locality is in the Cerrillos del Coyote (sec. 24, T2S, R1E) in the Joyita Hills northeast of Socorro. Stratigraphically, locality 6708 is high in the Abo Formation (Fig. 1), in the Cañon de Espinoso Member of Lucas et al. (2005a), about 9 m below the base of the overlying Arroyo de Alamillo Formation of the Yeso Group. The trace fossils from NMMNH locality 6708 are preserved in positive hyporelief, on the base of a very thin mud layer, below a 0.3 m thick, fine-grained, ripple-laminated sandstone (Fig. 2A). Trace fossils are also preserved in negative epirelief and positive hyporelief on the mud draped surfaces of thin, fine-grained, ripple-laminated sandstones in a 0.1 m section below the thick sandstone bed. Raindrop imprints (Fig. 2B-C) and halite pseudomorphs (Fig. 2D-E) are found in association with many of the trace fossils. The fine-grained nature of the mud drape surfaces has allowed for detailed preservation of the trace fossils.

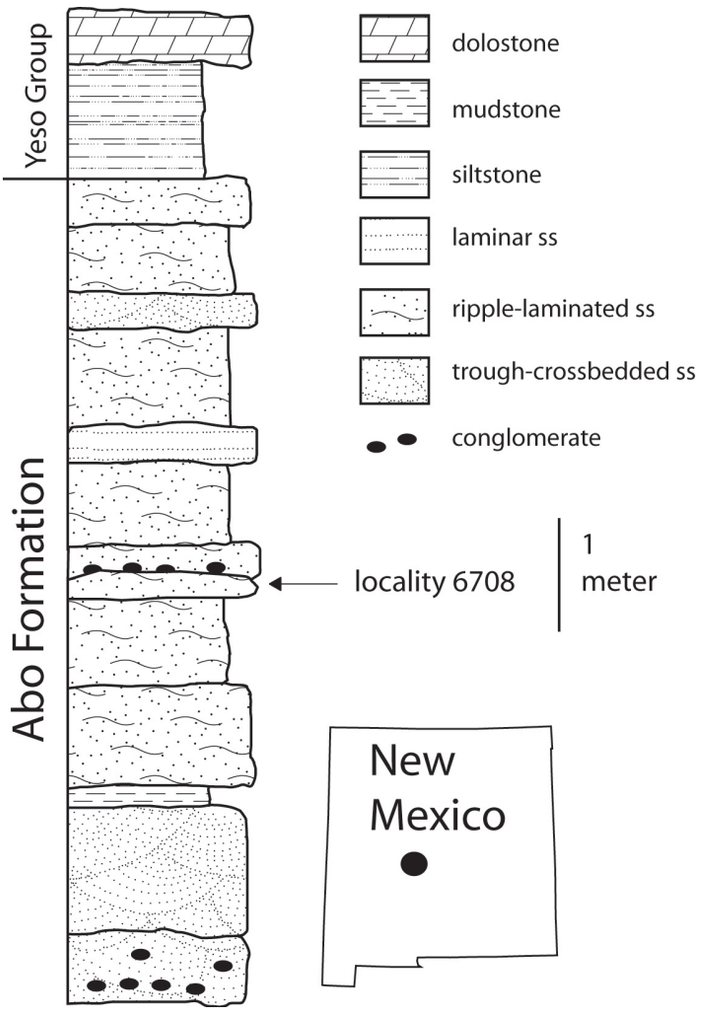


FIGURE 1. Measured stratigraphic section of the uppermost Abo Formation and base of the Yeso Group at NMMNH locality 6708.

