Appendix B from N. D. Sheldon and J. M. M. Hamer, "Evidence for an Early Sagebrush Ecosystem in the Latest Eocene of Montana"
(J. Geol., vol 118, no. 4, p. 435)

Formal Ichnological Descriptions

Type 1: Downward Branching, Sometimes Redoximorphic (Ichnogenus: Rudicites erraticus; Arefiev and Naugolnykh 1998), Root Traces

Number of Specimens: >200.

General Form: Filamentous structures that range in diameter from 0.1 to 0.8 cm with circular cross sections and depths from 1.0 to 75 cm depth. They can be extremely abundant locally and drab gray in color, with well-defined outer edges that overlap and crosscut each other. Rarely, the downward-branching structures are present as rhizoliths and are noncalcareous to weakly calcareous, noncarbonaceous, branching replacement structures that spread downward from the top surface of the paleosols; the majority of the traces are weakly redoximorphic and without textural difference with the surrounding sedimentary matrix to classify them as rhizoliths.

Wall Structure: Absent.

Branching/Morphology: They commonly taper downward and exhibit downward and lateral branching of smaller diameter that also tapers to a point.

Nature of Fill: Passively filled.

Occurrence: These are commonly found in mudstone and siltstone.

Trace Maker: These structures were formed by the roots of plants, most likely herbaceous vegetation.

Interpretation: These rhizohaloes, as defined by Kraus and Hasiotis (2006), are found in weakly developed to well-developed paleosols formed on proximal to distal floodplain sediments. The drab colors associated with these traces are typical of redoximorphic features present in modern soils that develop in response to changes in redox conditions from fluctuations in the degree of saturation of the soil (e.g., Vepraskas et al. 1992; Vepraskas 1994). Drab colors are areas depleted in Fe that formed when the soil was saturated and relatively depleted in oxygen (e.g., Duchaufour 1982; Kraus and Hasiotis 2006). The overall small size of rhizohaloes suggests that the landscape was probably dominated by low-lying herbaceous vegetation (e.g., Hamer et al. 2007*b*).

Type 2: Ovoid Structures

Number of Specimens: >10.

General Form: Multioriented ovoid structures with a length of 1.0–1.5 cm and a width of 0.5–1.0 cm. They have one line of symmetry only along their longest plane, with one end of the oval appearing truncated. They weather in epi-relief and are easily removed from the surrounding matrix.

Wall Structure: Unconstructed, unlined, and unornamented. The wall has a smooth surface.

Branching/Morphology: Unbranched. This structure is solitary, i.e., does not form clusters.

Nature of Fill: Passively filled?

Occurrence: These structures are associated with *Taenidium barretti* within the A horizon of paleosols at Little Pipestone. The A horizons have a grain size of silt to medium sand.

Trace Maker: Unknown. Possibly ground-dwelling bees (Hymenoptera: Apoidea).

Interpretation: Despite being identified within the same horizons and having similar widths as *T. barretti*, these traces are not found as a composite structure with *T. barretti*. The ovoid structures are similar in size and morphology to *Celliforma*; however, they lack the spiral cap and do not occur with any other features (e.g., shafts, adjoining cells) that are commonly associated with *Celliforma*. The occurrence of these ichnofossils within poorly to moderately developed paleosols suggests that the trace maker was terraphilic in habit (Hasiotis 2002).

Type 3: Ichnogenus: Steinichnus (Bromley and Asgaard 1979)

Number of Specimens: >10.

General Form: Found in epi-relief, predominantly horizontal to subhorizontal in orientation, and with a length of 2–10 cm and a diameter of 0.5–1.5 cm. They are elliptical in cross section and are found on upper bedding planes; they rarely penetrate deeper than 2 cm from the bed surface. Detail of burrow morphology is poor due to the relatively large grain size obscuring fine-scale detail.

Wall Structure: The walls of the burrow are transversely striated, with the ornamentation ranging from crescentic, crosscutting ridges to knobbly markings. Each striae has a maximum relief of 0.5 mm.

Branching/Morphology: Predominantly unbranched but can exhibit Y- and T-shaped branching.

Nature of Fill: Actively filled, but no backfilled menisci.

Occurrence: These traces are found in fine- to coarse-grained sand interpreted as crevasse splay deposits and are commonly associated with cross laminations and rare imbricated clasts.

Trace Maker: Mud-loving beetles and mole crickets (Orthoptera:Gryllotalipidae; Bromley and Asgaard 1979; Ratcliffe and Fagerstrom 1980; Hasiotis 2004).

Interpretation: The association of *Steinichnus* isp. along bedding planes that exhibit cross laminations and cross-bedding indicates that these traces were constructed in water-saturated environments associated with channel and crevasse splay deposits. Mole crickets have legs that are adapted for pushing aside sediment as they move forward, and burrows constructed by modern mole crickets are documented by several authors as occurring in moist sediment near water bodies (e.g., Ratcliffe and Fagerstrom 1980).

Type 4: Ichnogenus: Taenidium (Heer 1877); Ichnospecies: Taenidium barretti (Bradshaw 1981)

Number of Specimens: >100.

General Form: Primarily vertical to subvertical burrows, although some occur horizontally. Burrow diameter varies between approximately 0.8 and 2.4 cm. Preserved most abundantly on the bedding surface in convex epi-relief. Bioturbation of individual beds by this ichnofossil is commonly 80%–90%.

Wall Structure: No wall linings or ornamentation are present.

Branching/Morphology: There is no evidence of branching.

Nature of Fill: The fill is crescentic, backfilled, and meniscate. No compartmentalization of backfill.

Occurrence: Found in greatest abundance within the A horizon of pedogenically modified channel silts and sands. This ichnofossil is also found in mudstone and in lower parts of paleosol profiles, but in much less significant numbers.

Trace Maker: In terrestrial environments, similar traces have been attributed historically to cicada nymphs (O'Geen and Busacca 2001). However, sand roaches (order Dictyoptera) are also recorded as forming *T. barretti* burrows in modern desert aeolian sediments (e.g., Crawford 1981; Ekdale et al. 2007).

Interpretation: The high abundance of *T. barretti* at Little Pipestone suggests that the trace maker dominated the invertebrate fauna at this locality. The *T. barretti* were most abundant in paleosol A horizons, particularly of the weakly developed Entisols and Inceptisols, suggesting that the trace maker was an opportunistic colonizer that moved in shortly after flooding events; they were present but much less common in the Alfisols. *Taenidium barretti* is also found in close proximity to and crosscutting roots in all of the paleosol types present at Little Pipestone. The overall vertical orientation of these ichnofossils as well as their greatest abundance within the upper horizons of paleosols suggests that the trace maker is not permanently present in the medium and interacts with the sediment surface, further supporting the interpretation that these are the ichnofossils constructed by the feeding and locomotion of cicada nymphs (O'Geen and Busacca 2001; O'Geen et al. 2002).

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