AN EXCEPTIONAL OCCURRENCE OF THE TRACE FOSSIL CRUZIANA ON A BEDDING SURFACE FROM A CORE OF THE BLOOMSBURG RED BEDS (SILURIAN), NORTHWESTERN NEW JERSEY

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ABSTRACT: A red, to greenish gray siltstone bedding surface from a remnant core from the Tocks Island Dam Project, northwestern New Jersey, has yielded an exceptional abundance of the trace fossil *Cruziana*, associated with sporadic *Rusophycus*, as well as the first record of a specimen of *Diplichnites* from the Silurian Bloomsburg Red Beds. Trace making is interpreted to have been produced by arthropods, with trilobites being responsible for *Cruziana* and *Rusophycus*. Though the Bloomsburg Red Beds have been interpreted to represent a largely meandering stream-floodplain environment, temporary brackish to shallow marine incursions were locally present and account for the presence of these marine traces.

INTRODUCTION

Worthington State Forest of New Jersey is home to several massive (mostly 0.9 m in diameter) cores of the Bloomsburg Red Beds left as drilling remnants of the now defunct Tocks Island Dam Project (Figure 1). The project, authorized by Congress in 1962, would provide flood control, hydroelectric power, as well as a national recreation area. The 49 m wide earthen dam was to span the Delaware River at Tocks Island. Many owners were quickly forced to evacuate their properties, often at much lower than appraisal values, though the project would not be completed for many years. Subsequently, however, evidence from the Army Corps of Engineers coring project indicated potential problems concerning support of the dam at this location. In addition, numerous delays in funding, much public opposition, as well as political considerations resulted in de-authorization in the early 1990’s.

GEOLOGIC SETTING

The Bloomsburg Red Beds (Middle to Upper Silurian) of northwestern New Jersey are composed of up to 460 m of thin- to thick-bedded red, green, and gray sandstone, siltstone, shale, as well as local conglomerate. Planar and cross-stratification are commonly found in the sandstones, while the siltstones and shale sporadically exhibit bioturbation, desiccation cracks, and small-scale ripples (Epstein, 1971). In addition, the first evidence of an ancestral horseshoe crab from New Jersey has been documented from these deposits (Metz, 2000). Well-defined, fining-upward sequences are common and consist of fine to coarse grained sandstone grading upward into siltstone and shale (Smith, 1967). These sequences have resulted in a largely meandering stream-floodplain interpretation for the Bloomsburg Red Beds (Smith, 1967; Epstein and Epstein, 1969; Epstein, 1971). However, the local presence of fish scales (Beerbower and Hait, 1959; Epstein, 1971) as well as the trace fossils *Rusophycus*, *Cruziana*, and *Skolithos* (Martino and Zapecza, 1978; Metz, 2000) may record temporary brackish to shallow marine conditions (also see Brett, 1995; Brett et al., 1990).

Previous research by Martino and Zapecza (1978) documented the presence of the trace fossil *Rusophycus* at six localities in the Bloomsburg Red Beds. Two of those locations also yielded rare to subordinate occurrences of the trace fossil *Cruziana* (Martino and Zapecza, 1978). In addition, they detailed strong evidence for both traces being produced by trilobites, which likely inhabited inter-distributary bays of an elongate delta complex that provided brackish to marine conditions (see Martino and Zapecza, 1978, for...
Figure 2 - Bedding surface of the Bloomsburg Red Beds core. Scale is 85 mm.

details). Interestingly, however, none of these studies detailed the Tocks Island Dam cores, and their documentation did not include illustrations of *Cruziana*. Portions of eight cores, varying in length from approximately 0.4 m to 5 m, were investigated at the site shown on Figure 1. Only one of the bedding surfaces exhibited fossil evidence, in this case trace fossils. Thus, the purpose of this paper is to document an exceptional occurrence of numerous *Cruziana*, sporadic *Rusophycus*, and a specimen of *Diplichnites* on a single moderate red, and grayish green siltstone bedding surface (Figure 2; 41° 00´ 55" latitude, 75° 04´ 12" longitude) of a remnant core of the Bloomsburg Red Beds from the Tocks Island Dam Project.

