A redescription and reassessment of the fossil trail Trisulcus laqueatus Hitchcock, 1865 from the Early Jurassic of Massachusetts

Authors: Getty, Patrick R., and Goldstein, Donald H.

Source: Palaeodiversity, 15(1) : 61-71

Published By: Stuttgart State Museum of Natural History

URL: https://doi.org/10.18476/pale.v15.a4

A redescription and reassessment of the fossil trail *Trisulcus laqueatus* Hitchcock, 1865 from the Early Jurassic of Massachusetts

Patrick R. Getty† & Donald H. Goldstein

Abstract

The ichnospecies *Trisulcus laqueatus* is an epichnial trail that is constructed of three grooves separated by two ridges. It exhibits significant amounts of extramorphological variation because the maker was moving through wet sediment. Thus, most details of the maker are obscured. Nonetheless, there is evidence of it having been made by arthropods, including the sharply-angled turns in one example, the division of the lateral grooves into separate imprints in some locations along the length of the trail, and comparison to modern trails produced by Cydnidae (burrower bugs).

Keywords: Ichnology, actuopaleontology, Early Jurassic, Arthropoda, Repichnia.

1. Introduction

Almost half a century ago, Häntzschel (1975) remarked that the number of established ichnotaxa was excessive, especially because some ichnotaxonomic names, and the older ones in particular, were "useless." Their lack of utility resulted especially from the naming of poorly defined or incomplete traces that could not be compared to ichnotaxa from elsewhere. Further, many of these ichnotaxa were badly illustrated, which hampered comparisons with other trace fossils. Since Häntzschel wrote, ichnologists have been coming to a consensus on how to define new ichnotaxa using specific morphological features called ichnotaxobases (e.g., Bertling et al. 2006), which should prevent new taxonomic problems, such as the establishment of unrecognizable taxa, if they are followed.

These guidelines, however, do not address the whole issue because many of the problematic taxa were established in the 19th century, when most researchers were working alone during the infancy of paleoichnology. The pioneers of 19th century ichnology sometimes did not understand that they were working with trace fossils, instead identifying the fossils as fucoids or algae (Osgood 1975). One such ichnological pioneer was Edward Hitchcock, who spent nearly thirty years studying the Early Jurassic trace fossils of the Hartford and Deerfield basins of Massachusetts and Connecticut. He was an early proponent of the animal origin of many trace fossils and in 1848 he named his first ichnogenus of invertebrate origin, *Herpystezoum* (Hitchcock 1848: 245). He also created the extensive ichnology collection at Amherst College to which future writers could "refer, to test the accuracy of drawings and descriptions" (Hitchcock 1858). Hitchcock was, however, in modern terms, a taxonomic splitter who used slight differences in trace morphology as justification for the erection of 31 new ichnogenera and 60 ichnospecies from invertebrate traces that he studied. Many of the diagnoses that he provided are lacking by modern standards. For example, his diagnosis for the ichnogenus *Saltator* was "animals small, generally moving by leaps." Note that this diagnosis included no morphological details of the trace, but instead relied on Hitchcock's interpretation of the locomotion of the tracemaker. Hitchcock's illustrations of his specimens were sometimes inadequately detailed. Scientific illustrations in that period before photography, generally showed what the scientist thought was most salient, sometimes omitting important secondary details (Goldstein & Getty 2022). Details were also sometimes altered or lost in the process of preparing lithographs for publication. This focus has made it difficult for later scientists to correlate newly found traces with those described. For example, Hitchcock's ichnospecies *Halysichnus tardigradus* is indistinguishable from its junior subjective synonym *Treptichnus bifurcus*, which was named decades later, but this was unknown until recently due to the nature of the illustration (Goldstein et al. 2017). Hitchcock (1865) noted that his drawing of *Trisulcus* (Fig. 1), which is the subject of this paper, was imperfect.

Over the years, several researchers have begun to reevaluate Edward Hitchcock's vertebrate and invertebrate ichnotaxa (e.g., Lull 1915, 1953; Olsen & Padian 1986; Olsen et al. 1998; Olsen & Rainforth 2003; Dalman & Weems 2013; Lucas et al. 2013; Getty 2016, 2017, 2018; Getty & Loeb 2018; Getty et al. 2021). Although a monographic treatment would be best, such an undertaking would be time-consuming. Instead, the revisions to Hitchcock's ichnotaxa usually analyze one or a few ichnogenera and their included ichnospecies. The same is true of the present paper, in which we address the ichnogenus *Trisulcus* and its sole ichnospecies, *T. laqueatus*.

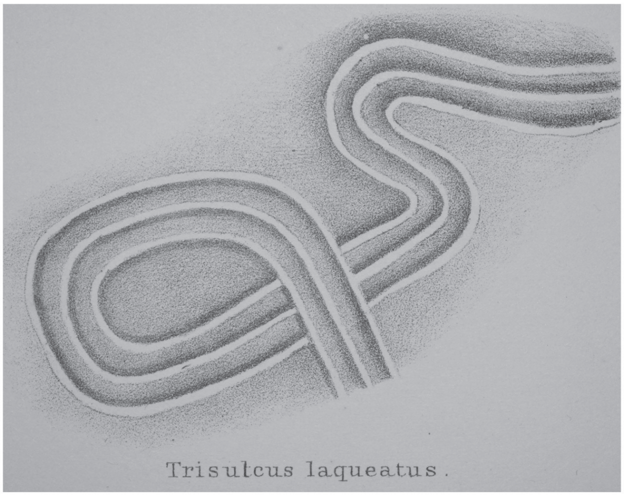

Fig. 1. Edward Hitchcock's 1865 illustration of *Trisulcus laqueatus*. Note the relatively smooth curvature of the loop, as drawn, and compare this to the photograph of the same specimen in Fig. 5E.

Institutional abbreviations: Beneski Museum of Natural History Ichnology Collection (Amherst College, Amherst, Massachusetts, USA): ACM ICH.

Geographical and stratigraphic abbreviations (for Fig. 2): CT, Connecticut; MA, Massachusetts; RI, Rhode Island; Jdb, Jurassic Deerfield Basalt; Jm, Jurassic Mount Toby Formation; Js, Jurassic Fall River Beds; Jt, Jurassic Turners Falls Sandstone; Om, Ordovician Moretown Formation; Trs, Triassic Sugarloaf Formation.

