AN ENSIFERAN (CRICKET) FOSSIL FROM THE LATE TRIASSIC LOCKATONG FORMATION, NEWARK BASIN, PENNSYLVANIA

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Abstract—Insect ichnofossils are commonplace in the Triassic and Jurassic Newark Basin strata. However, insect body fossils are very rare. In the Carnian-Norian Lockatong Formation, Pennsylvania, an external mold of an insect body was recovered. Sedimentary structures indicate a marginal lacustrine setting of deposition. This specimen is interpreted as a member of the family Gryllidae. It is only the second insect body fossil, an external mold, described and the first recovered from the Triassic-age strata of the Newark Basin of Pennsylvania.

INTRODUCTION

Partly due to increased knowledge of the numerous and diverse invertebrate ichnogenera in the fossil record, invertebrate ichnology has moved to the forefront in aiding the reconstruction of the paleoecology of Triassic and Jurassic fluvial and lacustrine sequences in the Newark Basin (Metz, 1987, 1989, 1996, 2000, 2007; Szajna and Boyland, 2010; Szajna et al., 2012). Many of these continental ichnogenera have been attributed to the action of insects and other arthropods (Metz, 1987, 1989, 1996, 2000, 2007; Szajna and Boyland, 2010; Szajna et al., 2012). In spite of the prolific record of insect trace fossils, strikingly only one insect body fossil has previously been reported in the literature from the Triassic strata of the Newark Basin (Metz, 2012) and only one species was reported from the Jurassic age strata of New Jersey (Huber et al., 2003).

Newark Supergroup strata located in other east coast basins yield insect body fossils for collection and detailed systematic classification (Huber et al., 2003; Fraser and Grimaldi, 2003). Of the east coast Triassic-Jurassic basins, the Danville Basin spanning the Virginia and North Carolina border has produced a diverse insect Konservatte Lagerstätte from the Carnian Solite Quarry (Fraser et al., 1996; Fraser and Grimaldi, 2003; Blagoderov et al., 2007; Liutkus et al., 2010). This spectacular Lagerstätte pushes back the age of the global fossil record of thrips and waterbugs and records the first occurrence of true flies in North America (Fraser and Grimaldi, 2003).

This paper describes and interprets the external mold of an ensiferan (cricket) discovered in the Triassic Newark Basin strata and discusses its paleoecologic implications in relation to the lithology and depositional environment. This is the first Ensifera external mold reported from the Newark Basin.

GEOLOGY

In eastern Pennsylvania, USA, the Newark Basin Triassic age strata consist of three formations, from oldest to youngest, the Stockton, Lockatong, and Passaic (Fig. 1). The transition from the Stockton to the Lockatong formations reflects a shift from conglomerates, sandstones, and mudstones, deposited in braided to meandering stream systems, to finer-grained sandstones and mudstones of dominantly lacustrine facies (Smoot, 1991; Smoot and Olsen, 1988, 1994; Schlische and Olsen, 1990). The younger Passaic Formation reflects a lacustrine and marginal lacustrine setting and is composed predominantly of red mudstones and sandstones (Smoot, 1991; Smoot and Olsen, 1988, 1994; Schlische and Olsen, 1990).

Based on the Newark Basin astronomically calibrated geomagnetic polarity timescale, the Lockatong Formation formed from approximately 229 to 215 Ma (Olsen et al., 2010). The Lockatong Formation was originally assigned a Carnian age based on palynological data (Cornet, 1977, 1993), but more recently there has been the recognition of a long Norian stage (18-20 Ma in duration) based on detailed magnetostratigraphic analysis (Olsen et al., 2010). The long stage duration places the Norian boundary below the Stockton–Lockatong formations and contact (Olsen et al., 2010). The long length of the Norian Stage has been shown to be very problematic (Lucas et al., 2012). Lucas et al. (2012) place the beginning of the Norian closer to 220 Ma. This recent revision places the Carnian-Norian boundary near the top of the Lockatong Formation (Lucas et al., 2012). Therefore, this external mold is either Carnian, if the shorter duration holds scrutiny, or Norian, if the long duration is further supported by additional evidence.

In the greater than 5 km thick rift fill found in southeastern Pennsylvania, Van Houten (1964), Olsen (1986), Olsen and Kent (1996), and Olsen et al. (1996) identified various Milankovitch frequency cycles throughout the formations. Olsen et al. (1996) extracted four superim-
posed lacustrine cycle periodicities: 1) Van Houten cycles (~20 kyr), 2) short modulating cycles (~90 and 125 kyr), 3) McLaughlin cycles (~413 kyr), and 4) long modulating cycles (~2000 kyr). The Van Houten cycles consist of three phases of lake rise to fall recorded in various facies: D1) lake-level rise, D2) lake high stand, D3) lake level fall. Through detailed sedimentological analysis of Van Houten cycles, Smoot (1991) documents that D1 and D3 reflect more arid intervals with less precipitation and are associated with more saline ephemeral-lake systems, whereas D2 reflects more humid intervals with more precipitation and represents a shift to fresh-water perennial lake systems.