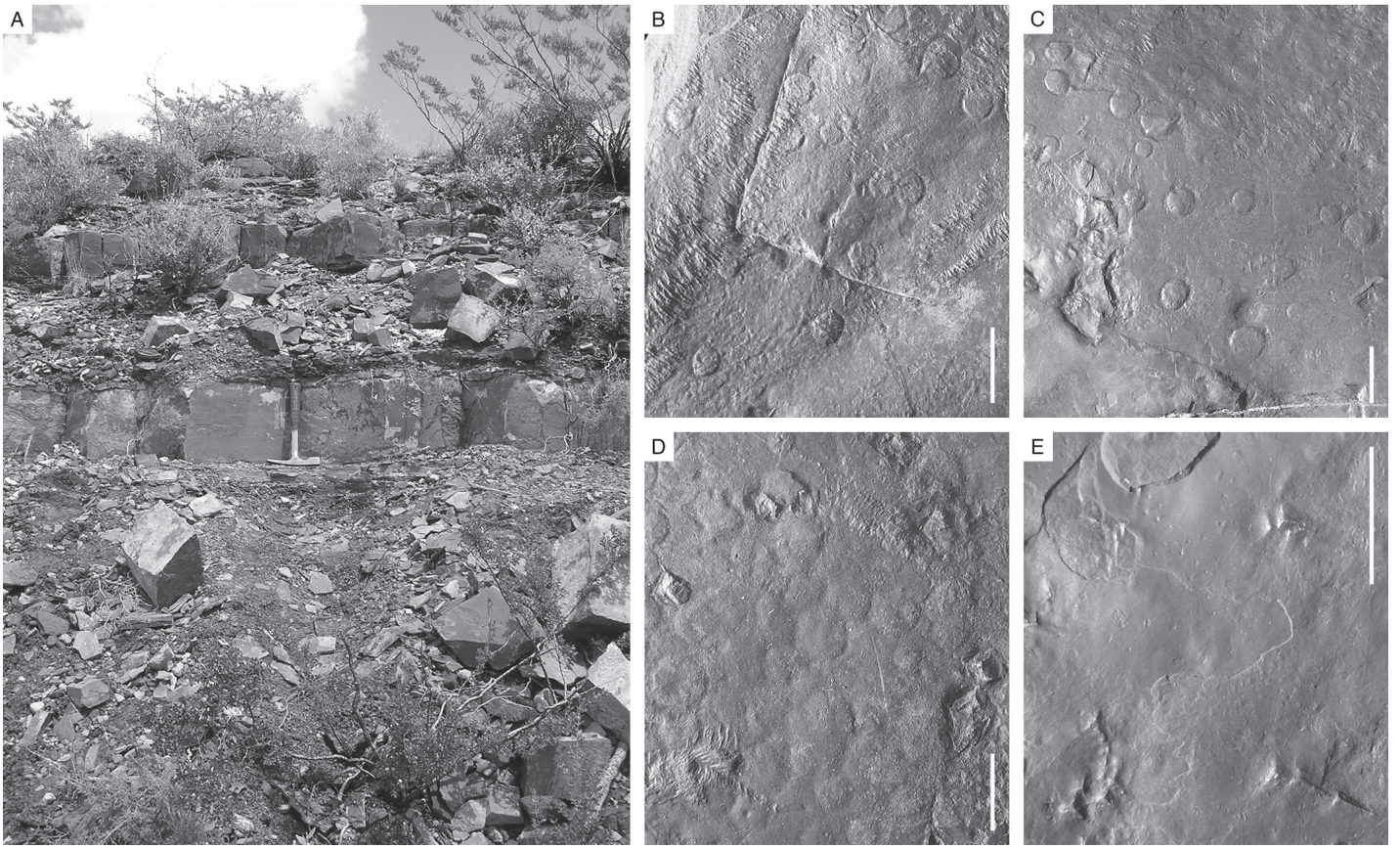


FIGURE 2. **A,** Trace fossil bearing beds at locality 6708. Trace fossils are preserved in positive hyporelief in a thin mud layer at the base of a 0.3 m thick sandstone (indicated by hammer) and in negative epirelief and positive hyporelief on the mud draped surfaces of thin, ripple-laminated, fine-grained sandstones in a 0.1 m section below. **B,** Raindrop imprints preserved on the same surface as NMMNH P-50101.5a (*Cruziana problematica*) and NMMNH P-50101.5b (*Rusophycus carbonarius*). **C,** Raindrop imprints preserved on the same surface as NMMNH P-51568 (*Cruziana problematica*) and NMMNH P-51569 (*Rusophycus carbonarius*). **D,** Halite pseudomorphs preserved on the same surface as NMMNH P-50101.7a (*Cruziana problematica*) and NMMNH P-50101.7b (*Rusophycus carbonarius*). **E,** Halite pseudomorphs preserved on the same surface as NMMNH P-51560a (*Diplichnites gouldi*) and NMMNH P-51560b (*Diplichnites gouldi*).