2. Geological and historical context

Trisulcus laqueatus has been found at only one location: Turner's Falls in Massachusetts, USA (Hitchcock 1865; Fig. 2). The precise collection locality at Turners Falls is unknown, because Edward Hitchcock, who described the fossils, used the term "Turner's Falls" generically for several exposures along a 6.2 km stretch of river (Hitchcock 1858; Olsen et al. 1992: 516; this paper, Figs. 2, 3). Localities that Hitchcock (1858: 13) considered as part of Turner's Falls include the north bank of the Connecticut River opposite the mouth of Millers River, the Horse Race (north and south bank of the river), the Lily Pond, the Orchard in Gill, the Ferry above Turner's Falls, the north bank "a little" below the Falls, the mouth of the Fall River close to Rocky Mountain, and the locks of the canal at Turner's Falls, on the south bank. Turner's Falls is in the Deerfield Basin, which is one of several basins that formed in eastern North America as Pangaea broke apart, filling with sediments and igneous rocks during the Late Triassic through the Early Jurassic (Manspeizer & Cousminer 1988; Olsen 1978, 1997; Olsen et al. 1992; Van Houten 1977). The Deerfield Basin sediments started to accumulate in the Late Triassic with coarse, fluvial sediment of the Sugarloaf Formation (see Weems et al. 2016 for a synonymy of Newark Supergroup lithostratigraphic names). In the Early Jurassic, deposition shifted to fine-grained lacustrine sediments of the Fall River beds and Turner's Falls formations as the rate of crustal extension increased. Coincident with the shift in deposition was the eruption, from fissures to the east, of two basaltic lava flows known as the Deerfield Basalt, which are part of the larger series of volcanic eruptions known as the Central Atlantic Magmatic Province (Olsen et al. 1996), whose earliest eruptions have been implicated in the end-Triassic extinction (Blackburn et al. 2013).

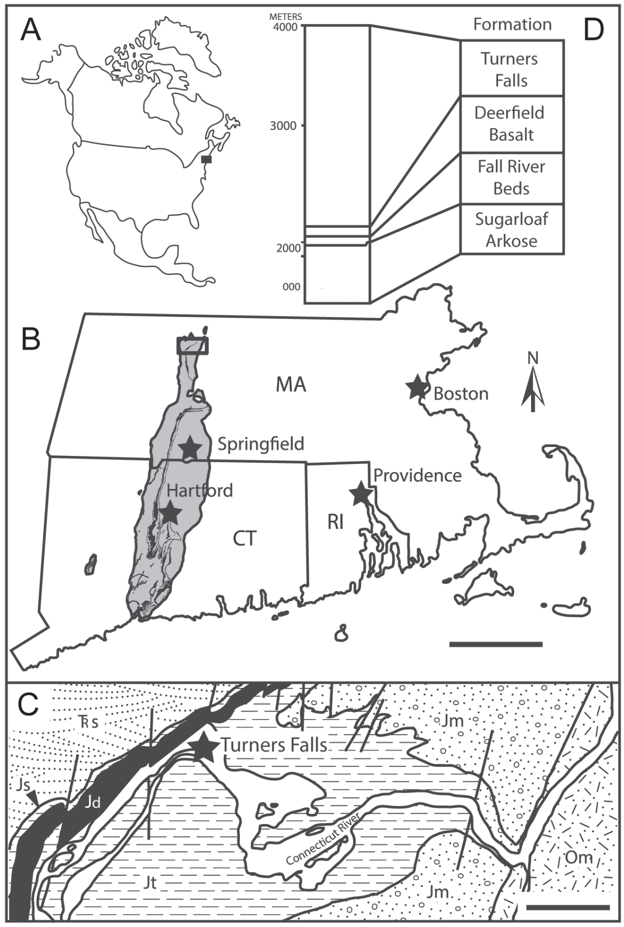

Fig. 2. *Trisulcus laqueatus* geographic and stratigraphic context; **A**: map of North America with southern New England shaded by a black box; **B**: map of southern New England showing Newark Supergroup Mesozoic sedimentary rocks in gray and igneous rocks in black; **C**: bedrock geologic map of the boxed area in **B**. The stars indicate where the fossils were collected; **D**: simple stratigraphic column of the Deerfield Basin. – Scale: 50 km in **B** and 4 km in **C**.

