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# GEOLOGY

COMMONWEALTH OF PENNSYLVANIA
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## ON THE COVER

Horseshoe crabs and a trace fossil produced by a horseshoe crab from the Upper Devonian Chadakoin Formation in Erie County, Pa. Body fossils of *Kasibelinurus randalli* (upper left) are part of a mass accumulation of variously disarticulated remains. The trace fossil *Protolimulus eriensis* (lower right) is a resting or burrowing trace probably produced by *K. randalli* on a tidal flat. Specimens collected by Scott C. McKenzie and deposited in the U.S. National Museum of Natural History (USNM 484524, left; USNM 484525, right); x1. Photograph by Loren E. Babcock.

## PENNSYLVANIA GEOLOGY

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STATE GEOLOGIST'S EDITORIAL

# GEOLOGICAL PRODUCTS ("the times they") ARE "A-CHANGIN'"

Geologic and topographic information traditionally has been provided in the form of physical products, such as printed reports illustrated with figures and tables, as well as maps that have multicolored lines and patterns to summarize complex geological data and relationships in a printed graphic format.

Printed products are very time consuming to produce. And, except for popular, educational, or selected other products, only a relatively few tens of copies of scientific reports and maps are usually required to meet user needs. Printing, however, by its very nature, is designed to produce many copies that require bulk storage.

Traditional methods of information distribution are changing. Most Survey reports reproduced for dissemination now involve some digital technology. For example, all Pennsylvania Survey reports now are prepared using word-processing computer software. Most texts of geologic and hydrogeologic reports now easily fit on one or two small computer disks. Geographic and geologic databases created from groundwater and oil and gas well records are increasingly distributed via digital methods. Compilation of base topographic maps now is almost exclusively done using digital technology.

The newly revised physiographic map of Pennsylvania (see announcement on page 16) was prepared for distribution using digital technology and can be provided to you in digital format. Graphic copies of this map can also be individually "printed" by commercial outlets, as well as by users who have access to digital printers and software that can read Arc/Info export files, rather than by standard printing, to avoid needless bulk storage. As necessary changes are made to this map, no manual drafting is required to provide an improved version.

The future of timely and economical information distribution of geological and topographic information is thus largely digital. At the Pennsylvania Geological Survey, we plan to increase digital distribution of geologic and topographic information.

In order to best serve you, the users of Survey distributed information, we seek your comments on planned information distribution

*(continued on page 14)*

# Horseshoe Crabs and Their Trace Fossils From the Devonian of Pennsylvania

## New Data Suggest Reinterpretation of Their Sedimentary Environments as Marginal Marine

by Loren E. Babcock and Marilyn D. Wegweiser, The Ohio State University; Arthur E. Wegweiser, Edinboro University of Pennsylvania; Thomas M. Stanley, Kansas Geological Survey; and Scott C. McKenzie, Erie, PA

Horseshoe crabs that thrive today along the Atlantic coast of the United States belong to an ancient group of pincer-bearing arthropods (jointed-leg animals). These fascinating creatures left numerous fossils in the Upper Devonian rocks of northern Pennsylvania and adjacent areas of New York and Ohio. Based on trace fossils and new sedimentologic evidence, the depositional environments where many of these creatures lived are reinterpreted here as marginal marine.

EVOLUTIONARY HISTORY OF HORSESHOE CRABS. The horseshoe crabs (order Xiphosurida) are a small group of arthropods whose origins date back at least 500 million years. This group commonly has been cited for its conservatism in shape and behavior. This interpretation, although not entirely correct (Fisher, 1984), may have been an inevitable consequence of the rather primitive, trilobite-like appearance of living horseshoe crabs. Also, as demonstrated by fossil examples (Figure 1), some of these creatures looked basically the same 365 million years ago as their relatives do today.