The Abo Formation is assigned a middle-late Wolfcampian age regionally; however, in Socorro County no precise data can be used to place the base of the Leonardian, which is conventionally considered to be at the base of the Yeso Group (e.g., Mack and Dinterman, 2002; Lucas et al., 2005a). Therefore, we assign NMMNH locality 6708 a late Wolfcampian age, though it could be early Leonardian.

SYSTEMATIC ICHNOLOGY

In the following text, catalogue numbers with decimal places refer to separate slabs with the same number, whereas those denoted with additional letters refer to separate specimens on the same slab.

Discrete ichnotaxa
Ichnogenus *Cruziana* d'Orbigny, 1842
Cruziana problematica (Schindewolf, 1928)
Fig. 3A-C

Referred specimens: NMMNH P-51562 preserved in negative epirelief. NMMNH P-50101.1a, P-50101.2a, P-50101.3, P-50101.4a, P-50101.5a, P-50101.6a, P-50101.7a, P-51557a, P-51559a, P-51561, P-51564, P-51566, P-51568, P-51572a, P-51573a, P-51589a, P-51590, P-51591a and P-51591b preserved in positive hyporelief.

Description: Small, straight, striated, bilobate traces ranging in external width from 5.0 to 13.0 mm (Fig. 3A-B). The lobes range in width from 1.0 to 6.0 mm, with a separation of 0.5-6.0 mm, and preserve fine, closely-spaced striations oriented perpendicular to oblique to the midline of the trace. The majority of examples lack well-defined lobes and consist of just paired parallel rows of striations oriented perpendicular to oblique to the midline of the trace (Fig. 3C). These types of traces include those with the greater external widths.

Remarks: The use of the names *Cruziana*, *Rusophycus* and *Isopodichnus* for small bilobate traces with striations has been debated. The consensus is that *Isopodichnus* is no longer valid, and *Cruziana* should be used for long forms, where the length is greater than twice the external width of the trace, and *Rusophycus*

