Systematic ichnology of microborings from the Cenozoic White Limestone Group, Jamaica, West Indies

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Key words – ichnotaxonomy, microborings, Jamaica, West Indies, Eocene, Oligocene, Miocene.
The Middle Eocene to Middle Miocene White Limestone Group of Jamaica contains a common and diverse, poorly to well-preserved microboring ichnofauna, namely *Centrichnus eccentricus* Bromley & Martinell, *Curvichnus pediformis* isp. nov., *Dendrorete balani* Tavernier, Campbell & Golubic, *Dipatulichnus rotundus* Nielsen & Nielsen, *Entobia volzi* Bromley & D'Alessandro, *Entobia* isp. cf. *E. ovula* Bromley & D'Alessandro, *Entobia* isp. forms A and B, *Fossichnus solus* Nielsen, Nielsen & Bromley, *Maeandropolydora elegans* Bromley & D'Alessandro, *Maeandropolydora sulcans* Voigt, *Oichnus asperus* Nielsen & Nielsen, *Oichnus excavatus* Donovan & Jagt, *Oichnus gradatus* Nielsen & Nielsen, *Oichnus ovalis* Bromley, *Oichnus paraboloides* Bromley, *Oichnus simplex* Bromley, *Oichnus* isp., *Planobola microgota* Schmidt, *Podichnus centrifugalis* Bromley & Surlyk, *Ramosulcichnus biforans* Hillmer & Schulz, *Reticulina elegans* Radtke, *Scolecia filosa* Radtke, *Scolecia maeandria* Radtke, *Stellatichnus radiatus* Nielsen & Nielsen, *Trypanites fimbriatus* (Stephenson), *Trypanites solitarius* (Hagenow), *Trypanites weisei* Mägdefrau, and one example each of an unnamed crescent-shaped and a sub-horizontal to undulatory boring. These ichnospecies are distributed within three formations, the Somerset, Moneague and Montpelier formations, of the White Limestone Group. The majority of these microborings are preserved in the foraminifers *Lepidocylina* spp. within the Somerset Formation.

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Introduction

Microendolithic trace fossils, typically with diameters less than 100 µm and geometrically variable, are known from the late Proterozoic to the Neogene (Glaub & Vogel, 2004; Vogel & Marincovich, 2004, and references therein). Comparable ethological microendoliths have also been documented from modern environments (e.g., Perry, 2000; Perry & Macdonald, 2002). Generally, these types of borings can be produced by various organisms such as red, green and blue-green algae, fungi, polycheate worms, foraminifers and sponges (Wisshak *et al.*, 2005; Blissett *et al.*, 2006, and references therein). The microendoliths, the topic of this contribution, are described ichnotaxonomically herein. Elsewhere, such structures have been used to infer palaeobathymetry, palaeoenvironments and palaeophotic zones.

This study focuses on the ichnotaxonomy of microendoliths from the Middle Eocene to Middle Miocene White Limestone Group, Jamaica, West Indies, with the majority of specimens collected from the Middle Eocene Somerset Formation, and preserved within the foraminifers *Lepidocylina* spp. (see Table 1 for a complete stratigraphic distribution of the microborings within the White Limestone Group). This study also serves to add to the previously described detailed ichnotaxonomy of the soft-sediment and macro-boring trace fossils by Blissett & Pickerill (2003a, b, c, 2004) from the White Limestone Group, and also augments the regional and global diversity of microendoliths.

Previous work and geological setting

There have been very few studies of microendolithic trace fossils from Jamaica. Underwood & Mitchell (2004) were the first to record microborings, within shark teeth, from the Lower Miocene Montpelier Formation of the White Limestone Group. They identified the microboring *Mycelites ossifragus* Roux, 1887, and also suggested the presence of *Oichnus* Bromley, 1981, from their collections. Perry (1998), while working in modern marine environments from Jamaica, documented several microboring forms that were morphologically similar to anologues previously identified from the fossil record. The assemblage of microendolithic trace fossils described herein is therefore