Horseshoe crabs from Pennsylvania and adjacent states belong to two extinct lineages of the order Xiphosurida (Fisher, 1984). *Kasibelinurus randalli* (Figure 1A–C and cover photograph) belongs to the ancestral group that gave rise to "*Euproops*" *morani* (Figure 1D) and the modern horseshoe crabs (Fisher, 1984). The familiar modern species *Limulus polyphemus* (Figure 1E) is the one that occurs in abundance along the Atlantic coast, and often it can be observed swimming in shallow nearshore waters or in estuaries, or crawling along beaches or tidal flats. The best time to see living horseshoe crabs is during the late spring and early summer, when *L. polyphemus* comes ashore in great numbers to lay eggs on tidal flats and beaches.

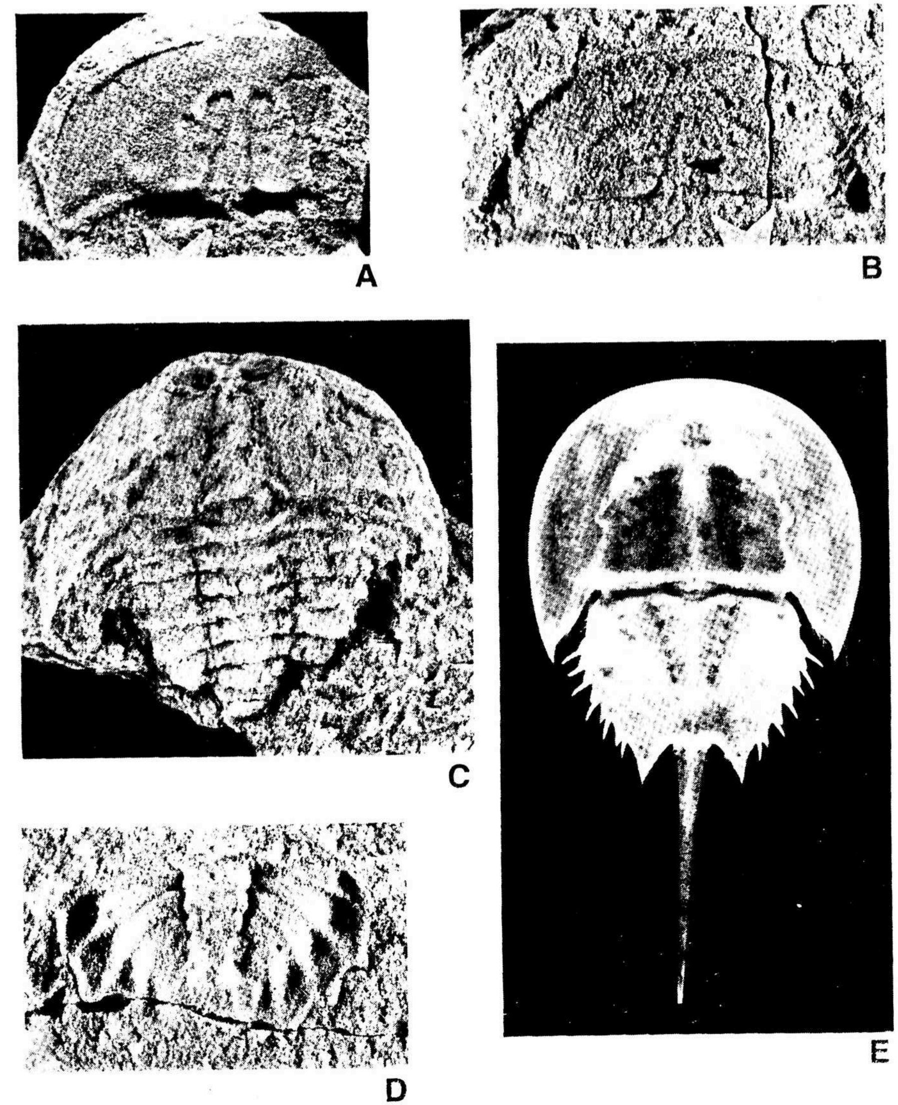

Figure 1. A. *Kasibelinurus randalli*, holotype prosoma (head shield) probably from the Venango Formation (Upper Devonian) of Warren County, Pa. (YPM 9010; x1.25). B. *Kasibelinurus randalli*, paratype prosoma from the same location as the holotype (YPM 30656; x1). C. *Kasibelinurus randalli*, a more complete specimen from the Chadakoin Formation of Allegany County, N. Y. (CM 11065; x1.25). D. "*Euproops*" *morani*, holotype abdomen from the Venango Formation of Warren County, Pa. (CM 11574; x1.25). E. *Limulus polyphemus*, Holocene (recent) from the Atlantic coast of the United States, shown for comparison (x1). Fossil specimens are in the Peabody Museum of Natural History, Yale University (YPM), and the Carnegie Museum of Natural History (CM).