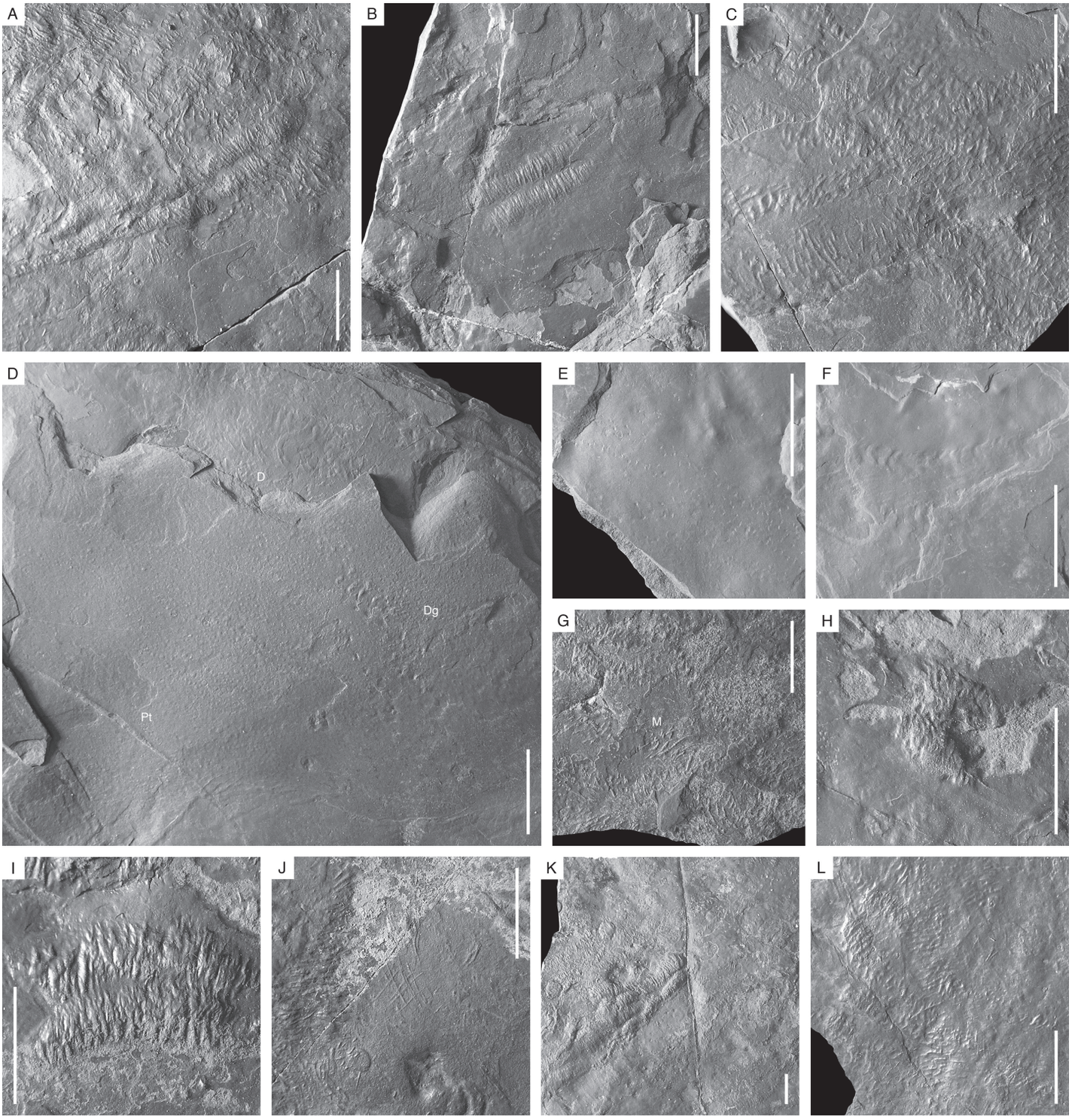


FIGURE 3. **A-C,** *Cruziana problematica*. **A,** NMMNH P-51572a. **B,** NMMNH P-51591b. **C,** NMMNH P-51566. Note the lack of lobes. **D-F,** *Diplichnites gouldi*. **D,** P-51588a (Dg). Note also the presence of *Diplichnites* isp. (D), NMMNH P-51588b, and *Palaeophycus tubularis* (Pt), NMMNH P-51588c. **E,** NMMNH P-51560a. **F,** NMMNH P-51560b. **G,** *Monomorphichnus* isp., NMMNH P-50101.4b. **H-I,** *Rusophycus carbonarius*. **H,** NMMNH P-51567a. **I,** NMMNH P-50101.1c. Note the occurrence in a linear succession. **J,** *Striatichnium* cf. *natalis*, NMMNH P-51589b. **K-L,** *Cruziana problematica* × *Rusophycus carbonarius*. **K,** NMMNH P-50101.6c. **L,** NMMNH P-51559c.

should be used for shorter, "coffee-bean" forms (Bromley and Asgaard, 1972, 1979; Keighley and Pickerill, 1996; Minter et al., 2007a). The morphology of the traces documented here is consistent with the diagnosis of *Cruziana problematica* in that they have fine, closely-spaced striations oriented perpendicular to oblique to the midline of the trace and the range of external widths is similar to that reported by Keighley and Pickerill (1996). The majority of examples are similar to the "appendage mark" traces of Trewin (1976) and are considered as minor morphological variants of *C. problematica*, most likely due to minor preservational variation, where the observed surface is below the plane along which the original trace was produced. The "appendage mark" traces may also be due to minor behavioral variation, where the producer was just raking the surface as opposed to plowing through the substrate.

Discussion: Notostracan branchiopod crustaceans are the most likely producers of these traces. The modern notostracans *Apus*, *Triops* and *Lepidurus* have been observed to plow through the substrate while feeding and produced traces very similar to *C. problematica* (Fox, 1949; Bromley and Asgaard, 1972; Gand et al., 2008). Notostracans are adapted for exploiting ephemeral water bodies (Hamer and Appleton, 1991). They produce eggs that can survive dormant for tens of years (Dexter, 1973) and can resist extreme temperatures (Carlisle 1968) before hatching following an influx of water (Su and Mulla, 2002) and completing their lifecycle within a matter of weeks.

Ichnogenus *Diplichnites* Dawson 1862
Diplichnites gouldi (Bradshaw, 1981)
Fig. 3D-F

Referred specimens: NMMNH P-51560a and P-51560b preserved in negative epirelief. NMMNH P-51588a preserved in positive hyporelief.