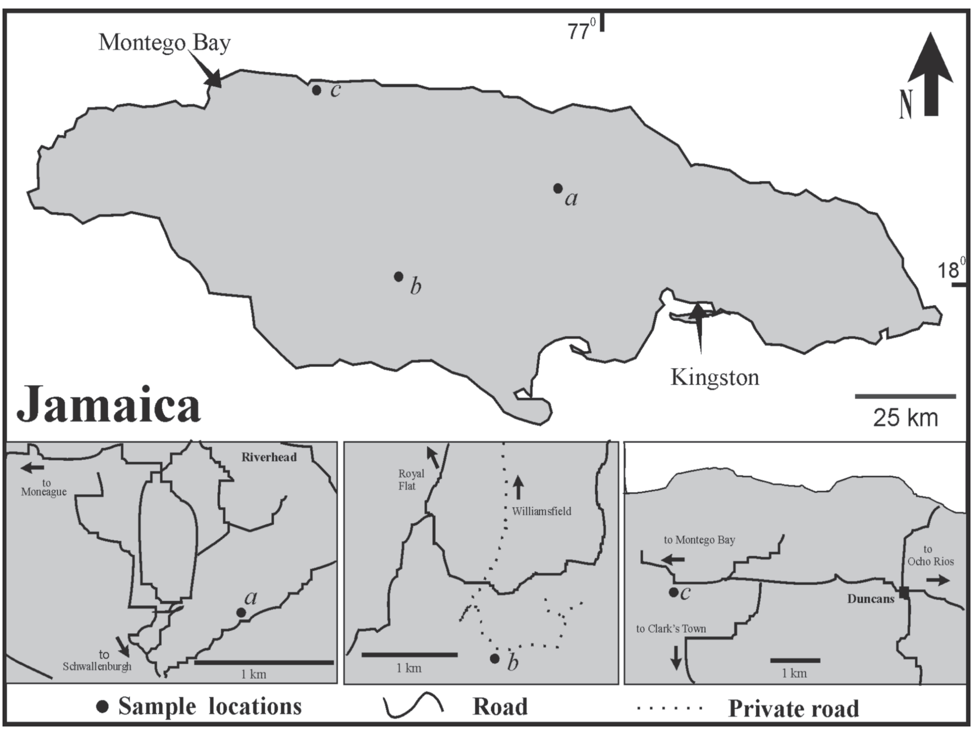

Fig. 1. Outline map of Jamaica depicting the locations of the three sample sites within the White Limestone Group (labelled *a-c*). Lower section depicts detailed road maps of the three areas wherein the sites *a-c* are located. Key: shading = landmass; blank areas = Caribbean Sea.

considered an important contribution in improving the ichnological database, not only for the White Limestone Group, but for all lithostratigraphic units in Jamaica and the Caribbean.

Three localities within the White Limestone Group have yielded microborings (labelled *a-c* in Fig. 1). This group comprises, in ascending stratigraphic order, the Middle Eocene Troy, the Middle Eocene Swanswick, the Middle Eocene Somerset, the Early Oligocene to Middle Miocene Moneague, and the Lower Miocene Montpelier and Pelleu Island formations (Mitchell, 2004).

The Middle Eocene Somerset Formation consists of fossiliferous packstones with subordinate foraminiferal- and gastropod-bearing wackestones and micrites, and is typically very thinly bedded (0·1-0·2 m). The Somerset Formation is exposed along a road cut in an abandoned bauxite quarry at Riverhead, located approximately 3·5 km east of the town of Moneague, parish of St. Ann (Fig. 1, locality *a*). At this locality the Somerset Formation is represented by molluscan and unconsolidated foraminiferal packstones.

Table 1. Distribution of microborings in the White Limestone Group. Key: SF = Somerset Formation; MrF = Montpelier Formation; MF = Moneague Formation.

	SF	MrF	MF
Centrichnus eccentricus	X		
Curvichnus pediformis isp. nov.	X		
Dendrorete balani	X		
Dipatulichnus rotundus	X		
Entobia volzi	X		
Entobia isp. cf. *E. ovula*	X		
Entobia isp. form A	X		
Entobia isp. form B	X		
Fossichnus solus	X		
Maeandropolydora elegans	X		
Maeandropolydora sulcans	X		
Oichnus asperus	X		
Oichnus excavatus	X		
Oichnus gradatus	X		
Oichnus ovalis	X		
Oichnus paraboloides	X		
Oichnus simplex	X	X	
Oichnus isp.	X		
Planobola microgota	X		
Podichnus centrifugalis	X		
Ramosulcichnus biforans	X		
Reticulina elegans	X		X
Scolecia maeandria	X		
Scolecia filosa	X		
Stellatichnus radiatus	X		
Trypanites fimbriatus	X		
Trypanites solitarius	X		
Trypanites weisei	X		
crescent-shaped boring	X		
sub-horizontal boring	X		

Outcrop *b* (Fig. 1) occurs on a private haulage road within the WINDALCO (formerly ALCOA mines) mining area, 6 km south of the town of Williamsfield, parish of Manchester, and exposes the Lower Oligocene to Middle Miocene Moneague Formation. At this locality the formation comprises sporadically distributed, 4 m high, scleractinian coral-rich rudstone-floatstone layers.

Outcrop *c* (Fig. 1), located approximately 5 km west of the town of Duncans, in the parish of Trelawny, exhibits two distinctive lithological sequences of the Lower Miocene Montpelier Formation. The first lithology consists of 0·5-2·0 m beds of fine- to very coarse-grained chalky limestones interbedded with thinly bedded greyish calcareous mudstones associated with nodular to bedded chert. Chert is also evident in joints and fractures. The second lithology consists of extraclastic, coral-rich rudstones-floatstones with echinoids, crab carapaces, foraminifers, benthic molluscs and nautiloids.