**TRACE FOSSILS OF HORSESHOE CRABS.** Fossils of the body parts of horseshoe crabs are generally rare in Upper Devonian rocks of Pennsylvania. Evidence of their existence in the form of trace fossils produced by their movement (Figures 2, 3, and cover photograph), however, tends to be quite common in those same rocks, particularly at exposures in Erie, Warren, McKean, and Susquehanna Counties.

Trace fossils produced by horseshoe crabs include both elongate trails or trackways and resting or burrowing pits. Trails or trackways (Figure 2) are similar in shape to the better-known trace called *Cruziana*. *Cruziana* is thought to have been formed by trilobites ploughing through sediment. Other trace fossils are resting or burrowing traces named *Protolimulus eriensis* (Figure 3 and cover photograph). Previously, *Protolimulus* was regarded as being a body fossil of a horseshoe crab (Packard, 1886; Lesley, 1889). It is clear from its preservation, however, that it is actually a trace fossil. All known specimens of *Protolimulus* are impressions produced by the bottom, or ventral, side of the animal, and many specimens show distinct scratches or depressions made in sediment by the appendages or telson (tail spine).

Traces made by horseshoe crabs are commonly preserved in relief and found protruding from the undersides of siltstone or sandstone beds as natural casts. The traces were originally left in soft, unconsolidated sediment (such as silt or clay) and then filled by the rapid deposition of a silt or sand layer. After turning to rock, the less resistant shaly layers were removed by weathering and erosion, revealing detailed casts in siltstone or sandstone.

The traces are important not just because they reveal information about how early horseshoe crabs lived, but also where they lived. Because the traces were formed in unconsolidated sediments, they would have been easily destroyed by current action, and therefore

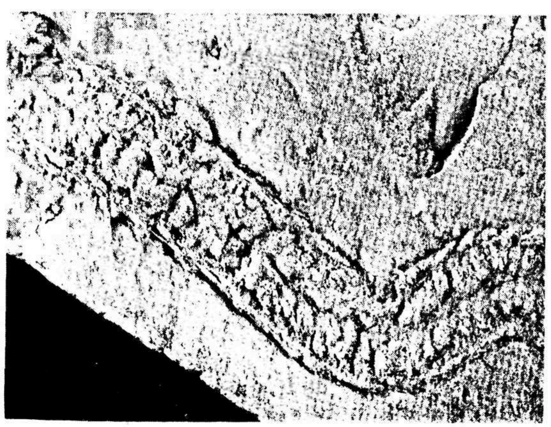

**Figure 2.** A trace fossil (ploughing trail) probably produced by *Kasibelinurus randalli*, from the Chadakoin Formation (Upper Devonian) of Erie County, Pa. (x0.75). The animal was moving from right to left. The specimen is in the U.S. National Museum of Natural History (USNM 484523).



**Figure 3.** *Protolimulus eriensis*, plaster cast of the holotype, a resting or burrowing trace probably produced by *Kasibelinurus randalli*, from either the upper Chadakoin Formation or the lower Venango Formation (Upper Devonian) of Erie County, Pa. (x0.75). The cast is in the Carnegie Museum of Natural History (CM 11571).

could not have been transported any distance. Body fossils, on the other hand, could have been transported, although most in the rock record are probably of relatively local origin. Horseshoe crab exoskeletons are remarkably resistant to disarticulation and breakdown, and can be transported tens of kilometers without showing any obvious effects of transport (Babcock, 1994). For this reason, the presence of horseshoe crab body fossils alone is insufficient evidence that horseshoe crabs were living in any one particular area. Traces of their activities that were made in unconsolidated sediment, though, show that horseshoe crabs lived in the places where the traces have been preserved.