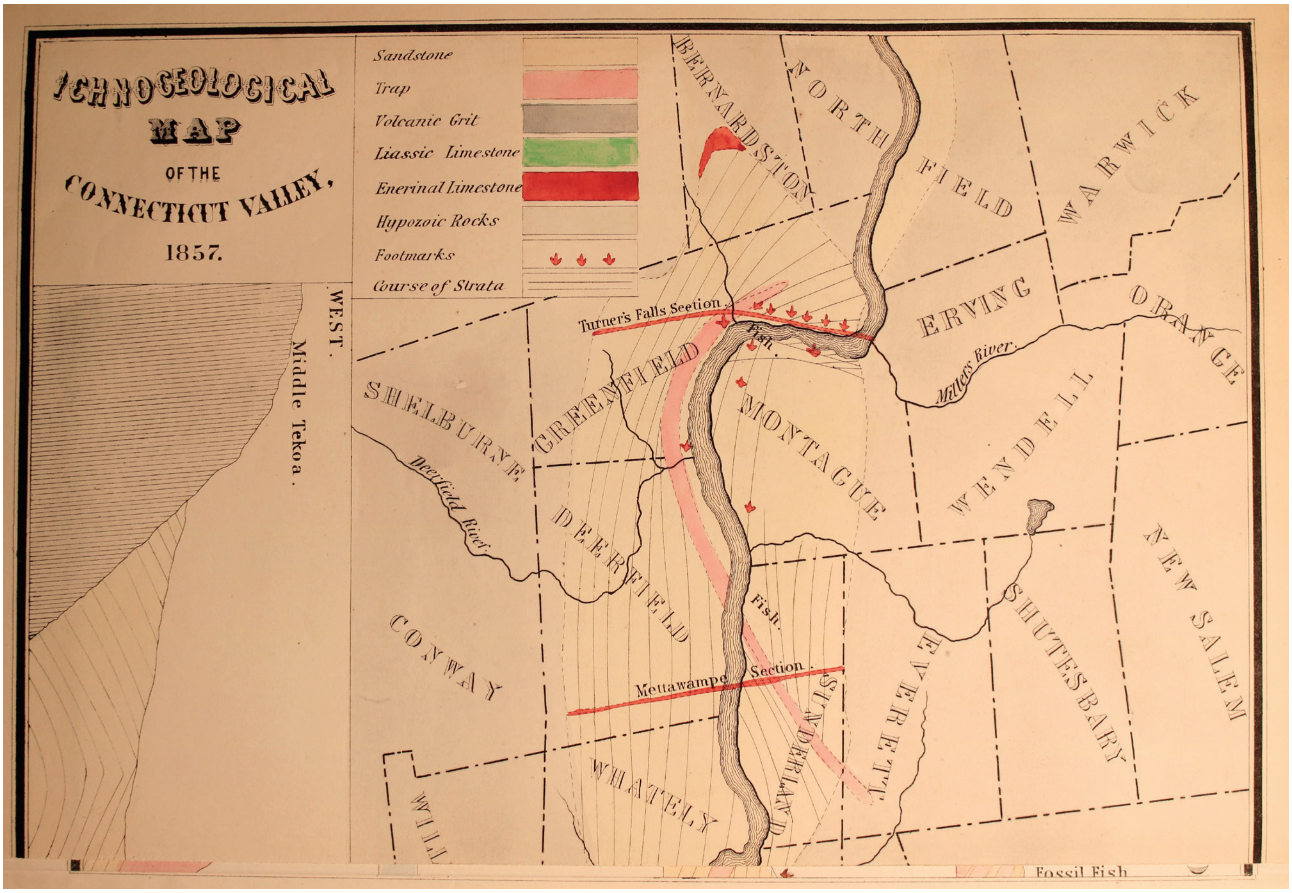

Fig. 3. Photograph of the upper portion of the Ichno-Geological Map of the Connecticut Valley, 1857, plate II in Hitchcock (1858). This part of the map contains the legend and shows the line of the Turner's Falls section. One thousand copies of the book were printed, and the colors for the transects, stone types, and track sites were added by hand before distribution. The hand coloring varies from copy to copy. On this copy, the approximate track site localities are indicated by red, 3-toed "footmarks". Courtesy of: The New York Public Library, Astor, Lenox and Tilden Foundations, Stuart collection, rare book collection.

North America moved northward at a rate of about 0.6° of latitude per million years from the Late Triassic into the Early Jurassic, which caused the Deerfield Basin to move into a subtropical arid belt (Kent & Tauxe 2005). The region's aridity was moderated somewhat by monsoonal rains derived from the Tethys Sea (Chandler et al. 1992; Parrish 1993), but dry conditions dominated, as evidenced by such features as ventifacts in the Sugarloaf Formation, caliche deposits in the Hartford Basin, and eolian sandstones in the Pomperaug, Hartford, Fundy, and Argana basins (e.g., Hubert 1978; LeTourneau & Huber 2006). Cyclicity within lake deposits of the Newark Supergroup, including the Deerfield Basin, from red to gray and black shales, has been attributed to Milankovich Cycle-influenced climate changes (Olsen 1986; Olsen & Kent 1999), although this has recently been challenged by Tanner & Lucas (2015).

The Turner's Falls localities expose rocks of the 2-km-thick Turner's Falls Formation, which is composed of playa and playa-lake red beds, gray to black lacustrine strata, and minor fluvial strata (Hubert & Dutcher 2005). *Trisulcus laqueatus* occurs on the upper surfaces of slabs of red shale, one of which also preserves dinosaur tracks (*Anomoepus scambus*). The occurrence of the tracks, along with the red color of the shale, suggests that *Trisulcus* was produced in the shallow playa-lake deposits of the formation. As Lull (1953) and Olsen et al. (1992) noted, the Turner's Falls sites were among the most important of Hitchcock's collecting localities, yielding many well-defined vertebrate and invertebrate traces.

Edward Hitchcock introduced *Trisulcus* and other discoveries at the 10 December 1862 meeting of the American Academy of Arts and Sciences in Boston, Massachusetts (Hitchcock 1862, draft). At that time the slabs may have been in the possession of Roswell Field. Field was one of several local citizens of the Connecticut Valley who collected fossil footprints and supplied museums with excellent specimens. Many of these early collectors, including Dr. Joseph Barratt, James Deane, Dexter Marsh, Dr. John Collins Warren, and Field, wrote articles for scientific journals and the occasional monograph (for bibliography, see Hitchcock 1858: IX–XII; Herbert & Doyle, 2013). Roswell field was a farmer, the owner of a large tract of land on the north bank of the Connecticut River in Gill, Massachusetts, which included quarry sites such as the Lily Pond (Shoemaker & Tomb 2016). Prior to 1853, Dexter Marsh of Greenfield Massachusetts, supplied many of the fossil tracks to collectors and museums. On at least one occasion, Field allowed Dexter Marsh to dig for fossils on his land (Field 1848; Fig. 4), and many of the fossils sold by Marsh may have originated from Field's farm (Field 1860). After Marsh's death in 1853 and the auction of his collection, much of which was bought by the museum at Amherst College, Field became a principal supplier of the region's fossil tracks (Herbert et al. 2013). In 1859, Field delivered an address to the American Association for the Advancement of Science, contending that the tracks from the valley's stone were made by reptiles, not birds (Field 1860).

In the draft of his 1862 talk (p. 1), Hitchcock wrote, "In order to ascertain the true character of the tracks…it would be desirable that the collection should be enlarged" so that "the varieties are gathered in one cabinet". His intent to purchase Field's collection was announced during the meeting (Hitchcock 1866: 92). "Within a few days, through the liberal donations of a few friends of science, the entire collection of Roswell Field, made at Turner's Falls, has been added, which will increase the collection by several thousand tracks." The purchase is documented by three entries in a journal totaling $750 made to Roswell Field under the heading, "Expenses in the Footmark Enterprise", dated January 1, January 12, and February 16, 1863 (Hitchcock 1857–1860). A corresponding receipt of payment for $750, dated February 14, 1863 is preserved in the Amherst College Library Archives and Special Collections (Field 1863). The records of the Amherst College Museum show the date of acquisition of the two slabs containing the *Trisulcus laqueatus* (52/12 and 52/14) as 1863 (Hayley Singleton, personal communication, 2021). Specimen numbers were added later, in the final draft of the Supplement (Hitchcock, 1863 p. 46).

In his posthumously published *Supplement to the Ichnology of New England*, Edward Hitchcock (1865: 1) acknowledged the value of the purchase: "A still more fruitful source of new information has been the purchase from Mr. Roswell Field, of a large collection… The late addition has already brought out disclosures amply compensating for the thousand dollars paid for it." This would be equivalent to nearly 23,000 US dollars today.