Material and methods

Approximately 16,000 foraminifers were bulk sampled from consolidated to unconsolidated foraminiferal grainstones (locality *a*) along with slabs of bedded chert and various coral specimens, from localities *b* and *c* (Fig. 1). These were examined for evidence of bioerosional structures using a binocular microscope. Systematic identification of the bioerosional structures was aided by the use of SEM (JEOL JSM 6400). Preparation of the samples included rinsing in water to remove surficial particulate debris and rinsing in very dilute (< 1 per cent) hydrochloric acid to remove these carbonate grains. All material described herein is housed in the University of the West Indies Geology Museum (UWIGM 2005.34-2005.35) and in the Nationaal Natuurhistorisch Muséum, Leiden (RGM 211 601-211 623).

Systematic ichnology

The White Limestone Group contains a common and diverse, poorly to well-preserved microboring ichnofauna. From the approximately 16,000 foraminifers examined, 50% exhibit evidence of bioerosional structures. To date, 15 ichnogenera, represented by 28 nominal ichnospecies and two *problematica*, have been identified including a new ichnospecies. Of the six formations that comprise the White Limestone Group, microendoliths have been identified from the Somerset, Montpelier and Moneague formations (Table 1). Detailed systematics of these ichnospecies are documented below.

The majority of the figured specimens occur in the Middle Eocene Somerset Formation and are preserved within the foraminifers *Lepidocylina* spp. The ichnospecies *Reticulina elegans* Radtke, 1991, is the only trace fossil which occurs in the Middle Miocene Moneague Formation on the scleractinian coral *Porites* sp. As a result the subsection 'Occurrence,' as it relates to individual ichnospecies, has been eliminated to avoid unnecessary repetition. The subsection 'Stratigraphical range' is also excluded because, stratigraphically, microendoliths are currently underdocumented and therefore require further studies before additional commentary is warranted.

The descriptions are presented alphabetically (cf. Pickerill & Donovan, 1991; Blissett & Pickerill, 2004), rather than in morphological (cf. Uchman, 1995; Schlirf, 2000) or ethological groupings (cf. Seilacher, 1964), and are employed for ease of reference.

Ichnogenus *Centrichnus* Bromley & Martinell, 1991

Type ichnospecies – *Centrichnus eccentricus* Bromley & Martinell, 1991.

Diagnosis – (After Bromley & Martinell, 1991, p. 247.) "Shallow biogenic etching traces on carbonate lithic or skeletal substrates comprising centrically arranged arcuate or ring-shaped grooves."

Centrichnus eccentricus Bromley & Martinell, 1991
Fig. 2.

Diagnosis – (After Bromley & Martinell 1991, p. 247.) "Tear- or drop-shaped *Centrichnus* comprising a series of bundled or crowded, bow-shaped grooves concave toward the pointed end."

Material – Single specimen, RGM 211 601, locality *a* (Fig. 1), Somerset Formation.

Description – Teardrop-shaped boring, radius of 2·5 mm, consisting of four concentric concavities, concaving towards the apex. Width of the concavities average 300 μm and are consistent throughout.

Remarks – Weakly developed forms of *C. eccentricus* may resemble the trace fossil *Renichnus arcuatus* Mayoral, 1987 (Bromley & Martinell, 1991). However, this specimen lacks the spiraling form attributed to *R. arcuatus*, also comprises a continuous non-spiraled outline and, therefore, is teardrop-shaped (Fig. 2).

Ichnogenus *Curvichnus* Nielsen, 2002

Type ichnospecies – *Curvichnus semorbis* Nielsen, 2002.

Diagnosis – (Emended after Nielsen, 2002, p. 674.) Biogenic structure having an irregular, semicircular, circular to oval outline and situated in skeletal substrates.

Remarks – The emendation of the diagnostic features of this ichnogenus is considered necessary to include the variation in shape of the proposed ichnospecies to the original diagnostic properties of the ichnogenus. Nielsen (2002) noted that one of the