Description: Trackways consisting of overlapping, low angle, en echelon series of tracks with opposite symmetry. NMMNH P-51588a consists of series of six to seven curvilinear tracks, 1.5 mm in greatest dimension, oriented perpendicular to the midline of the trackway (Fig. 3D). The external width is 8.0 mm. The high degree of low angle overlap between series in NMMNH P-51560a (Fig. 3E) means that it is difficult to accurately determine the number of tracks in a true series. Series of four to five ovate tracks, 0.2-0.5 mm in maximum dimension, can be observed, but these are likely to be "false series" (Minter et al., 2007b). The external width is 3.0-3.5 mm. NMMNH P-51560b consists of series of curvilinear tracks, 2.0 mm in maximum dimension. There is a very high degree of overlap between the en echelon series, so it is not possible to determine the number of tracks within a series (Fig. 3F). The external width is 7.5 mm.

Remarks: The ichnotaxonomy of *Diplichnites* and similar forms is in dire need of revision. Trackways with overlapping low angle en echelon series of tracks with opposite symmetry are generally referred to *Diplichnites gouldi* (Trewin and McNamara, 1995; Smith et al., 2003; Minter et al., 2007a). The trackways documented here are similar to those identified as *D. gouldi* type A by Minter et al. (2007a). In particular, NMMNH P-51588a is very similar to one trackway illustrated by Minter et al. (2007a, fig. 7B), and NMMNH P-51560b is very similar to another specimen illustrated by Minter et al. (2007a, fig. 7C). These assignments may be revised in the future but are followed here for consistency.

Discussion: These trackways were most likely produced by notostracan branchiopod crustaceans. Notostracans possess 11 thoracic limbs, the first of which is modified, and the remainder decrease in length from the cephalon to telson (McLaughlin, 1980). This variation in limb length is consistent with the presence of low angle en echelon series of tracks. However, notostracans would be expected to produce trackways with ten tracks, so it would mean that not all of the tracks are preserved. The non-preservation of tracks from multi-limbed arthropods is common (Davis et al., 2007) and is most likely due to non-formation of tracks in the first instance or subsequent loss due to undertracking, both of which are fundamentally due to differences in the stiffness of the substrate and forces exerted by the various limbs. The trackways documented here lack paired medial impressions, which would be expected if the paired rami of the telson of notostracans made contact with the substrate. Trackways produced by the modern notostracans, *Triops* and *Lepidurus* (Trusheim, 1931; Gand et al., 2008), are similar to *D. gouldi*. Euthycarcinoids are an enigmatic group of extinct arthropods that are morphologically similar and may have affinities with anostracans (Wilson and Almond, 2001). They have also been interpreted as being adapted to live in ephemeral water bodies and having modes of life similar to those of branchiopod crustaceans (Anderson and Trewin, 2003). Euthycarcinoids are therefore also possible producers of trackways such as *D. gouldi* (Minter et al., 2007a).

Diplichnites isp.
Fig. 3D

Referred specimen: NMMNH P-51588b preserved in positive hyporelief.

Description: Trackway consisting of two parallel track rows and lacking discernible series. NMMNH P-51588b appears to consist of curvilinear tracks, 2.5 mm in maximum dimension, that occur in pairs in places. Only one track row is well preserved, so it is difficult to determine the symmetry (Fig. 3D). The external width is approximately 9.0 mm.

Remarks: This trackway is referred to *Diplichnites* isp. because it lacks any discernible series and obvious alternate symmetry, although it is poorly preserved. The presence of possible paired tracks would ally it with "*Permichnium*-like" minor morphological variants of *Lithographus* (Minter et al., 2007b), although it would be necessary to demonstrate that the trackway had alternate symmetry for such an assignment.

Discussion: This trackway was produced by an arthropod and, as with *D. gouldi*, it was most likely produced by a notostracan branchiopod crustacean or euthycarcinoid. However, the lack of obvious en echelon series suggests that a myriapod producer is also possible. Hexapods are responsible for trackways with alternating series of two to three curvilinear tracks (Davis et al., 2007).

Ichnogenus *Monomorphichnus* Crimes, 1970
***Monomorphichnus* isp.**
Fig. 3G

Referred specimens: NMMNH P-50101.4b, P-51563a and P-51565 preserved in positive hyporelief.

Description: Clusters of five to six, elongate, straight to sigmoidal, striations that are approximately 5 to 6 mm long and are separated by 1.5 mm (Fig. 3G). The striations overlap in some cases but do not occur in paired parallel rows or lobes.