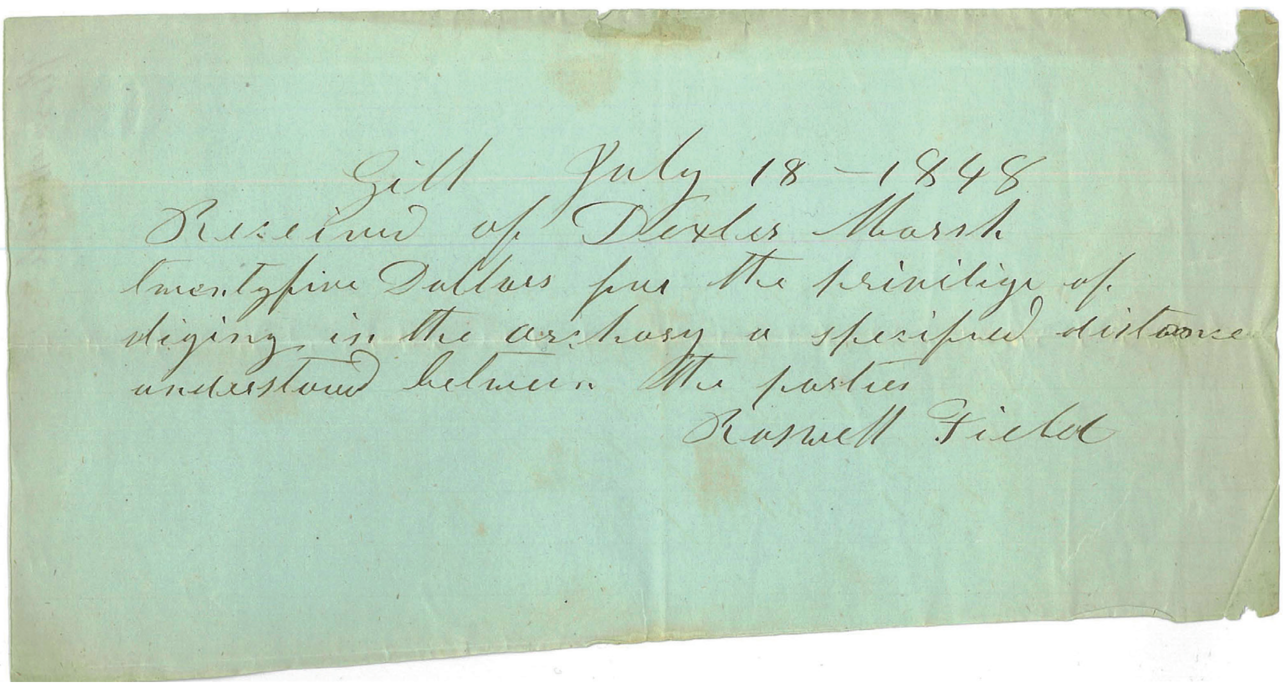
Gill July 18 – 1848
Received of Dexter Marsh
twentyfive Dollars for the privilige of
diging in the archary a specified distance
understood between the parties
Roswell Field

Fig. 4. Roswell Field's record of payment. "Gill, July 18, 1848, Received of Dexter Marsh, twenty five dollars for the privilige of digging in the archary a specified distance understood between the parties. Roswell Field". Photo courtesy of Amherst College Archives and special collections. Dexter Marsh Papers, bills and receipts, undated, in Box 1, Folder 11.

3. Material and methods

Only three specimens of *Trisulcus laqueatus* are known, and these occur on two slabs at the Amherst College Museum of Natural History: ACM ICH 52/12 and ACM ICH 52/14 (Figs. 5, 6). The trackways were photographed and examined in detail under low-angle sunlight. Measurements from the trails were later taken from the photographs using the public-domain image-processing and analysis program ImageJ (Rasband 2014). Measurements included trail length and width, as well as the width of the central and lateral furrows and of the two ridges.

4. Systematic paleontology

Ichnogenus *Trisulcus* Hitchcock, 1865

Type species: *Trisulcus laqueatus* Hitchcock, 1865, by original monotypy.

Diagnosis: Concave epirelief trail composed of three grooves between which are two raised ridges of sediment. The central groove and raised ridges are equal to subequal in width. The lateral grooves are variable, from equal to wider than the central groove and ridges.Remarks: The morphology of *Trisulcus* is, as is the case with all such trace fossils, the result of the anatomy and behavior of the tracemaker, coupled with the saturation of the sediment across which it moved. In this case, it appears that sediment saturation played a significant role in producing the three grooves that make up the trace. In a few locations the lateral groove separates into distinct tracks, presumably where the sediment was a bit firmer. The ridges are sometimes smooth and sometimes beaded in appearance.

Trisulcus laqueatus Hitchcock, 1865
Figs. 1, 5, 6

v* 1865 *Trisulcus laqueatus* nov. ichnosp. – E. Hitchcock, p. 18, pl. 3, fig. 4.
1865 *Trisulcus laqueatus* E. Hitchcock. – C. H. Hitchcock, p. 84.
1889 *Trisulcus laqueatus* E. Hitchcock. – C.H. Hitchcock, p. 119.
1915 *Trisulcus laqueatus* E. Hitchcock. – Lull, p. 69, fig. 8.
1953 *Trisulcus laqueatus* E. Hitchcock. – Lull, p. 53, fig. 8.
1975 *Trisulcus laqueatus* E. Hitchcock. – Häntzschel, p. W118.
2005 *Trisulcus laqueatus* E. Hitchcock. – Rainforth, p. 886, fig. 5.54.

Diagnosis: As for the ichnogenus.

Description: Trackways measure between 26.6 and 36.9 cm long. They range in width along their course, from 0.5 to 1.0 cm. The ridges that separate the furrows are between 0.1 and 0.3 cm wide, and the central furrow is 0.1 to 0.2 cm wide. The lateral grooves range from 0.2 to 0.35 cm wide. The trackways take a gently to tightly meandering course across the slabs on which they are preserved; the tight turns display discrete short segments from 0.67 to 0.84 cm in length and sharply angled changes of direction. The ridges between the grooves may have the same width along the course of the trail, appearing continuous, or may be formed by a series of conjoined, ovate packets of sediment to give a pinched and swollen, beaded appearance. The central groove is continuous, whereas the lateral grooves may be continuous or intermittent. The lateral grooves sometimes break into discrete, rounded or crescentic indentations (Fig. 5C, arrowed).

Remarks: Hitchcock's illustration of *Trisulcus laqueatus* (Fig. 1) is somewhat misleading in that the trail does not loop back over itself (Fig. 5D, E). The trail in question, on ACM ICH 52/12, does, however, take a sharp meander, which is what Hitchcock (1865) had interpreted as a loop. The course of the trail around the meander is a series of short segments with many sharp-angled turns; it is not smooth, as illustrated by Hitchcock (1865).

5. Potential tracemakers

Hitchcock (1865) considered *Trisulcus laqueatus* to have been made by an annelid, in part because the trace is a trail rather than a trackway. Lull (1915), however, rejected the idea that *Trisulcus laqueatus* could have been made by an annelid because it is composed of multiple parallel grooves. By contrast, annelid trails consist of a single groove (Wetzel et al. 2016). Lull suggested that the trace might have been made by a mollusk. He later placed the ichnogenus in a group of trace fossils made by worm-like forms (Lull 1953), thus apparently returning to Hitchcock's (1865) original hypothesis. However, several lines of evidence suggest that *Trisulcus laqueatus* was made by a short-bodied animal with a skeleton and appendages, which suggests an arthropod tracemaker. First, the two lateral grooves are sometimes marked by discrete circular or crescentic indentations in the substrate, indicating the distal end of a limb digging in to gain purchase (Fig. 5C). Second, the trails are constructed of discrete segments each angled to the next when making tight turns (Fig. 5D, E), rather than smoothly curving as the trail changes direction. The incremental progression of the trace and the ratio of segment length to width has been suggested as an indicator of short, rigid-bodied tracemakers, (Martin & Rindsberg 2003). The range of segment length to track width on the specimens here, (length, 0.67–0.92 cm, width. 0.5–1cm), suggests that the tracemaker was an animal less than twice as long as it was wide. Third, the ridges are sometimes constructed of ovate packets of sediment, giving them a beaded appearance, which suggests that discrete amounts of sediment were manipulated at a given time (Fig. 6C). These combined features form the bioprint, the unique signature of the tracemaker. This includes three of the bioprint features of traces made by modern juvenile limulids, suggesting short-bodied animals with paired appendages (Rindsberg & Martin 2007). Only lacking here are the