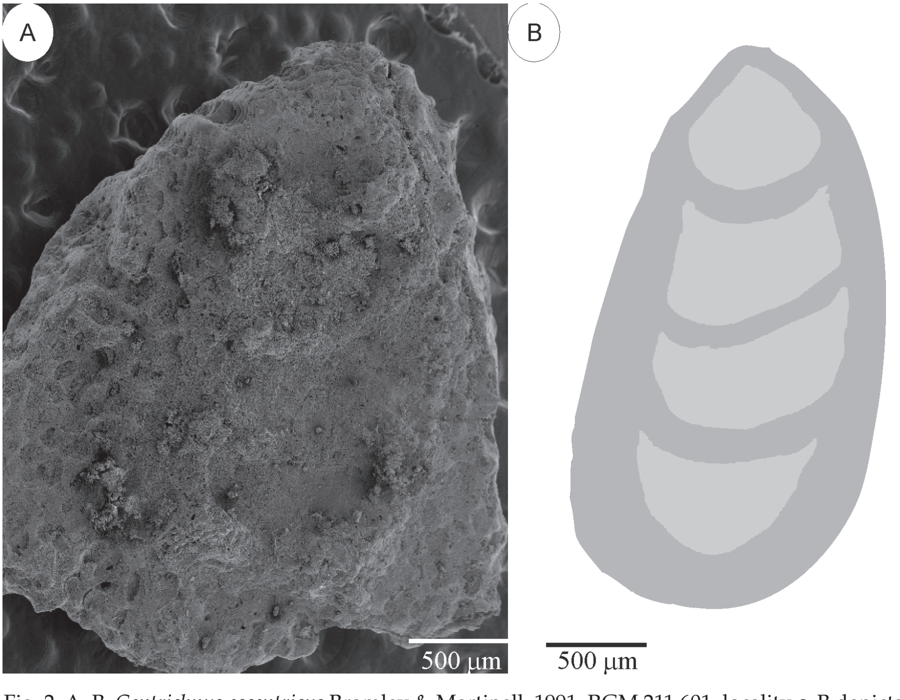

Fig. 2. A, B. *Centrichnus eccentricus* Bromley & Martinell, 1991, RGM 211 601, locality *a*. B depicts a computer generated line drawing of A.

distinctive features of *C. semorbis* was its lack of passage to the outer surface. Nielsen (2002) did not include this feature in the original diagnosis of the ichnogenus.

***Curvichnus pediformis* isp. nov.**
Pl. 1, figs. 1-6.

Derivation of name – *Pedi* from the Latin *pedis* meaning foot and *formis* from the Latin *forma* meaning shape. Referring to the similarity in shape of the ichnospecies to a human foot.

Type material – Holotype: RGM 211 602.1 (Pl. 1, fig. 1); paratypes (Pl. 1 figs. 2-6): RGM 211 620, 211 621.1, 211 622, 211 623 and 211 607.1.

Additional material – Twenty-six additional specimens, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – Biogenic cavity characterized by an irregular, semielliptical outline that lies parallel to the surface of the substrate. The margin may or may not be crenulated; where crenulation is absent it may be smooth or may possess a raised rim. The outer margin may or may not overhang the cavity. The cavity does not totally penetrate the substrate, but ends in a relatively shallow depression.

Description – The outline of individual specimens varies in shape from an irregular oval (pedal) to a quasi-semicircular form (Pl. 1). The margin may be crenulated (holotype) or smooth, and may also be characterized by a raised rim. The extremities are lobate along their long axes. The cavities lie parallel to and within substrate surfaces, and do not totally penetrate the substrates, but end in smooth, essentially U-shaped depressions. The outer margins overhang the cavities in some specimens. These overhanging lips may or may not be continuous on individual specimens. The dimensions of the depressions along the long axes vary between 170-450 µm, and vary between 70-190 µm and 45-120 µm across their widest and narrowest diameter, respectively.

Remarks – The characteristic features of *Curvichnus pediformis* isp. nov. are its easily identifiable outline, and its occurrence parallel to and partial penetration of the substrate surface. This new ichnospecies differs from *C. semorbis* in its occurrence at the substrate surface. The only ichnospecies that remotely resembles this structure is *Oichnus asperus* Nielsen & Nielsen, 2001. However, the latter is typically characterized by a regular elongate-oval outline and lacks the regular curvature of *C. pediformis*.

Ichnogenus *Dendrorete* Tavernier, Campbell & Golubic, 1992

Type ichnospecies – *Dendrorete balani* Tavernier, Campbell & Golubic, 1992.

Diagnosis – (Emended after Tavernier *et al.*, 1992, p. 304.) Shallow, palmate to prostrate, reticulate system of borings composed of tubular, radiating, branched and/or anastomosing tunnels. Fine tubules may arise from various sections of the system.

Morphology changes with ontogeny. At points of mutual contact, the tunnels do not exhibit avoidance, but fuse into an interconnected network.

Remarks – The emendation to the diagnosis of the ichnogenus is deemed necessary to incorporate what seems to be one of the main diagnostic features, change in morphology with ontogeny, which was previously excluded. As noted by Tavernier *et al*. (1992), the boring initially starts from a single point and spreads in a radiating manner, and in later stages becomes prostrate masking the radiating pattern. Essentially, the boring system is organized into three zones. The youngest (peripheral) one is characterized by lateral spreading with shallow 'exploratory' tunnels. In the second zone the tunnels interconnect to form a horizontal reticulum and commonly, in the oldest zone, branches are oriented such that the zone forms a three-dimensional reticulum.

Dendrorete balani Tavernier, Campbell & Golubic, 1992

Fig. 3.

Material – Single specimen, RGM 211603, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Emended after Tavernier *et al*. , 1992, p. 305.) Shallow, subdichotomous or laterally branched and/or anastomosing tubular borings sporadically radiating from a central point of entry to form a complex network. Where radial branches do not occur the tunnels may be prostrate. Secondary branching may or may not occur. Slight swelling may develop at branching nodes.