The specimen (State Museum of Pennsylvania, Invertebrate Paleontology Collection – SMP IP 12829) was recovered from a construction site located at 40° 20' 41.78" N latitude and 75° 14' 50.79" W longitude in eastern Pennsylvania. The locality is in the informal “A2” Lockatong lithofacies of Willard et al. (1959) (Fig. 2). Olsen et al. (1996) formalized the stratigraphic nomenclature of the Lockatong Formation. This formal revision places the “A2” and the overlying “double red” lithofacies of Willard et al. (1959) into the formal Tumbling Falls Member near the top of the Lockatong Formation (Olsen et al., 1996). Within the construction site, D3 and D1 subdivisions of the Van Houten cycles are present. The external mold of the body fossil is developed in red siltstone in the Tumbling Falls Member near the transition from the old stratigraphic term A2 to the double red units of Willard et al. (1959).

DESCRIPTION

Sedimentary structures found in close association with the mold characterize the D1 and D3 facies. These features include: 1) rain drop impressions, 2) various morphologies of current ripples, 3) simple to complex cross laminations, 4) tufas, 5) roots, 6) ~1 cm wavelength symmetrical ripples, and 7) wave ripples crosscut by desiccation cracks.

While other interpretations may be possible, we assert that the evidence indicates that SMP IP 12829 most likely represents an external mold (negative relief) of the dorsal surface. Irregular elongate depressions occur at the posterior end of the specimen, but the overall body plan is recognizable. The external mold (negative relief) represents the dorsal side down as recorded in the strata (Figs. 2 and 3). The bedding surface on which the external mold is developed has low-amplitude current ripples developed above parallel laminations. The long axis of the fossil and associated feature is parallel to the trough axis. The original body fossil is absent and the counterpart has not been recovered at this time.

The mold of the corpse is approximately 6 mm long with a width of 2.6 mm. The head is approximately 0.8 mm and the thorax, base of the head to the wing connection, is 0.9 mm. The overall wing length is 4.3 mm long and 1.2 mm wide. A crease on the thorax paralleling the long axis of the depression may indicate the presence of wings. The most anterior legs are approximately 5 mm in length and are oriented anteriorly. The second pair of legs may be represented as a low bump between the anterior and posterior legs. The feature that is most striking is the rear pair of legs, pointed posteriorly and greatly enlarged. The leg length is 4.2 mm, including what appears to be a greatly enlarged femur.

Located posterior to the body impression is a series of elongate depressions (Fig. 2). The depressions are 22 mm in total length and a maximum 6 mm wide and consist of wave-like segments. The elongate feature is more deeply impressed proximal to the body impression and fades in depth distally. In fact, the feature is more deeply depressed than the body impression. Wave-like segments get longer towards the body impression with one side of greater depth. Margins of the features are sharp and well defined. Nine traverse marks extend laterally from the feature.

INTERPRETATION

The suite of sedimentary structures is indicative of a marginal lacustrine strandline, where water levels fluctuated from shallow depth to complete exposure. Low wavelength and amplitude wave ripples indicate water levels may not have exceeded a meter in depth. Cross
cutting desiccation cracks and raindrop impressions indicate exposure followed the inundating waters. In addition, the presence of associated tufas is compelling evidence for a strandline lacustrine setting for this fossil.

In considering SMP IP 12829 a body fossil as opposed to a trace we follow the reasoning of Ekdale (1985) wherein it is argued that if a living body is impressed and moves on, it would be a trace fossil, but if it dies and is impressed it is a body fossil even if the body is dissolved away. We interpret this specimen to be an external mold of the dorsal surface of an insect that is consistent with the order Orthoptera, most likely the Suborder Ensifera (Grimaldi and Engel, 2005; Legendre et al., 2010). A dorsal surface is interpreted to be preserved in this specimen because of the truncation of legs beneath the overlying carapace impression (see Figs. 3, 4A and 4B). This type of dorsal impression contrasts with the reported ventral body impressions that do not show this type of truncation and in fact show appendages attaching medially to a central linear impression (Collette and Hagadorn, 2010; Collette et al., 2010). Grimaldi and Engel (2005) illustrate the differences in complexity of the preserved ventral versus dorsal view, with the ventral showing more complexity of the appendages attaching to the body (their figure 7.31 – ventral and 7.34 – dorsal, see Figs. 4B, 5A and 5B). In trace fossils, the best example of a preserved ventral surface of a generalized arthropod is the jumping trace fossil *Tonganoxichnus* (Braddy and Briggs, 2002) and its variant species (Buatois and Mángano, 2011; Lucas et al., 2011). *Tonganoxichnus* has impressions of the appendages and possible post abdomen in some cases and not the entire ventral surface (Braddy and Briggs, 2002; Lucas et al., 2011).

FIGURE 3. Labeled parts of the Ensiferan fossil. Note scale in Fig. 2.