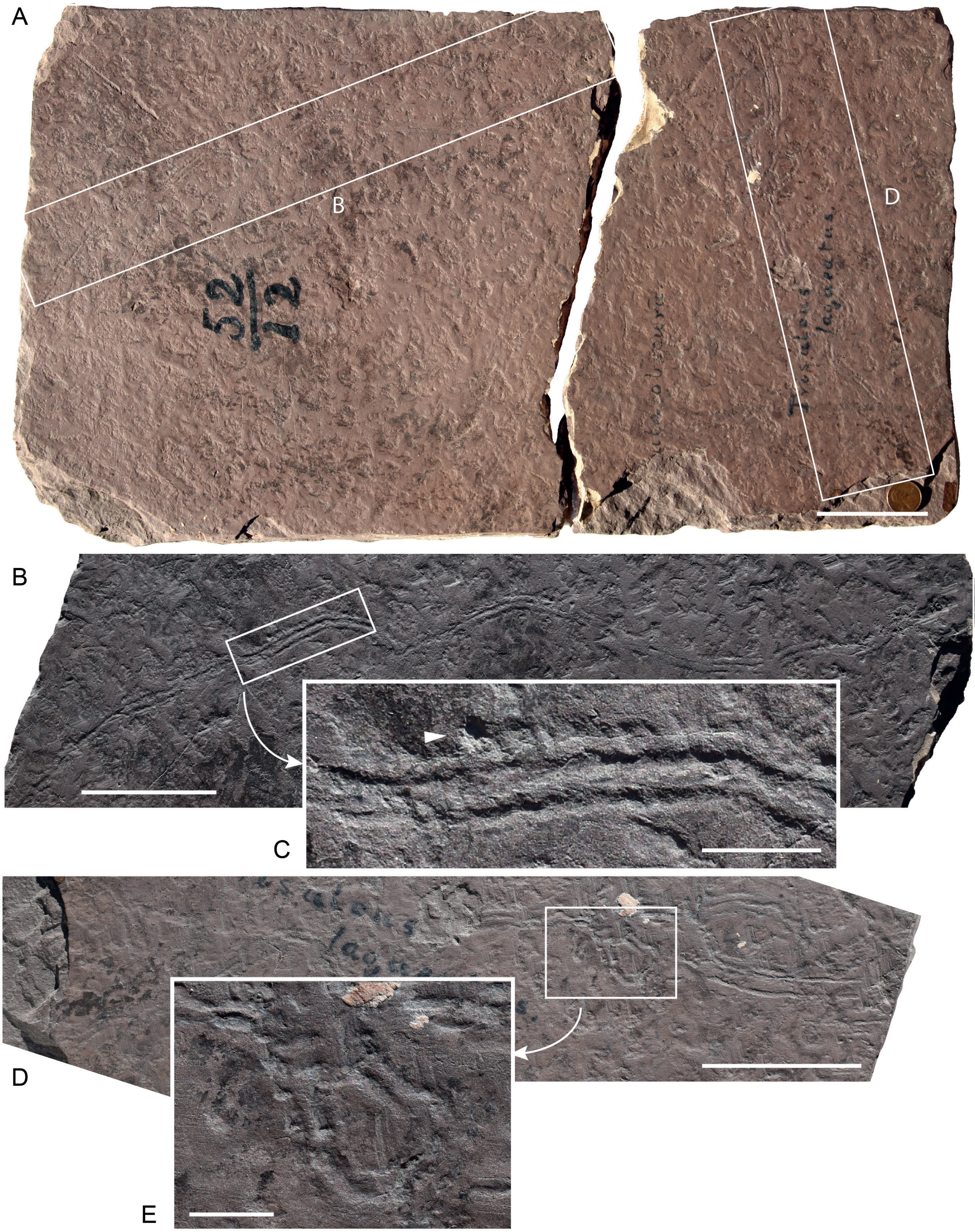

Fig. 5. *Trisulcus laqueatus* on ACM ICH 52/12; **A**: The entire slab, with the location of the *Trisulcus* trails in boxes labeled B and D; **B**: close-up of the left boxed region in A, showing the entire *Trisulcus* trail; **C**: close-up of the boxed region in B, showing the segmented ridges and furrows (arrowed); **D**: close-up of the right boxed region in A, showing the entire *Trisulcus* trail; **E**: close-up of the boxed region in C, showing the angled turn taken by the tracemaker. Compare to Fig. 1. – Scale: 5 cm in **A**, **B,** and **D**, 1 cm in **C** and **E**.