Description – Crudely palmate boring consisting of tubular tunnels, parallel to the substrate surface, each varying in diameter and length. Maximum length attained by these tubes is 2·5 mm with the diameter averaging 190 µm. Swellings are sporadically distributed along each tube and at branching nodes. Second order branching is also evident. Tubules are not prominent along the tubes, but three subvertical tubules arise proximally from the main system.

Remarks – The emendation of the diagnosis of the ichnospecies is also essential in order to eliminate size and dimension, a poor ichnotaxobase (see Pickerill, 1994; Bertling *et al*., 2006); to remove ambiguity; and to exclude descriptive phrases and terminologies which are best reserved for discussion within a systematic contribution. The closest analogue to the ichnospecies here described is *Conchotrema* ispp. Teichert, but it possesses a main trunk that is not apparent with *Dendrorete* ispp.

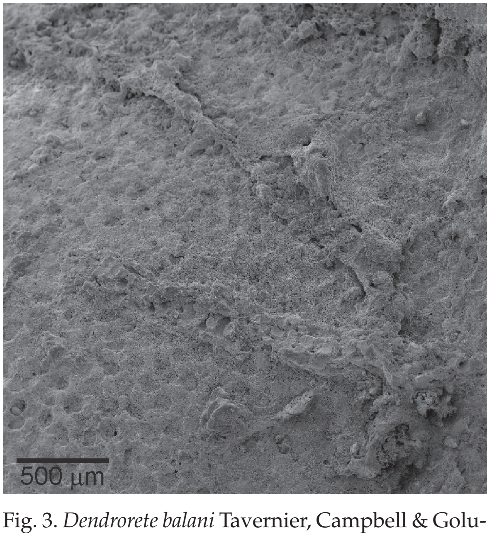

Fig. 3. *Dendrorete balani* Tavernier, Campbell & Golubic, 1992, RGM 211 603, locality *a*.

Ichnogenus *Dipatulichnus* Nielsen & Nielsen, 2001

Type ichnospecies – *Dipatulichnus rotundus* Nielsen & Nielsen, 2001.

Diagnosis – (After Nielsen & Nielsen, 2001, p. 111.) "Pair of biogenic holes, unconnected, but situated in the same skeletal substrate. Each hole has a simple cylindrical form, oriented perpendicular to the substrate surface. Both external and internal openings are sharp and circular in outline."

***Dipatulichnus rotundus* Nielsen & Nielsen, 2001**
Pl. 2, fig. 1.

Material – Twelve specimens, including RGM 211 604.1, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – As for the ichnogenus.

Description – Pairs of closely spaced, sub-circular, sub-cylindrical unconnected holes *c*. 400 µm apart. The diameters, averaging 119 µm, of these openings are constant and perpendicular to the substrate surface.

Remarks – The difficultly in isolating this ichnospecies is the similarity of each of the cylindrical-like 'holes' to *Oichnus simplex* Bromley, 1981, and the semi-interpretive aspect of one of the diagnostic features as it relates to proximity of these biogenic holes.

Ichnogenus *Entobia* Bronn, 1837

Type ichnospecies – *Entobia cretacea* Portlock, 1843.

Diagnosis – (Modified after Bromley & D'Alessandro, 1984, p. 238.) Boring in carbonate substrates comprising a single chamber (swollen, fusiform portions of sponge boring), networks or boxworks of galleries connected to the surface by several or numerous apertures. Morphology changes markedly with ontogeny. Diameters of galleries show progressive increase in growth; in some forms, inflation at regular distances produces closely interconnected chambers; in other forms, chamber development is restricted; while in others, cameration (any stage of growth that is characterized by inflation or swelling of discrete parts of the system to produce chambers) is developed. Fine apophyses (minute hair-like extensions that commonly extend from all parts of the sponge boring) arise from all surfaces of the system.

Remarks – *Entobia* ispp. are complex borings that involve a variety of descriptive terminologies. Reference to these terms is illustrated in Bromley & D'Alessandro (1984, fig. 2) and Blissett & Pickerill (2004, fig. 4).

***Entobia volzi* Bromley & D'Alessandro, 1984**
Pl. 2, fig. 2.

Material – Single specimen, RGM 211 605, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (After Bromley & D'Alessandro, 1984, p. 261.) "Diminutively camerate entobian consisting, in phase, of chambers connected by wide intercameral canals or partially fused, taking a form resembling an irregular, close framework. This system is crossed in all direction by relatively wide, subcylindrical canals that connect with the substrate surface through large apertures. Growth front compact. Phases B and C are considerably reduced, characterized by appearance of irregular chambers or clusters of chambers as swellings on the walls of the wide canals. Phase A comprises long, slender canals arranged irregularly and branched as a boxwork, having palmate expansions at nodal points. Apertures of two sizes, circular to oval, very irregularly distributed."

Description – Complex framework of a camerate entobian consisting of irregular chambers, averaging 170 µm in diameter, clustered around a central canal with a diameter of *c*. 540 µm. At least two interconnected canals appear to branch from the main canal. The chambers appear to be fused or interconnected by very short intercameral canals. Palmate expansions at nodal points attributed to Phase A were not observed.