**SYSTEMATIC ICHNOLOGY**

*Ichnogenus Cruziana* d’Orbigny, 1842 (Figures 3, 4, and 5)

*Cruziana problematica* (Schindewolf, 1921)

**Material:** At least 52 core occurrences.

**Description:** Ribbon-like, bilobate traces moderately preserved in convex hyporelief on the bedding surface of a coarse-grained, mostly red to sporadic greenish gray siltstone. Specimens are straight to winding, in many places level crossing; traces up to 150 mm long, 6 to 9 mm wide, composed of two lobes 2-4 mm wide, separated by a median furrow 1-2 mm wide. Poorly preserved, faint, unevenly spaced transverse to nearly transverse scratch marks are present on a number of specimens. The poor evidence of transverse scratches may be attributable partially to the effects of subsequent exposure and weathering of the bedding surface.

**Remarks:** Though Seilacher (1955, 1970) suggested inclusion of *Rusophycus* (short excavations) under *Cruziana* (long furrows) owing to similar scratch marks that can be attributed to the same animal, most authors have considered their morphologies to differ significantly, thus retaining the two as separate ichnotaxa (e.g., Fillion and Pickerill, 1990; Jensen, 1997). The specimens from the Bloomsburg core are very similar in appearance to *Cruziana problematica* (Schindewolf, 1921) as figured by Bromley and Asgaard (1979, Fig. 18) and Fillion and Pickerill (1990, Plate 3, Fig. 2 and Fig. 4). Gand et al. (2008), in revising the systematics of *C. problematica*, considered the diagnosis of Bromley and Asgaard...
(1979) to be the most useful. Bromley and Asgaard (1979) noted that *C. problematica* was the smallest ichnospecies of *Cruziana*, and the size alone (e.g., width 1-11 mm) could almost be enough to distinguish it from other ichnospecies. In addition, they included *Isopedichnus* Bornemann, 1889 within *Cruziana* since they were found to differ only in accessory features, as well as combining three existing ribbonlike ichnospecies of *Isopedichnus* (including *I. stromnessi*) under *Cruziana problematica*. Thus, the range of width of the present specimens, presence of faint transverse striae in sporadic specimens, as well as general lack of evidence of striae in certain specimens (compare to Bromley and Asgaard, 1979, Fig. 18) allows assignment to *C. problematica*.

*Cruziana* is typically a shallow-water marine form (Seilacher, 1985). However, *Cruziana problematica* is interpreted to be a common non-marine trace fossil (e.g., Bromley and Asgaard, 1972; Trewin, 1976; Pollard, 1985). It has also been recorded from marginal-marine (Miller, 1979), and other fully marine sequences (e.g., Fillion and Pickerill, 1990). It has been found in Lower Cambrian to Triassic deposits. Most *Cruziana* have been attributed to trilobites (Seilacher, 1970), though some traces may have been produced by aglaspidids (Fischer, 1978), branchiopods (Bromley and Asgaard, 1979), as well as vertebrates (Shone, 1978). The intimate association of *Cruziana* and *Rusophycus* (trilobite-produced, see Martino and Zapecka, 1978 for details) allows for attribution of the present specimens of *Cruziana* to a similar origin.

**Ichnogenus Diplichnites Dawson, 1873** (Figures 6 and 7)

*Diplichnites* isp.

**Material:** One core occurrence.

**Description:** The trackway, preserved in convex hyporelief, consists of two parallel rows of somewhat disorganized, closely spaced, largely circular to slightly elongate imprints, with a maximum width of 7 mm and an internal width of 4 mm. Circular imprints 1-1.5 mm in diameter. The length of the trackway is approximately 100 mm. The depth and number of imprints are displayed in high preservational variability along the trackway, and are most numerous and well preserved in the bottom portion of the Figures 6 and 7.

**Remarks:** Although assignment to *Diplichnites* appears well justified, Keighley and Pickerill (1998) discuss the many problems associated with this ichnotaxon. As noted by Bradshaw (2010), for example, this includes great variability in the widths of the trackways, varying number of imprints per cycle, and the overall degree of preservation. In addition, Bradshaw (2010) indicates the difficulty of dealing with trackways since both the nature of the substrate as well as orientation of the animal affects the final trackway.