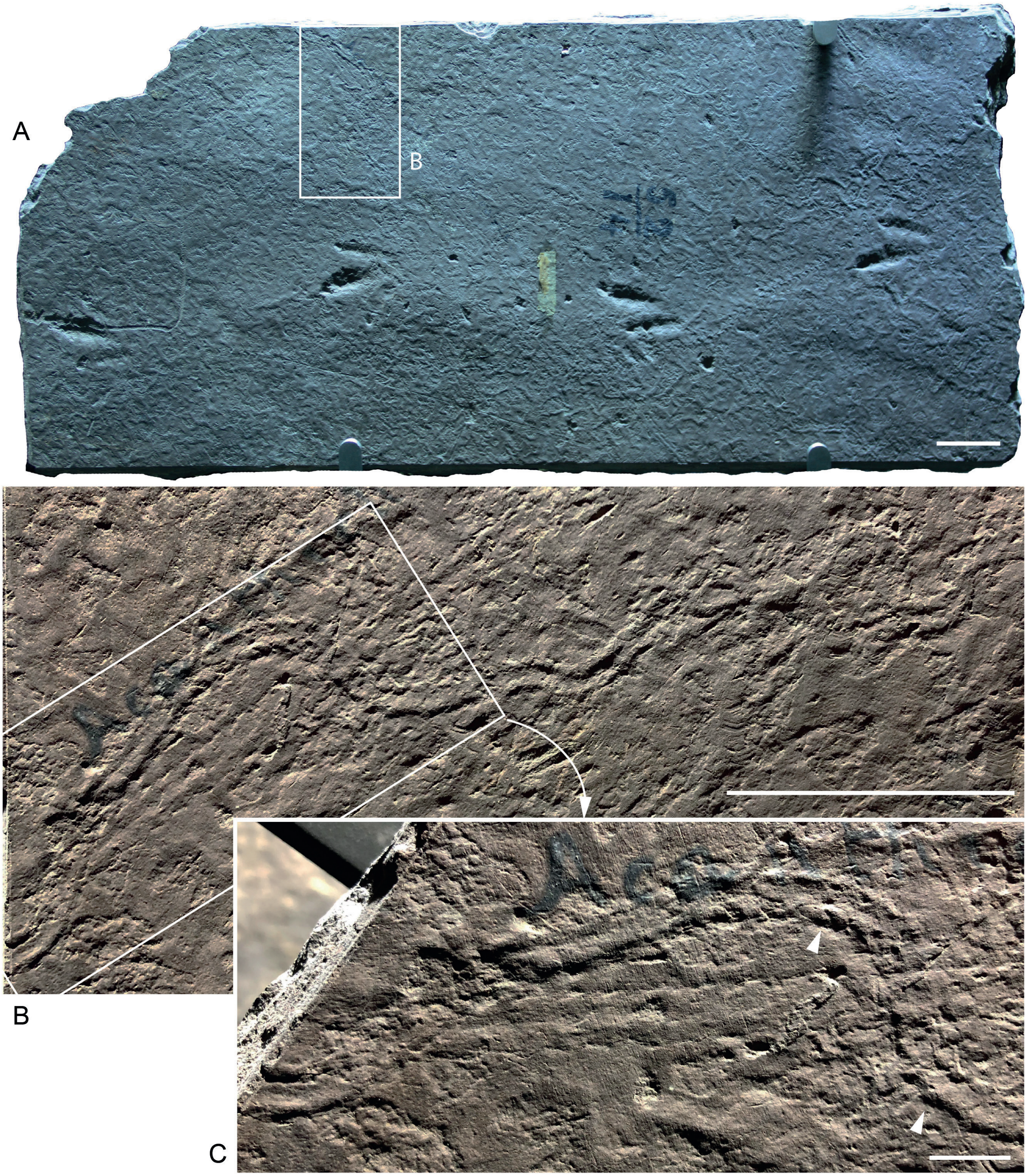

Fig. 6. *Trisulcus laqueatus* on ACM ICH 52/14; **A**: The entire slab, with the location of the *Trisulcus* trail in a box labeled B. Note the *Anomoepus scambus* dinosaur trackway; **B**: close-up of the boxed region in A, showing the entire *Trisulcus* trail; **C**: close-up of the boxed region in B, showing the segmented ridges and furrows (arrowed). – Scale: 5 cm in **A** and **B**, 1 cm in **C**.

traces of the tail (or telson) and resting traces. Our impression is of a small, short-bodied, tailless animal pulling its body through the substrate in discrete sets of strides, piling material against the body during the backward push of each appendage. The body forms the central groove; the outer segments of the legs dig into the substrate forming the lateral grooves and indentations; and the material displaced laterally by the body and disturbed and moved medially by the legs' motion forms the two, sometimes beaded ridges.

In saturated sediment, some insects and their larvae can leave traces superficially similar to the fossil *Trisulcus*. For example, a dragonfly larva crawling subaerially on mud of different degrees of saturation produces a trace that consists of a large central furrow excavated by the abdomen, as well as two rows of tracks that come close to merging in places (Fig. 7). This modern trace bears some resemblance to the fossil trail illustrated in Fig. 5C. More convincing is a trail produced by a burrower bug (Cydnidae) that was figured by Metz (1987, fig. 18), having three grooves separated by two ridges. One of the earliest discoveries of arthropod fossils in North America was *Mormolucoides articulatus* Hitchcock, 1858, an insect larva which was found "in the shale of Turner's Falls" by Roswell Field (Hitchcock 1858: 7). Other insect fossils, including larvae, and the elytra of adult beetles, have since been found in quarries from sediments of the same age, in the Deerfield Basin, the adjacent Hartford Basin, and the Newark Basin (Huber et al. 2003). Following these lines of evidence, we suggest that *Trisulcus laqueatus* is the trace of an arthropod, although little else can be said because it exhibits significant extramorphological variability; e.g., individual crescentic indentations are often merged to form the lateral grooves.

6. Conclusions

The ichnospecies *Trisulcus laqueatus* has been reexamined and reillustrated. The fossil is an epichnial trail that is known on only two slabs from the Deerfield Basin of Massachusetts, USA. The trails do not exhibit much morphological detail that would identify the maker, primarily because the animals that made the trails were crawling through wet mud, and thus the trails exhibit extramorphological variation. Nevertheless, evidence, such as the sharply angled turns and the occasional separation of the lateral grooves into separate imprints, indicates that the makers were arthropods rather than annelids (Hitchcock 1865) or mollusks (Lull 1915). The arthropod hypothesis is supported by neoichnological observations of a burrower bug (Cydnidae) trail that was figured by Metz (1987, fig. 18). This modern arthropod trail is nearly identical to the fossil trail. Fossil arthropods, including larval and

Fig. 7. Trackway produced by a dragonfly larva, seen on right, in mud of varying saturation levels. Note that in the center of the photograph, the abdomen produces a deep furrow and that the leg imprints become much closer together. Also note the ridges between the abdominal furrow and the leg imprints. Compare to Fig. 3C. – Scale: 5 cm.

adult beetles, are known from the Early Jurassic basins of the eastern United States (Huber et al. 2003).

Acknowledgements

We are indebted to Hayley Singleton of the Beneski Museum of Natural History at Amherst College for permitting us to study the *Trisulcus laqueatus* specimens. We appreciate the assistance of former Collin College students Madison Diaz and Micah Harter during the initial stages of the research project, and to professors Neal Alexandrowicz and Donna Cain for agreeing to supervise these students. We also wish to thank the archivists and librarians who helped us acquire the unpublished material that made our background discussion possible. These include Christina Barber and Tim Pinault, Amherst College Archives and Special Collections, Cristin Carpenter and Pam Shoemaker, Gill Historical Commission, James Burke and Deborah Richards, Mount Holyoke College Library and Archives, and Kyle Triplett, from the New York Public Library, Rare Book Collection. Finally, we appreciate the peer reviews and constructive suggestions of Andrew K. Rindsberg and Jerry Harris. This project received no external funding.

7. References

Bertling, M., Braddy, S. J., Bromley, R. G., Demathieu, G. R., Genise, J., Mikuláš, R., Nielsen, J. K., Nielsen K. S. S., Rindsberg, A. K., Schlirf, M. & Uchman, A. (2006): Names for trace fossils: a uniform approach. – Lethaia, **39**: 265–286.