Remarks – The distinctive morphological features of *Entobia volzi* are the large central canal, and the clustering of chambers around this canal which represent growth phases B and C.

Entobia isp. cf. _E. ovula_ Bromley & D'Alessandro, 1984
Pl. 2, fig. 3.

Material – Single specimen, RGM 211 606, locality *a* (Fig. 1), Somerset Formation.

Description – Camerate entobian consisting of spheriodal chambers that are in contact with each other via a very short intercameral canal. Dimensions of the chambers vary between 120-180 µm for the maximum diameter. The chambers are aligned and are each in contact either directly or indirectly via short intercameral canals. Sporadic fusion of adjoining chambers is observed (Pl. 2, fig. 3, arrowed).

Remarks – *Entobia* isp. cf. *E. ovula* could not be classified with confidence due to the lack of obvious apertural openings, but this particular specimen resembles that of Schmidt (1992, pl. 10, fig. 4).

Entobia isp. form A
Pl. 2, fig. 4.

Material – Single specimen, UWIGM 2005.34, locality *a* (Fig. 1), Somerset Formation.

Description – Camerate entobian comprised of large flattened, crudely rounded to ovate chambers that are commonly fused. Where the chambers are not fused they are connected by multiple intercameral canals. The diameters of the chambers attain a maximum of 452 µm (short diameter) and 650 µm (long diameter).

Remarks – Growth phases A, B and E of *Entobia* isp. form A are not evident or poorly preserved and the preserved growth phase represents either a late growth phase C, growth phase D or both phases. Hence, we are reluctant to assign the material to a nominal ichnospecies.

Entobia isp. form B
Pl. 2, fig. 5.

Material – Single specimen, RGM 211 607.2, locality *a* (Fig. 1), Somerset Formation.

Description – Camerate entobian exhibiting swollen, ovate chambers interconnected by 4-6 intercameral canals. Sporadic fusion of chambers occurs. Where fusion is not apparent, the chambers are relatively consistent in shape with a diameter of *c*. 170 µm. Where fusion occurs the shapes of the chambers are irregular and of variable dimensions.

Remarks – In *Entobia* isp. form B, the phase preserved appears to be growth phase D of *E. ovula*, but, in the latter, fusion of chambers does not occur within this phase (Bromley & D'Alessandro, 1984). Another morphologically similar ichnospecies to *Entobia* isp. form B is *E. laquea* Bromley & D'Alessandro, 1984, but without phase D the diagnostic features are impossible to differentiate from *E. ovula* (Bromley & D'Alessandro, 1984).

Ichnogenus _Fossichnus_ Nielsen, Nielsen & Bromley, 2003

Type ichnospecies – *Fossichnus solus* Nielsen, Nielsen & Bromley, 2003.

Diagnosis – (After Nielsen *et al*., 2003, p. 3.) "Biogenic concavity characterized by a circular to oval groove. Outer border conforms with inner border, both sharp in outline. Parts of the groove may penetrate through the substrate. Situated in skeletal substrates."

Fossichnus solus Nielsen, Nielsen & Bromley, 2003
Fig. 4.

Material – Single specimen, RGM 211 608.1, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – As for the ichnogenus.

Description – Crudely ovate boring consisting of a hollow ring around its circumference. The shortest diameter of the outer border is 83 µm with its longest diameter *c*. 102 µm. The dimension of the hollow ring is inconsistent, having minimum and maximum thicknesses of *c*. 9 and 30 µm, respectively.

Ichnogenus _Maeandropolydora_ Voigt, 1965

Type ichnospecies – *Maeandropolydora decipiens* Voigt, 1965.

Diagnosis – (After Bromley & D'Alessandro, 1983, p. 293.) "Long, cylindrical galleries having two or more apertures, running through the substrate sinuously or in irregular contortions. Galleries may run parallel in contact with each other in pairs, with or without fusion. Loose or tight loops may occur; the limbs of these may be connected by a vane or form a pouch."

***Maeandropolydora elegans* Bromley & D'Alessandro, 1983**
Pl. 2, fig. 6.

Material – Single specimen, RGM 211 609, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (After Bromley & D'Alessandro, 1983, p. 296.) "System composed of cylindrical galleries of constant diameter, irregularly sinuous, tending to run in paired fashion, the limbs touching but normally not fused. Numerous apertures."

Description – Cylindrical gallery having a constant diameter of *c*. 14 µm and two prominent apertures. The gallery loops sharply onto itself and lacks blind ends, pouches and vanes. Fusing of limbs was not observed.

***Maeandropolydora sulcans* Voigt, 1965**
Pl. 3, fig. 1.

Material – Seven specimens, including RGM 211 610, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (After Bromley & D'Alessandro, 1983, p. 295.) "Cylindrical gallery having at least two apertures, irregularly contorted, commonly bent in loops, never showing fusion where walls are in mutual contact; vane absent."