Remarks: *Monomorphichnus* consists of clusters of striations. *Dimorphichnus* is a similar ichnogenus that consists of a row of elongate striations and a parallel row of shorter striations. The distinction between these two ichnogenera is contended with Seilacher (1985) observing that the type material of the type ichnospecies of *Monomorphichnus*, *M. bilinearis*, preserves a faint row of shorter striations and therefore belongs within *Dimorphichnus*. However, Fillion and Pickerill (1990) state that such features are not present in the type material of *M. bilinearis*. Mángano et al. (2005) further suggested that *Monomorphichnus* should be retained, at least pending a full revision, even if *M. bilinearis* turns out to belong to *Dimorphichnus* because the other established ichnospecies of *Monomorphichnus* would not be able to be referred to *Dimorphichnus* without substantial emendation of the diagnosis.

The lack of well-preserved material from the Joyita Hills means that it is difficult to make an ichnospecific assignment. These specimens are most similar to *M. lineatus*, which comprises clusters of four to six striations (Crimes et al., 1977), although the striations overlap in places in these specimens. *M. intersectus* consists of overlapping striations (Fillion and Pickerill, 1990), although there are a much greater number of striations present in this ichnospecies. This material does not closely conform to any established ichnospecies of *Monomorphichnus*, so it is referred to *Monomorphichnus* isp.

Discussion: These traces were probably produced by arthropods raking the surface of the substrate while feeding. Notostracan branchiopod crustaceans are possible producers, although they tend to plow through the substrate while feeding (Fox, 1949; Bromley and Asgaard, 1972, 1979; Gand et al., 2008). Other branchiopods, such as anostracans, are more likely producers because they have been observed to rake the substrate (Fryer, 1966, 1983), and the extinct lipostracans are interpreted to have had a similar mode of feeding (Fryer, 1985). Anostracans are also adapted to living in ephemeral water bodies (Hamer and Appleton 1991). Euthycarcinoids are interpreted to have fed in a similar way (Anderson and Trewin, 2003) and are also possible producers.

Ichnogenus *Palaeophycus* Hall, 1847
***Palaeophycus tubularis* Hall, 1847**
Fig. 3D

Referred specimen: NMMNH P-51588c preserved in full relief.

Description: Curved, unbranched, horizontal cylindrical burrow, 0.8 mm in diameter. The burrow has a thin lining, and the fill is the same as the host sediment.

Remarks: *Palaeophycus* is distinguished from *Planolites* by the presence of a lining (Pemberton and Frey, 1982; Keighley and Pickerill, 1995). This material is assigned to *Palaeophycus tubularis* because it has a thin lining that lacks striations (Pemberton and Frey, 1982).

Discussion: The presence of a lining and similar fill to the host sediment indicate that this specimen was an open dwelling burrow of a suspension feeder or predator (Pemberton and Frey, 1982). This burrow was probably produced by a vermiform animal, although arthropods are also possible producers.

Ichnogenus *Rusophycus* Hall, 1852
***Rusophycus carbonarius* Dawson, 1864**
Fig. 3H-I

Referred specimens: NMMNH P-51558 preserved in negative epirelief. NMMNH P-50101.1b, P-50101.1c, P-50101.2b, P-50101.5b, P-50101.6b, P-50101.7b, P-50101.8, P-51557b, P-51559b, P-51563b, P-51567a, P51567b, P-51569, P-51570, P-51571, P-51572b, P-51574, P-51575, P-51591c and P-51591d preserved in positive hyporelief.

Description: Short, striated, bilobate traces, ranging from 4.0 to 13.0 mm long and 6.5 to 12.0 mm in external width (Fig. 3H). The lobes preserve fine, closely-spaced striations oriented perpendicular to oblique to the midline of the trace. The lobes expand towards one end, with maximum lobe widths ranging from 2.0 to 5.5 mm. Lobes may also be separated medially at one end by up to 6.5 mm. Some examples occur in linear successions (Fig. 3I) or in compound traces with *C. problematica* (Fig. 3K-L).

Remarks: As mentioned above, the use of the names *Cruziana*, *Rusophycus* and *Isopodichnus* has been debated, with the consensus to abandon *Isopodichnus* and use *Rusophycus* for short, bilobate "coffee-bean" traces such as the specimens documented here (Bromley and Asgaard, 1972, 1979; Keighley and Pickerill, 1996; Minter et al., 2007a). This material is assigned to *Rusophycus carbonarius* due to the presence of striations oriented perpendicular to oblique to the midline of the trace (Dawson, 1864; Schlirf et al., 2001). The examples that occur in linear successions are similar to *R. versans*, although the individual traces in *R. versans* are in a fan-like arrangement (Schlirf et al., 2001).