Blackburn, T. J., Olsen, P. E., Bowring, S. A., McLean, N. M., Kent, D. V., Puffer, J., McHone, G., Rasbury, E. T. & Et-Touhami, M. (2013): Zircon U-Pb geochronology links the end-Triassic extinction with the Central Atlantic Magmatic Province. – Science, **340**: 941–945.

Chandler, M. A., Rind, D. & Reudy, R. (1992): Pangaean climate during the Early Jurassic: GCM simulations and the sedimentary record of paleoclimate. – Geological Society of America Bulletins, **104**: 543–559.

Dalman, S. G. & Weems, R. E. (2013): A new look at morphological variation in the ichnogenus *Anomoepus,* with special reference to material from the Lower Jurassic Newark Supergroup: implications for ichnotaxonomy and ichnodiversity. – Bulletin of the Peabody Museum of Natural History, **54**: 67–124.

Field, R. (1848): Receipt of payment from Dexter Marsh, July 18, 1848. – Amherst College Archives and Special Collections, Dexter Marsh Papers, bills and receipts, undated, in Box 1, Folder 13.

Field, R. (1860): Ornithichnites. – Proceedings of the American Association for the Advancement of Science, thirteenth meeting, held at Springfield, Massachusetts, August, 1859, **13**: 337–340.

Field, R. (1863): Edward Hitchcock receipt of payment to Roswell Field, 1863, February 14. – Amherst College Archives and Special Collections, Edward and Orra White Hitchcock Papers, Amherst College Library, in Box 2, Folder 21.

Getty, P. R. (2016): *Bifurculapes* Hitchcock 1858: a revision of the ichnogenus. – Atlantic Geology, **52**: 247–255.

Getty, P. R. (2017): *Lunulipes*, a replacement name for the trace fossil *Lunula* Hitchcock, 1865, preoccupied. – Journal of Paleontology, **91**: 577.

Getty, P. R. (2018): Revision of the Early Jurassic arthropod trackways *Camurichnus* and *Hamipes*. – Boletín de la Sociedad Geológica Mexicana, **70**: 281–292.

Getty, P. R. & Loeb, S. B. (2018): Aquatic insect trackways from Jurassic playa lakes: Reinterpretation of *Lunulipes obscurus* (Hitchcock, 1865) based on neoichnological experiments. – Palaeodiversity, **11**: 1–10.

Getty, P. R., Ward, M., & Simon, J. (2021): *Grammepus* Hitchcock, 1858: a sedimentary variant of the fossil insect trackway *Lithographus*. – Annales Societatis Geologorum Poloniae, **91**: 113–120.

Goldstein, D. H. & Getty, P. R. (2022): The illustration of dinosaur tracks through time. – In: Clary, R.M., Rosenberg, G.D. & Evans, D.C. (eds.): The Evolution of Paleontological Art: 139–150; Boulder (Geological Society of America).

Goldstein, D. H., Getty, P. R. & Bush, A. M. (2017): Hitchcock's treptichnid trace fossils (Jurassic, Massachusetts, USA): conflicting interpretations in the "Age of Fucoids". – Bollettino della Società Paleontologica Italiana, **56**: 109–116.

Häntzschel, W. (1975): Trace fossils and problematica. – In: Teichert, C. (ed.): Treatise on Invertebrate Paleontology, Part W. Miscellanea, supplement I: 269 pp.; Boulder & Lawrence (Geological Society of America & University of Kansas).

Herbert, R. L. & Doyle, S. (2013): The dinosaur tracks of Dexter Marsh, Greenfield's Lost Museum, 1846–1853. – Mount Holyoke College Institutional Digital Archive. Viewed Nov. 29, 2019, https://ida.mtholyoke.edu/handle/10166/3203.

Herbert, R. L., Doyle, S., Fowler, J., Mayo, L. H. & Shoemaker, P. (2013): Roswell Field's dinosaur footprints, 1854–1880. – Mount Holyoke College Institutional Digital Archive. Viewed Jan. 12, 2022, Gill Historical Commission, https://gillmass.org/files/2013-Robert-Herbert-Roswell-Field.pdf

Hitchcock, C. H. (1865): Appendix B: Descriptive catalogue of the specimens in the Hitchcock Ichnological Cabinet of Amherst College. – In: Hitchcock, E.: Supplement to the Ichnology of New England. – 96 pp.; Boston (Wright & Potter).

Hitchcock, C. H. (1889): Recent progress in ichnology. – Proceedings of the Boston Society of Natural History, **24**: 117–127.

Hitchcock, E. (1848): An attempt to discriminate and describe the animals that made the fossil footmarks of the United States, and especially of New England. – Memoirs of the American Academy of Arts and Sciences, New Series, **3**: 129–256.

Hitchcock, E. (1857–1860): Edward Hitchcock notebook, 1855–1857. – Amherst College and Archives Special Collections, Edward and Orra White Hitchcock Papers, Amherst College Library, in Box 2, Folder 16.

Hitchcock, E. (1858): Ichnology of New England. – 220 pp.; Boston (White).

Hitchcock, E. (1862): Draft address, Supplement to the Ichnology of New England, 1862 December 9. – Amherst College and Archives Special Collections, Edward and Orra White Hitchcock Papers, Amherst College Library, in Box 13, Folder 1.

Hitchcock, E. (1863): Final Draft, Supplement to the Ichnology of New England, 1863 – Amherst College and Archives Special Collections, Edward and Orra White Hitchcock Papers, Amherst College Library, in Box 13, Folder 4.

Hitchcock, E. (1865): Supplement to the Ichnology of New England. – 96 pp.; Boston (Wright & Potter).

Hitchcock, E. (1866): Five Hundred and Fifteenth Meeting. December 10, 1862. Monthly Meeting; Supplement to the Ichnology of New England. – Proceedings of the American Academy of Arts and Sciences, vol. 6, American Academy of Arts & Sciences, May 1862 to May 1865, pp. 84–95.

Huber, P., McDonald, N. G., Olsen, P. E. et al. (2003): Early Jurassic insects from the Newark Supergroup, northeastern United States. – In: Letourneau, P. M. & Olsen, P. E. (eds.): The Great Rift Valleys of Pangea in Eastern North America, volume 2. Sedimentology, Stratigraphy, and Paleontology: 206–223; New York (Columbia University Press).

Hubert, J. F. (1978): Paleosol caliche in the New Haven Arkose, Newark Group, Connecticut. –Palaeogeography, Palaeoclimatology, Palaeoecology, **24**: 151–168.

Hubert, J. F. & Dutcher, J. A. (2005): Synsedimentary sand pillows of a lacustrine delta slope (Turners Falls Formation) and sheetflood deposition of alluvial-fan gravels (Mount Toby Formation), Early Jurassic Deerfield Basin, Massachusetts. – Northeastern Geology & Environmental Sciences, **27**: 18–36.

Kent, D. V. & Tauxe, L. (2005): Corrected Late Triassic latitudes for continents adjacent to the North Atlantic. – Science, **307**: 240–244.