**STRATIGRAPHIC SETTING AND DEPOSITIONAL ENVIRONMENTS.** Horseshoe crab body or trace fossils are present in the Chadakoin, Venango, and Catskill Formations of Pennsylvania. In adjacent states, they are found in equivalent strata representing marginal marine to nonmarine depositional environments. The type specimens of *Kasibelinurus randalli* (Figure 1A and 1B) are apparently from the oil sands of the Venango Formation in Warren County, Pa. Since the time that Beecher (1902) named *K. randalli*, additional horseshoe crabs have been found in the Chadakoin and Venango Formations. Among them is a single specimen of *"Euproops" morani* (an incomplete abdomen, Figure 1D) from the Venango Formation of Warren County. The Chadakoin and Venango Formations are currently regarded (Berg and others, 1986) as being of late Famennian (late Devonian) age.

Trace fossils produced by horseshoe crabs are among the more common fossils in the upper Chadakoin and lower Venango Formations of Erie, Warren, and McKean Counties, Pa. Two places where they may be collected have been described by Hoskins and others

(1983) as localities 19 (Erie County) and 53 (Warren County). Additional specimens have been reported from the Catskill Formation of Susquehanna County (Caster, 1938).

*Kasibelinurus randalli* and "*Euproops*" *morani* probably lived in a marginal marine to nonmarine environment. For parts of the Chadakoin and Venango Formations at least, this interpretation differs markedly from previous views concerning the depositional environments of these units. Previous interpretations (for example, White, 1881; Caster, 1938) were principally based on the types of body fossils present in the units. The body fossils include brachiopods, molluscs, sponges, fish parts, crinoid pieces, horseshoe crabs, and abundant terrestrial plant remains. Most of the animal fossils seem to be of shallow-marine origin. It is possible that some of the animals could tolerate nearshore brackish water, although sedimentologic evidence suggests that most of the fossils were washed into marginal-marine to nonmarine environments by waves.

Sedimentologic characteristics of the rocks provide the strongest evidence of the depositional environments of the upper Chadakoin and lower Venango Formations in northwestern Pennsylvania. This succession mostly consists of siltstones, sandstones, and conglomeratic sandstones. Red beds, which are generally indicative of nonmarine sedimentation, are common. Siderite (iron carbonate), which often forms in marginal-marine areas that are influenced by freshwater influx from streams, is a common mineral in these units. Sedimentary structures include symmetrical to slightly asymmetrical ripple marks, flaser bedding, reactivation surfaces, intraclastic conglomerates, and mud cracks. Symmetrical ripple marks normally form in shallow, relatively quiet water by the oscillation of currents, whereas asymmetrical ones form where a unidirectional current is present. Flaser bedding develops mostly in tidal and stream environments where thin streaks of mud have accumulated in troughs of sand ripples. Reactivation surfaces are places where sedimentation of a single, migrating bed of unconsolidated sediment has stopped and another migrating bed has been deposited on top. They are formed where changes in flow rates, tidal stage, or tidal current direction occur. Intraclastic conglomerates are formed by the rip up and nearby redeposition of mud chips. Commonly, the mud chips are pieces of semihardened sediment that have broken from mud cracks on sun-dried mudflats. Mud cracks, which result from the wetting and drying of sediment, show unequivocally that some of the upper Chadakoin and Venango strata were subaerially exposed at times.

Finally, the abundance of horseshoe crab trace fossils offers evidence that the upper Chadakoin and lower Venango Formations were deposited in marginal-marine to nonmarine environments. Many similar trackways in the rock record are from estuarine (brackish water) and tidal-flat settings (Miller, 1982; Pickett, 1984), including those from the Catskill Formation of Pennsylvania (Caster, 1938). These are the environments where many potentially preservable horseshoe crab tracks are being formed during modern times. The sediment must be cohesive (wet) enough at the time the animal passes through it for a trace to be preserved, and the environment must inhibit the existence of other creatures that subsequently could burrow through the sediment and destroy the trace. Such conditions occur commonly in marginal-marine, brackish-water, and freshwater settings.



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