Discussion: Together with the majority of traces from this locality, these traces were most likely produced by notostracan branchiopod crustaceans. These traces were probably produced as the animal was stationary and raking the substrate during feeding or resting. *C. problematica* is produced by the animal plowing through the substrate while feeding. The modern notostracans *Triops* and *Lepidurus* have been observed to produce similar traces (Bromley and Asgaard, 1972; Gand et al., 2008). Linear successions of *R. carbonarius* indicate that the producer repeatedly left the substrate before returning after a short distance and then raking at the substrate while stationary. *R. carbonarius* and *C. problematica* are often found on the same surfaces at this locality, and there are also compound examples of *Cruziana problematica* × *Rusophycus carbonarius*.

Ichnogenus *Striatichnium* Walter, 1982
***Striatichnium* cf. *S. natalis* Walter, 1982**
Fig. 3J

Referred specimen: NMMNH P-51589b preserved in positive hyporelief.

Description: Trace consisting of an overlapping pair of clusters of seven, elongate, sigmoidal, striations (Fig. 3J). The striations range in length from 5.0 to 10.0 mm and are separated by 0.2 to 1.0 mm. The opposing clusters of striations are oriented approximately perpendicular to one another.

Remarks: *Striatichnium natalis* consists of clusters of curved striations that overlap in an alternating sequence. The striations can be seen to extend for up to 10 mm in this specimen and overlap to a similar extent, as in *S. natalis*. However, the extent of the preserved trace means that it is not possible to determine if they are in an alternating sequence. This specimen is therefore referred to *Striatichnium* cf. *S. natalis*.

Discussion: This trace was most likely produced by an arthropod raking the substrate with its limbs while feeding. *S. natalis* was originally interpreted as having been produced by a spine-bearing animal such as an arthropod larva or worm (Walter, 1982). As with *Monomorphichnus* isp., notostracan branchiopod crustaceans are possible candidates. Schneider (1983) suggested that euthycarcinoids were the producers of *S. natalis*. Anostracan and lipostracan branchiopods, which would have just scraped the surface (Fryer, 1966, 1983, 1985) rather than plowing through it, are also likely producers.

Compound ichnotaxa
***Cruziana problematica* (Schindewolf, 1928) × *Rusophycus carbonarius* Dawson, 1864**
Fig. 3K-L

Referred specimens: NMMNH P-50101.6c and P-51559c preserved in positive hyporelief.

Description: Long, striated, bilobate traces intergrading with short striated bilobate traces. The lobes preserve fine, closely-spaced striations oriented perpendicular to oblique to the midline of the trace (Fig. 3K-L). NMMNH P-50101.6c (Fig. 3K) consists a long bilobate trace with an external width of 11.0 to 11.5 mm. The lobes are 5.5-6.0 mm wide, with a medial separation of 0.5 mm. This trace intergrades with a linear succession of short bilobate traces that have external widths of 8.0-11.0 mm and lengths of 8.0-13.0 mm. The lobes of the short bilobate traces range in width from 4.0 to 4.5 mm and have medial separations ranging from 0.5 to 4.0 mm. NMMNH P-51559c (Fig. 3L) consists of a long pair of parallel rows of striations, with an external width of 9.0 mm, which lack well-developed lobes. The striations are oriented perpendicular to the midline of the trace, and each row is 3.0 to 3.5 mm wide with a medial separation of 2.0 mm. This long trace intergrades with a short bilobate trace with an external width of 9.5 mm, length of 7.0 mm, lobe width of 3.0-4.0 mm, and a medial separation of 4.5 mm.

Remarks: The morphologies of the individual traces in these compound structures correspond with *C. problematica* and *R. carbonarius*. The compound nature of these traces is documented using a hybrid nomenclature system following Minter et al. (2007b).