Description – Cylindrical galleries having varying diameter (*c*. 100-200 µm) in individual specimens. The galleries in each specimen are contorted, branched with at least three apertures and two blind ends. Vanes and pouches are absent.

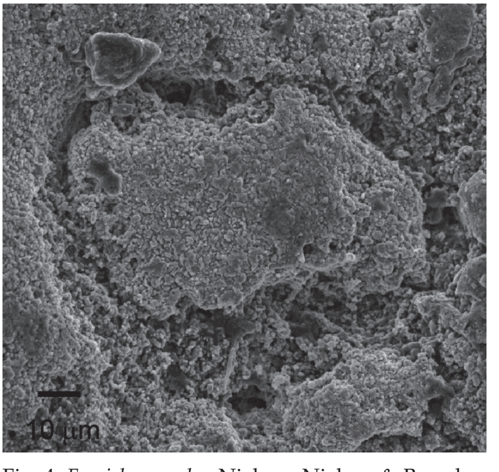

Fig. 4. *Fossichnus solus* Nielsen, Nielsen & Bromley, 2003, RGM 211 608.1, locality *a* .

Remarks – *Maeandropolydora elegans* and *M. sulcans* differ from other *Maeandropolydora* ispp. due to the lack of pouches and vanes. *Maeandropolydora* ispp. show a close affinity to *Caulostrepsis* ispp., but the latter lack well-developed cylindrical galleries (Bromley & D'Alessandro, 1983).

Ichnogenus *Oichnus* Bromley, 1981

Type ichnospecies – *Oichnus simplex* Bromley, 1981.

Diagnosis – (After Donovan & Pickerill, 2002, p. 87.) “Small, circular, subcircular, oval or rhomboidal holes or pits of biogenic origin in hard substrates, commonly perpendicular to subperpendicular to substrate surface. Excavation may pass directly through substrate as a penetration, most commonly where the substrate is a thin shell, or may end within the substrate as a shallow to moderately deep depression or short, subcylindrical pit, commonly with a depth: width ratio of ≤1, with or without a central boss.”

Remarks – Differentiation of the various *Oichnus* ispp., namely *O. asperus* Nielsen & Nielsen, 2001, *O. coronatus* Nielsen & Nielsen, 2001, *O. excavatus* Donovan & Jagt, 2002, *O. gradatus* Nielsen & Nielsen, 2001, *O. ovalis* Bromley, 1993, *O. paraboloides* Bromley, 1981, and *O. simplex* Bromley, 1981, are provided as line drawings in Nielsen & Nielsen (2001), Donovan & Jagt (2002) and Blissett & Pickerill (2003c).

***Oichnus asperus* Nielsen & Nielsen, 2001**
Pl. 3, fig. 2.

Material – Forty two specimens, including RGM 211 611.1, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (After Nielsen & Nielsen, 2001, p. 110.) “*Oichnus* having openings of regular to irregular elongate-oval outline. The margin is perpendicular to the substrate surface.”

Description – *Oichnus* having regular elongate oval-shape. The margin of each opening is perpendicular to the substrate surfaces, and the dimensions of the external and internal openings are unequal. The dimensions of the openings vary between specimens with external lengths *c*. 240 µm, widths *c*. 100 µm and internal lengths *c*. 150 µm, widths *c*. 90 µm.

***Oichnus excavatus* Donovan & Jagt, 2002**
Pl. 3, fig. 3.

Material – Two specimens, including RGM 211 612.1, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (After Blissett & Pickerill, 2003c, p. 223.) “Circular to elliptical, non-penetrative *Oichnus*, almost invariably with a broad, high, raised central boss. Aperture of boring may or may not be overhanging, but walls typically concave and may be V-shaped.”

Description – Non-penetrative, elliptical depressions each with a raised central boss. The diameter of the figured specimen is *c*. 100 µm. The raised bosses are crudely knob-like with height less than the depth of each depression. The bases of the depressions are essentially flat. The walls of the structures are V-shaped in vertical section.

***Oichnus gradatus* Nielsen & Nielsen, 2001**
Pl. 3, fig. 4.

Material – Ten specimens, including RGM 211 612.2, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (After Nielsen & Nielsen, 2001, p. 110.) "An *Oichnus* that abruptly changes diameter from wide externally to narrow internally. The two parts are concentric."

Description – Non-penetrative (failed), elliptical borings that change diameter in external width, averaging 90 µm longest diameter and 75 µm shortest diameter, to narrow internal width, *c*. 30 µm. The margins of both parts are perpendicular to the substrate surface.

***Oichnus ovalis* Bromley, 1993**
Pl. 3, figs. 2, 5.

Material – Thirteen specimens, including RGM 211 602.3 and 211 611.2, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Emended after Bromley, 1993, pp. 170, 171.) Oval *Oichnus* tapering subparabolically from a relatively large external aperture to a minute inner one.

