

**COMMENT: MARINE INFLUENCE IN THE UPPER ORDOVICIAN JUNIATA FORMATION (POTTERS MILLS, PENNSYLVANIA): IMPLICATIONS FOR THE HISTORY OF LIFE ON LAND: PALAIOS, v. 25, no. 8, p. 527–539, 2010**

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## COMMENT

**MARINE INFLUENCE IN THE UPPER ORDOVICIAN JUNIATA FORMATION (POTTERS MILLS, PENNSYLVANIA): IMPLICATIONS FOR THE HISTORY OF LIFE ON LAND: PALAIOS, v. 25, no. 8, p. 527–539, 2010.**

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Davies et al. (2010, abstract) propose that, contrary to past studies, “The evidence suggests that the Juniata Formation at Potters Mills was deposited in a marginal marine setting and, as such, no evidence for early life on land can be inferred from its strata.” The new evidence they present, not only from the Juniata Formation at Potters Mills, but from other localities in Pennsylvania, is a facies analysis and description of sedimentary structures. This is a welcome approach to the problem, because there are distinctive marine sedimentary structures and facies such as turbidites, hummocky cross-bedding, and flaser and lenticular bedding. However, this promising approach failed because neither these nor any diagnostic marine sedimentary structure is described from the Juniata Formation by these or prior authors. The sole plausible exception is a single case of reversing cross stratification at Waggoners Gap, which is inadequately exposed and qualified by Davies et al. (2010) as a possible artifact of outcrop orientation. The sedimentary structures and facies of the Juniata Formation have long been interpreted as formed in braided streams (Cotter, 1978), thus explaining the lack of lateral accretion deposits formed by meandering streams.

“Under other circumstances, particularly given the nondiagnostic nature of the sedimentary facies, it would be standard practice to assume significant marine influence in the Juniata Formation based on the diverse and abundant trace fossils,” write Davies et al. (2010, p. 535), although they make an exception for repichnia (surface tracks and trails). “The lack of evidence for repichnial trackways in the Juniata sets it apart from all other early Paleozoic, terrestrial trace-fossil-bearing successions described to date” (Davies et al., 2010, p. 535). This statement is directly contradicted by their own illustrations of such fossils from the Juniata Formation (Davies et al., 2010, fig. 5N) labeled as “repichnial crossing trails on base of sandstone.” Davies et al. (2010) also failed to note other trackways from the Juniata Formation recorded by Diecchio and Hall (1998). Terrestrial arthropod trackways of Ordovician and Cambrian age were initially controversial, but are now accepted (Retallack, 2009a; Collette et al., 2010). So the argument for marine paleoenvironment comes down to non-repichnial trace fossils of the Juniata Formation, presented by Davies et al. (2010) in an unsystematic account, and illustrated with field photographs of indeterminate specimens. For example, “U-shaped burrows” are inferred from converging but unconnected burrows (“apparent U-shaped lined burrow” Davies et al., 2010, caption to fig. 5D) and from “aperture pairing” seen on surfaces only (“exposures of burrow tops appear to exhibit aperture pairing (Fig. 5L), potentially indicative of U-shaped burrows,” Davies et al., 2010, p. 534). Only eight ichnogenera are known from the Juniata Formation (cf. *Diplichnites*, *Circulichnus*, *Helminthopsis*?, *Palaeophycus*, *Planolites*, *Scolicia*?, *Scoyenia*, *Skolithos*: Retallack, 1985, 2001; Diecchio and Hall, 1998; Davies et al., 2010) and comparable forms are found elsewhere in Cambrian–Ordovician fluvial and lacustrine rocks (Trewin and McNamara, 1994; Mikuláš, 1995; Retallack, 2008, 2009a, 2009b). The Juniata Formation has not yet yielded such traces as *Rusophycus* or *Chondrites*, common among at

least 22 ichnogenera in Ordovician (Katian) marine rocks around Cincinnati, Ohio, United States (Osgood, 1970).

The particular burrows disputed by Davies et al. (2010, p. 536) at Potters Mills are within paleosols recognized from a variety of lines of evidence. The micritic replacive nodules at Potters Mills can be seen in field and thin section to both predate and postdate the burrows, and have light isotopic values ( $\delta^{13}\text{C}_{\text{calcite}} -4.11\text{‰}$  to  $-6.93\text{‰}$ ) as found only in soils and paleosols (Retallack, 2001). Marine carbonate isotopic compositions are close to zero by definition, and approach mantle values ( $\delta^{13}\text{C}$  of  $-5\text{‰}$ ) only with complete global cessation of photosynthesis (Hoffman and Schrag, 2001). The paleosols at Potters Mills have soil structures (peds and cutans) and microstructures (sepic plasmic fabric) unknown in marine strata (Retallack, 1997). Hydrolytic weathering (loss of alkali and alkaline earth bases) documented within these thin paleosol profiles is the opposite of marine hydromorphism, which restores bases to clays (Feakes and Retallack, 1988). None of these three lines of evidence are mentioned or disputed by Davies et al. (2010, p. 535), who mistakenly regard the paleosols as weakly developed despite their own illustrations (Davies et al., 2010, fig. 4C) of large caliche nodules (moderately developed by definition: Retallack, 1997). These paleosols cannot have formed in the intertidal zone as suggested by Davies et al. (2010, p. 536) because caliche requires an extended season of dry soil (Retallack, 1997). Nodules in intertidal to estuarine soils and paleosols are pyritic in fully marine salinities, and phosphatic or sideritic in brackish tidally perched waters, as demonstrated for paleosols at the transition between the Juniata Formation and overlying Clinch Sandstone in Tennessee by Driese and Foreman (1992).