LeTourneau, P. M. & Huber, P. (2006): Early Jurassic dune field, Pomperaug Basin, Connecticut and related synrift deposits: stratigraphic framework and paleoclimatic context. – Sedimentary Geology, **187**: 63–81.

Lucas, S. G., Voigt, S., Lerner, A. J. & Rainforth (2013): *Sphaerapus,* a poorly known invertebrate trace fossil from nonmarine Permian and Jurassic strata of North America. – Ichnos, **20**: 142–152.

Lull, R. S. (1915): Triassic Life of the Connecticut Valley. – Connecticut State Geological and Natural History Survey Bulletin, **24**: 285 pp.

Lull, R. S. (1953): Triassic Life of the Connecticut Valley. – Connecticut State Geological and Natural History Survey Bulletin, **81**: 336 pp.

Manspeizer, W. & Cousminer, H. L. (1988): Late Triassic–Early Jurassic synrift basins of the U.S. Atlantic margin. – In: Sheridan, R. E. & Grow, J. A. (eds.): The Atlantic Continental Margin–U.S. The Geology of North America I2: 197–216; Boulder (Geological Society of America).

Martin, A. J. & Rindsberg, A. K. (2007): Arthropod tracemakers of *Nereites*?: neoichnological observations and their paleoichnological applications – In: Miller, W. III. (ed.): Trace Fossils: Concepts, Problems, and Prospects: 478–491; Amsterdam (Elsevier).

Metz, R. (1987): Insect traces from nonmarine ephemeral puddles. – Boreas, **16**: 189–195.

Olsen, P. E. (1978): On the use of the term Newark for Triassic and Early Jurassic rocks of eastern North America. – Newsletters on Stratigraphy, **7**: 90–95.

Olsen, P. E. (1986): A 40-million-year lake record of early Mesozoic climate forcing. – Science, **234**: 842–848.

Olsen, P. E. (1997): Stratigraphic record of the early Mesozoic breakup of Pangea in the Laurasia-Gondwana rift system. – Annual Review of Earth and Planetary Sciences, **25**: 337–401.

Olsen, P. E. & Kent, D. V. (1999): Long-period Milankovitch cycles from the Late Triassic and Early Jurassic of eastern North America and their implications for the calibration of the Early Mesozoic time-scale and the long-term behaviour of the planets. – Philosophical Transactions of the Royal Society of London, (A), **357**: 1761–1786.

Olsen, P. E., McDonald, N. G., Huber, P. & Cornet, B. (1992): Stratigraphy and Paleoecology of the Deerfield rift basin (Triassic-Jurassic, Newark Supergroup), Massachusetts. – In: Robinson, P. & Brady, J. B. (eds.): Guidebook for Field Trips in the Connecticut Valley Region of Massachusetts and Adjacent States (vol. 2), New England Intercollegiate Geological Conference 84th Annual Meeting, Contribution no. **66**, Department of Geology and Geography, University of Massachusetts, Amherst, Massachusetts: 488–535.

Olsen, P. E. & Padian, K. (1986): Earliest records of *Batrachopus* from the southwestern United States, and a revision of some Early Mesozoic crocodylomorph ichnogenera. – In: Padian, K. (ed.): The Beginning of the Age of Dinosaurs, Faunal Change Across the Triassic-Jurassic Boundary: 259–273; New York (Cambridge University Press).

Olsen, P. E. & Rainforth, E. C. (2003): The Early Jurassic ornithischian dinosaurian ichnogenus *Anomoepus*. – In: Letourneau, P. M. & Olsen, P. E. (eds.): The Great Rift Valleys of Pangea in Eastern North America, volume 2. Sedimentology, Stratigraphy, and Paleontology: 314–367; New York (Columbia University Press).

Olsen, P. E., Schlische, R. W. & Fedosh, M. S. (1996): 580 ky duration of the Early Jurassic flood basalt event in eastern North America estimated using Milankovitch cyclostratigraphy. – In: Morales, M. (ed.): The Continental Jurassic: 11–22; Flagstaff (Museum of Northern Arizona).

Olsen, P. E., Smith, J. B. & Mcdonald, N. G. (1998): Type material of the type species of the classic theropod footprint genera *Eubrontes, Anchisauripus,* and *Grallator* (Early Jurassic, Hartford and Deerfield Basins, Connecticut and Massachusetts, U.S.A. – Journal of Vertebrate Paleontology, **18**: 586–601.

Osgood, R. G. (1975): The history of invertebrate ichnology. – In: Frey, R. W. (ed.): The Study of Trace Fossils: 3–12; New York, Berlin & Heidelberg (Springer).

Parrish, J. T. (1993): Climate of the supercontinent Pangea. – Journal of Geology, **101**: 215–233.

Rainforth, E. C. (2005): Ichnotaxonomy of the fossil footprints of the Connecticut Valley (Early Jurassic, Newark Supergroup, Connecticut and Massachusetts). – Ph.D. dissertation, Columbia University, New York, 1301 pp.

Rasband, W. S. (2014): ImageJ. U.S. Bethesda (National Institutes of Health).

Rindsberg, A. K. & Martin, A. J. (2003): *Arthrophycus* in the Silurian of Alabama (USA) and the problem of compound trace fossils. – Palaeogeography, Palaeoclimatology, Palaeoecology, **192**: 187–219.

Shoemaker, P. L. & Tomb, L. S. (2016): Riverside, life along the Connecticut in Gill, Massachusetts – 184 pp.; Gill (Historical Commission Town of Gill, Massachusetts).

Tanner, J. T. & Lucas, S. G. (2015): The Triassic-Jurassic strata of the Newark Basin, USA: a complete and accurate astronomically tuned timescale? – Stratigraphy, **12**: 47–65.

Weems, R. E., Tanner, L. H. & Lucas, S. G. (2016): Synthesis and revision of the lithostratigraphic groups and formations in the Upper Permian?–Lower Jurassic Newark Supergroup of eastern North America. – Stratigraphy, **13**: 111–153.

Wetzel, A., Uchman, A. & Bromley, R. G. (2016): Underground miners come out to the surface – trails of earthworms. – Ichnos, **23**: 99–107.

Van Houten, F. B. (1977): Triassic–Liassic deposits of Morocco and eastern North America: comparison. – American Association of Petroleum Geologists Bulletins, **61**: 79–99.

Addresses of the authors:

PATRICK R. GETTY (†), formerly of the Department of Geology, Collin College, 2800 E. Spring Creek Parkway, Plano, Texas, 75074, U.S.A.

DONALD H. GOLDSTEIN, Department of Geosciences, 354 Mansfield Road, U-1045, Storrs, Connecticut, 06269, U.S.A.; e-mail: donald.goldstein@uconn.edu

Manuscript received: 5 November 2021, revised version accepted: 21 April 2022.