Dawson (1873) proposed a non-trilobite origin for *Diplichnites*, although Seilacher (1955) provisionally adopted it for trilobite traces. Briggs et al. (1979) proposed that its use be limited to non-trilobite formed trackways. Bradshaw (2010) noted that the producer of *Diplichnites* was most likely an arthropod, though exact its nature was open to discussion. As such, depending on the paleoenvironmental setting and mode of locomotion, most commonly it
is attributed to trilobites (e.g., Pickerill et al., 1984; Fillion and Pickerill, 1990) or myriapods (e.g., Johnson et al., 1994; Buatois et al., 1998). Other suggested producers include notostracan branchiopods (e.g., Bromley and Asgaard, 1979), as well as eurypterids and xiphosurids (Trewin and McNamara, 1995). The presence of Diplichnites represents the first record of this trace fossil in the Bloomsburg Red Beds. Since the trace is on the same bedding surface and intimately associated with Cruziana and Rusophycus, it is tempting to also assign it to a trilobite origin. Metz (2003) previously documented Diplichnites, which was assigned to a myriapod origin. However, in contrast, the assigned myriapod trackway consisted of distinctive triangular impressions, thin marks that extended from several of the impressions, and a linear set of circular to bilateral impressions located between the paired triangular impressions. Smith et al. (2003) described several Diplichnites trackways, attributed to a myriapodtype producer, with features somewhat more consistent with the Bloomsburg specimen. Nevertheless, owing to the limited material and overall quality of preservation, the author assigns the present specimen to an arthropod producer (sensu: Bradshaw, 2010).

**Ichnogenus Rusophycus Hall, 1852 (Figures 3 and 5)**

**Rusophycus** isp.

**Material:** Five core occurrences.

**Description:** Shallow, bilobate convex hyporelief commonly with parallel lobes, varying in width from 7-10 mm, and length from 13-14 mm (one specimen 24 mm); lobes smooth, and only rarely exhibit poorly preserved scratch marks.

**Remarks:** Typically, Rusophycus is diagnosed as bilobate, coffee-bean in shape, preserved in convex hyporelief, with parallel to slightly divergent lobes which may be smooth or exhibit transverse scratch marks (e.g., Osgood, 1970; Fillion and Pickerill, 1990). Importantly, Keighley and Pickerill (1996) suggested that a 2:1 length-width ratio be set for distinguishing Rusophycus from Cruziana (e.g., length-width ratio for Rusophycus less than 2:1). Using that ratio for the current specimens results in a core bedding surface dominated (>10:1) by Cruziana. One specimen of Rusophycus is included even though it exceeds this ratio. This is due to its coffee-bean resemblance as well as a distinctively different overall morphology occurring along a ribbon-like Cruziana trace (Figure 5). In addition, one of the specimens (Figure 3) exhibits oblique scratch marks. Though the remaining three specimens “fit” the length-width ratio, they do not have a coffee-bean shape, have smooth parallel lobes, and one might argue whether they represent short locomotion traces or a “resting” situation (sensu: Keighley and Pickerill, 1996), although Garlock and Isaacson (1977) illustrate many examples of Rusophycus that do not have a typical coffee-bean shape. Owing to the limited specimens and morphologic details, the assignment is best left in open ichnospecific nomenclature.

Most Rusophycus are attributed to trilobites (e.g., Seilacher, 1970; Osgood, 1970) an exclusively marine arthropod (Harrington, 1959). Although evidence of a trilobite producer of Rusophycus is rarely found, documentation has occurred (e.g., Osgood, 1970; Gibb et al., 2010). However, though a common component of the Cruziana ichnofacies (Seilacher, 1967) under shallow-marine conditions, Rusophycus has been documented from intertidal (e.g., Legg, 1985) and deep marine deposits (e.g., Pickerill, 1995). In contrast, Bromley and Asgaard (1979) used the ichnotaxons Rusophycus, Cruziana, and Diplichnites in naming their non-marine bilobate trace fossils, noting however, that this procedure is not generally accepted by most workers, although subsequently it has been (e.g., Bradshaw, 2010). Rusophycus has been found in Lower Cambrian to the latest Triassic deposits.