![FIGURE 3. Labeled parts of the Ensiferan fossil. Note scale in Fig. 2.](image)

FIGURE 4. House cricket experiment. A, Generation of a dorsal mold. Modern house cricket (*Acheta domestica*) was manually impressed dorsal side down onto a bed of loosely packed fine sand. Dorsal side is in contact with the fine-grained sand. Note the juncture of the appendages with the “body” in this ventral view of the cricket with the dorsal side embedded in the fine sand. Scale is in mm. B, External mold of the house cricket (*Acheta domestica*) with cricket removed. Note the absence of fine anatomical detail in the external mold of the dorsal side and the style of impression left by the saltatorial hind limbs. Scale is in cm. C-D, Trails made by cricket (*Acheta domestica*). In C the sand is tighter packed that in D. Note the bilateral symmetry present in both trails. Scale is in cm. The house cricket was released unscathed into the local environment.
The taxonomy of the Orthoptera has been problematic (Carpenter, 1992; Béthoux and Nel, 2002). Recently, cladistic phylogenetic analyses were performed based on wing venation patterns (Béthoux and Nel, 2002). The fine details of the wings are not preserved in the external mold, consequently only the gross morphology will be used to narrow the classification of the specimen (Figs. 2, 4A and 4B).

Saltatorial hind legs are an apomorphy of Orthoptera (Grimaldi and Engel, 2005) and are a distinctive characteristic of this specimen. Comparison of the Ensifera to the Caelifera body plan indicates that the Triassic orthopteran most closely mimics the Ensifera – shorter, anterior-directed front limbs and greater body width compared to body length (Grimaldi and Engel, 2005). This body plan most closely matches the family Gryllidae (Grimaldi and Engel, 2005).

Ensifera are first present at the end of the Permian with gryllids occurring in the Early Triassic (Béthoux and Nel, 2002). The several examples of orthopterans, in particular eucranid orthopterans, recovered from the Triassic (Carinian) Solite Quarry are assigned to the family Eucranididae (Fraser et al., 1996; Fraser and Grimaldi, 2003; Blagoderov et al., 2007). These orthopterans are the largest insects recovered from this Solite site (Fraser and Grimaldi, 2003).

Most Orthoptera are generalist phytophages, with a diet that consists of plants, potentially including shrubs and trees; some modern species are carnivorous (Fraser and Grimaldi, 2003). Gryllidae are noted for their ability to produce chirping songs.

Several hypotheses can be put forth to explain the depressed features preserved posterior to the body mold. These include that the depressions represent: 1) postmortem transportation, 2) a death crawl (mortichnia), 3) scour behind the body, 4) death crawl followed by scour, 5) transport followed by scour, 6) burrow with preserved body, and 7) jumping followed by a scour event (Fig 2). Burrowing and jumping are inconsistent with the preservation of the dorsal side.

The taphonomy of insects is currently a focus of much research (Briggs et al., 1998; Smith, 2000; Martínez-Delclòs et al., 2004; Smith et al., 2006; Smith and Moe-Hoffman, 2007; Krassilov et al., 2007; Ilger, 2011). What is clear from the numerous taphonomic studies is that the more sturdy features will more likely survive transport. Impressions of antennae are absent from this preserved Lockatong fossil, perhaps lost during transport of the original insect body or folded underneath the body at burial (Fig. 3). Our taphonomy experiment in fine sand demonstrates that such delicate features, such as antennae, are not impressed into the sediment (Figs. 4A and 4B). The fidelity of the external mold is poor with respect to carapace ornamentation (Figs. 4A and 4B).

Crickets produce a distinctive track consisting of three footprints (Fig. 6; Stuart and Stuart, 2000; Gutterridge, 2008; Eiseman and Charney, 2010). The hind footprint is elongate and parallel to the body’s long axis. The middle footprint is larger than the front and perpendicular or at high angle to the body axis. The front leg is the most reduced, and when asymmetry is present, the long axis parallels the body (Stuart and Stuart, 2000; Gutterridge, 2008; Eiseman and Charney, 2010). Our preliminary track experiments show the diversity of traces that crickets can produce in various substrate conditions (Figs. 4C and 4D). No definitive track has specifically been assigned to crickets, but the trace Lithographus (Hitchcock, 1858) has a similar pattern (Minter et al., 2007). This pattern is inconsistent with the features behind the fossil being a walking trace. At this point in time, tracks of crickets have not been reported (Hitchcock, 1858) has a similar pattern (Minter et al., 2007). This pattern is inconsistent with the features behind the fossil being a walking trace. At this point in time, tracks of crickets have not been reported. The classification of the specimen (Figs. 2, 4A and 4B).

This specimen represents the second insect body fossil to be recovered from the Triassic of the Newark Basin and the first from Pennsylvania. The overall body plan matches that of Orthoptera, in particular the Ensifera and the family Gryllidae. Orthoptera are generalist phytophages that adapted to the lacustrine strandline setting.

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