Discussion: As with *C. problematica* and *R. carbonarius*, these traces were most likely produced by notostracan branchiopod crustaceans. The intergrading nature of these traces indicates a change in behavior, with the producer changing from plowing through the substrate while feeding to then stopping and raking deeper into the substrate. The traces that terminate with a single *R. carbonarius* indicate that the producer moved off from the substrate, while those with linear successions of *R. carbonarius* indicate that the producer repeatedly left the substrate for a short distance before returning to a stationary position and raking the substrate again.

DISCUSSION

Abo deposition in Socorro County took place on a broad floodplain about 140 km from the shoreline of the Early Permian sea (Hueco seaway) in southern New Mexico (Kues and Giles, 2004). At the onset of Yeso deposition, a marine transgression brought shallow marine, sabkha, tidal flat and eolian paleoenvironments into Socorro County (Mack and Dinterman, 2002). The Abo-Yeso contact in Socorro County is gradational, so it seems possible that the last phase of Abo deposition took place under increasing marine influence culminated by the stratigraphically lowest marine strata (dolostones) of the overlying Yeso Group. However, the trace fossil assemblage documented here indicates freshwater conditions during the last phase of Abo deposition, and this suggests that the oldest marine transgression of the overlying Yeso Group was a relatively rapid event after the end of Abo deposition.

The trace fossil assemblage from NMMNH locality 6708 in the Joyita Hills of Socorro County is high in the Abo Formation (Fig. 1) and the sedimentological context of the assemblage and the traces themselves indicate nonmarine conditions. The uppermost strata of the Abo Formation at locality 6708 (Figs 1-2) predominantly consist of mudstones and ripple-laminated sandstones that formed on a broad, arid, floodplain with unchannelized sheetfloods. Trace fossils are preserved on ripple-laminated surfaces with mud drapes, halite pseudomorphs and raindrop imprints. This indicates that the assemblage formed subaqueously within small ephemeral pools on the floodplain. Evaporation of water from the pools led to the formation of halite pseudomorphs and raindrop imprints indicate subsequent subaerial exposure.

Cruziana and *Rusophycus* are generally attributed to trilobites in marine settings (Seilacher, 1970; Birkenmajer and Bruton, 1971; Osgood and Drennen, 1975). This assertion contributed to an ichnotaxonomic debate over the use of the ichnogeneric names *Cruziana*, *Rusophycus* and *Isopodichnus*. *Cruziana* and *Rusophycus* were used for marine examples of striated bilobate traces attributed to trilobites (Seilacher, 1970; Birkenmajer and Bruton, 1971; Osgood and Drennen, 1975), whereas *Isopodichnus* was used for nonmarine examples of striated bilobate traces attributed to notostracan branchiopod crustaceans (Trewin, 1976; Pollard 1985). There are no morphological differences between *Cruz-*

iana-Rusophycus and *Isopodichnus*. *Cruziana* and *Rusophycus* are now recognized as facies-crossing ichnogenera, and examples from nonmarine settings are commonly attributed to notostracan branchiopod crustaceans (Bromley and Asgaard, 1972, 1979; Keighley and Pickerill, 1996; Minter et al., 2007a).

The trace fossil assemblage documented here differs from others discovered so far within the Abo Formation. Trace fossil assemblages from the Abo Formation in the Caballo and Fra Cristobal Mountains consist predominantly of the tetrapod trackway *Batrachichnus* and arthropod trace fossils *Tonganoxichnus* and *Stiaria* and formed during fleeting preservation windows on transitional subaqueous to subaerial surfaces following unchannelized sheetfloods on floodplains (Lucas et al., 2005b, c). Conversely, the trace fossil assemblage from the Joyita Hills is dominated by striated bilobate trace fossils and was formed subaqueously within ephemeral water bodies that were left behind after sheetfloods in the same general floodplain setting.

The trace fossil assemblage from the Joyita Hills is an example of the *Scoyenia* ichnofacies (Buatois and Mángano, 2004, 2007) and is similar to several other assemblages reported from ephemeral water bodies from the Permian of Argentina (Zhang et al., 1998) and France (Gand 1994), Carboniferous of Canada (Pickerill, 1992; Keighley and Pickerill, 2003), and Devonian of Norway (Pollard et al., 1982) and Scotland (Trewin, 1976; Trewin and Kneller, 1987). More diverse assemblages from the Permian of Texas (Minter et al., 2007a) and France (Demathieu et al., 1992), which also include meniscate backfilled burrows and abundant arthropod and tetrapod trackways, probably reflect larger and longer-lived ephemeral water bodies.

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