**DISCUSSION**

Though the trace fossils Cruziana and Rusophycus have been previously documented from various locations in northern New Jersey (e.g., Martino and Zapecka, 1978, Metz, 2003), the number of specimens from any one locality has typically been low (e.g., Cruziana). As such, however, this may simply be due to the need for further field research to document occurrences. However, this research presents somewhat of an enigma, specifically for the trace fossil Rusophycus and the controversy of its status.

Seilacher (1955, 1970, 2007) championed the placement of Rusophycus in synonymy with Cruziana since both were either likely made by the same trilobite or a possible branchiopod crustacean. In turn, Osgood (1970) opposed this approach and instead considered Rusophycus to represent short, bilobate coffee-bean imprints, while Cruziana was restricted to longer bilobate forms, both attributed to trilobites. He did note that one of the most diagnostic features of Rusophycus was the striae that covered the lobes. Finally, however, Osgood (1970) indicated the difficulty in drawing a dividing line between Rusophycus and Cruziana, and further indicated that not all Rusophycus-like traces were formed by trilobites (see, Seilacher, 1960).

Subsequently, most authors have continued to consider these two trace fossils as separate ichnotaxa (e.g., Garlock and Isaacson, 1977; Fillion and Pickerill, 1990; Keighley and Pickerill, 1996; Bradshaw, 2010). Using the 2:1 length-width ratio (Rusophycus <2:1) suggested by Keighley and Pickerill (1996), bilobate coffee-bean imprints, and presence of striae for the core specimens resulted in assigning two traces to Rusophycus (and, in fact, one of those is greater than 2:1) with some confidence. In comparison, Martino and Zapecka (1978) noted that 87% of the ratio measurements on their specimens of Rusophycus were larger than 2:1. In contrast, specimens of Cruziana on the bedding surface of the core greatly exceed the length to width ratio of 2:1, and lack short coffee-bean forms. In addition, Martino and Zapecka (1978) discussed the possibility of ancestral horseshoe crabs (suborder Synziphosurina) being responsible for their resting tracks (e.g., Rusophycus). They ruled out this possibility based on a difference in shape of the carapace of horseshoe crabs compared to trilobites, as well as a lack of evidence of any telson impressions. One of their locations documenting Rusophycus was in the Bloomsburg Red Beds at Buttermilk Falls, Sussex County, New Jersey. Ironically, Metz (2000) reported the first discovery of an ancestral horseshoe crab, associated occurrence of Skolithos, as well as a likely trackway from the same location in New Jersey, on the sole of Bloomsburg Red Beds approximately 1 m stratigraphically higher in the section than their report of Rusophycus. In comparing the monospecific
occurrence of *Skolithos* to the ichnological characteristics of brackish water ichnofaunas (e.g., Pemberton and Wrightman, 1992), Metz (2000) suggested a strong impetus for a brackish water origin for the horseshoe crab-bearing strata.

In summary, this author agrees with previous researchers (e.g., Garlock and Isaacson, 1977; Fillion and Pickerill, 1990; Keighley and Pickerill, 1996; Bradshaw, 2010) that consider *Cruziana* and *Rusophycus* as two separate ichnotaxa. The difference in length-width ratio between the two ichnotaxa in the present investigation, as well as the detail of the compound trace exhibited in Figure 5, contrasting the feeding habit of *Cruziana* versus the resting habit of *Rusophycus*, lend credence to this interpretation. The limited striae exhibited in both ichnotaxa are largely a result of a combination of the positioning of the core bedding surface (face up) and the weathering effects over more than 60 years of exposure. Thus, the present study provides additional evidence for a temporary incursion of shallow marine to brackish waters (e.g., Beerbower and Hait, 1969; Martino and Zapecka, 1978; Brett, 1995; Metz; 2000) during Bloomsburg deposition, superimposed upon a meandering stream floodplain environments (e.g., Smith, 1967). This incursion allowed certain arthropods (notably trilobites) and fish to take advantage of additional feeding areas.

The abundance of *Cruziana* on a single bedding surface of a core of the Bloomsburg Red Beds represents the most specimens reported to date of this trace fossil from northern New Jersey. Since the depth of the bedding surface of this core is unknown and the surface is limited by its 0.9 m width, one can only speculate on the sheer abundance of *Cruziana* that could be potentially documented if one could view further portions.

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