Davies et al. (2010, p. 536) are also mistaken in assuming that there were no myriapods older than Silurian. The early Cambrian *Pseudoiulia cambriensis* (Hou and Bergström, 1998), middle Cambrian *Cambropodus gracilis* (Robison, 1990), and late Cambrian *Xanthomyria spinosa* (Budd et al., 2001) are problematic mainly because they are incomplete and exceptionally rare in marine shale. These beautifully articulated remains are similar in all preserved features to iliid millipedes, scutigermorph centipedes, and archipolypodan millipedes, respectively. Even if these fossils could be shown to be phylogenetically independent of myriapods, morphologic convergence evolves for common function, and convergence of *Pseudoiulia* with burrowing millipedes is striking. Wilson (2006) and Shear and Edgecombe (2010) confirm trackways from the Lake District of England as evidence of Middle Ordovician (Darrivilian) myriapods, though of a type (Polyxenida or Arthropleurida) unlikely to have made the Potters Mills burrows. Other Cambrian and Ordovician subaerial trackways are attributed to creatures other than myriapods, especially euthycarcinoids (Retallack, 2009a; Collette et al., 2010).

Davies et al. (2010, p. 528) are correct that the maker of the Potters Mills burrows, like many trace makers, remains hypothetical. An animal with growth instars, elliptical cross section, and bilateral symmetry made the burrows in very dry soils, and also left ellipsoidal feces with diameter 20%–25% of burrow diameter and ferruginized linings. This suggests a

non-cylindrical arthropod and solid fecal pellets with peritrophic membranes like those of pill (Glomerida) or polyzoniid (Polyzoniida) millipedes (Retallack, 2001), not yet known as body fossils so far back in time, but cladistically plausible then (Shear and Edgecombe, 2010). The Silurian millipede considered a suitable candidate by Retallack (2001) because of its tergite flexibility and tergite-sternite angulation, was later interpreted by Wilson (2006) to have paraterga that may have impeded burrowing. Wilson (2006) also named this fossil *Pneumodesmus newmani*, and it was from Stonehaven (not Rhynie as mistakenly claimed by Davies et al., 2010, p. 536: Devonian Rhynie Chert has not produced millipede fossils to date). Other possible makers of the Potters Mills burrows are also rendered unlikely by recent research. Differences between the Potters Mills burrows and those of snake millipedes (Julida) are confirmed by well-illustrated recent studies of julid burrows (Hembree, 2009). Euthycarcinoid body fossils and tracks in Cambrian and Ordovician intertidal and fluvial facies have been a surprising recent discovery, but these creatures were more likely amphibious than burrowing (Retallack, 2009a, 2009b; Collette et al., 2010).

Davies et al. (2010, p. 535–536) err in assuming that non-repichnial trace fossils older than Silurian and that early Paleozoic calcareous paleosols are “anomalous.” I have found calcareous paleosols at five other localities in Pennsylvania (Retallack, 1985), and 867 paleosols in earliest Cambrian to latest Ordovician fluvial sequences of Australia (Retallack, 2008, 2009a, 2009b). Diverse lacustrine and fluvial Cambrian and Ordovician non-repichnial trace fossil assemblages have been described by Trewin and McNamara (1994), Mikuláš (1995), and Retallack (2008, 2009a). Because of revised age, the Tumblagooda Sandstone of Western Australia now has the oldest reported backfilled burrows in calcareous paleosols (“*Beaconites*” of Trewin and McNamara, 1994, at 704 m and 756 m, or 461 Ma and 458 Ma, in the age model of Retallack, 2009b), which is early Sandbian (earliest Late Ordovician), and thus predates the Katian or Hirnantian burrows from Potters Mills. Early Silurian backfilled burrows (“*Taenidium*”) from the Grampians in Victoria, Australia (Retallack, 2009a), now connect Ordovician records with late Silurian (Retallack, 1985) and Devonian backfilled burrows in paleosols (Gordon, 1988; Retallack and Huang, 2010, figs. 4–5). Trace fossils in paleosols are evidence of dramatically increased diversity and complexity of land animal communities in the Silurian and Devonian (Buatois et al., 1998; Retallack and Huang, 2010), the favored hypothesis of Davies et al. (2010, p. 537), but that does not require that no animals lived in soils before the Silurian.

In conclusion, the novel marine interpretation of the Juniata Formation advanced by Davies et al. (2010) finds no support from sedimentology or trace fossils in that formation in Pennsylvania—though the top 4 m of the Juniata Formation in Tennessee is a different story, as outlined using paleosol geochemistry by Driese and Foreman, 1991, 1992). The evidence of paleosols formed in part by their trace fossils is critical to the issue, and remains unfalsified. Terrestrial ecosystems of the Cambrian and Ordovician remain poorly known, but their presumed millipedes, euthycarcinoids, and liverworts have become apparent to many investigators (Johnson et al., 1994; Trewin and McNamara, 1994; Strother, 2000, 2004; Retallack, 2008, 2009a, 2009b; Collette et al., 2010). These trace and body fossils deserve more attention, not less. Nor should they be dismissed because of presumption that they were marine.

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