Description – Rhomboidal forms with side widths averaging 120 µm. The margins are perpendicular to the substrate surfaces. The borings do not appear to fully penetrate the substrate.

Remarks – The emendation to the diagnosis serves to remove the size restriction that was originally placed on the apertures (see Pickerill, 1994; Bertling *et al*., 2006).

***Oichnus paraboloides* Bromley, 1981**
Pl. 3, fig. 2.

Material – Five specimens, including RGM 211 611.3, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (After Bromley, 1981, p. 62.) "*Oichnus* having a spherical paraboloid form, truncated in those cases where the boring penetrates right through the substrate. Where it does not so penetrate, the paraboloid may be deformed by a slightly raised central boss."

Description – Simple borings resembling overturned cones with the apexes truncated. The structures are perpendicular to the substrate surface. The proximal diameters average 140 µm while the distal ones average 70 µm.

***Oichnus simplex* Bromley, 1981**
Pl. 3, fig. 6.

Material – One hundred and forty three specimens, including RGM 211 614, locality *a* (Fig. 1), Somerset Formation and nine specimens, locality *c* (Fig. 1), Montpelier Formation.

Diagnosis – (After Bromley, 1981, p. 60.) "Circular to subcircular holes of biogenic origin bored into hard substrates. The holes may pass right through the substrate as a penetration, where the substrate is a thin shell; or end within the substrate as a shallow to deep depression or short, subcylindrical pit."

Description – Circular to oval, vertically oriented borings. The majority of these borings do not totally penetrate the substrate. Diameters vary between 70-350 µm.

***Oichnus* isp.**
Pl. 4, fig. 1.

Material – Single specimen, RGM 211 604.2, locality *a* (Fig. 1), Somerset Formation.

Description – *Oichnus* having a heart-shaped opening. The margin is perpendicular to the substrate surface. The tip to tip length is 130 µm and the width at its broadest section is 120 µm.

Remarks – *Oichnus* ispp. are essentially easily recognizable. However, *Oichnus* isp., described herein, adds a new morphological variation to the expanding list of existing *Oichnus* ispp. Ichnospeciation was precluded as the specimen did not conform to the morphology of previously established ichnospecies and, without sufficient specimens, formulation of a new ichnospecies is not warranted.

Ichnogenus *Planobola* Schmidt, 1992

Type ichnospecies – *Planobola microgota* Schmidt, 1992.

Diagnosis – (Translated from the original German; Schmidt, 1992, p. 50.) "Spheroid or bulbous boring systems with latitudinal contact to the substrate surface."

***Planobola microgota* Schmidt, 1992**
Pl. 4, fig. 2.

Material – Single specimen, RGM 211 614, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Translated from the original German; Schmidt, 1992, p. 51.) "Spheroids with latitudinal contact to the substrate surface via vertical tubules."

Description – Coarse spherical-shaped boring system having an average diameter of 2·5 µm. Each spheroid is in latitudinal contact with the substrate though the connecting tubules were not observed.

Remarks – The ichnogenus *Planobola* was formulated, albeit without due consideration of sufficiently defined ichnotaxobases, along with four ichnospecies, namely *P. microgota* (type ichnospecies), *P. radicatus* Schmidt, 1992, *P. cebolla* Schmidt, 1992, and *P. macrogota* Schmidt, 1992. It is clear from the translated diagnosis of *P. macrogota* (gangsystem, deviates from the other spheroids by larger diameter) that its dimensions were the only ichnotaxobase used to distinguish this ichnospecies from *P. microgota*. However, this is regarded as a poor ichnotaxobase (Pickerill, 1994; Bertling *et al.*, 2006). As such, we recommend that *P. macrogota* be assigned as a junior synonym of *P. microgota* due to the inability to recognize or distinguish each ichnospecies as separate entities with confidence.

Ichnogenus *Podichnus* Bromley & Surlyk, 1973

Type ichnospecies – *Podichnus centrifugalis* Bromley & Surlyk, 1973.

Diagnosis – (Emended after Bromley & Surlyk, 1973, pp. 363, 364.) More or less compact groups of pits or cylindrical holes in hard, calcareous substrates. The pits at the centre of the group are more or less perpendicular to the surface; the more peripheral pits typically deeper and larger, entering the substrate obliquely and centrifugally.

Remarks – The emendation was deemed necessary to exclude the size constraints from the diagnosis as size should not be considered an ichnotaxomic criterion (Pickerill, 1994; Bertling *et al.*, 2006).

Podichnus centrifugalis Bromley & Surlyk, 1973
Pl. 4, fig. 3.

Material – Two specimens, RGM 211 602.2, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – As for the ichnogenus.

Description – Groups of cylindrical pits and holes, ovate in outline, that are essentially vertically oriented. Groupings of four and six are observed. The spacing between individual holes and pits vary between each other and between each sample. Diameters of individual holes or pits vary, ranging from 220-440 μm for *Podichnus* having groupings of four and between 20-60 μm for groupings of six.

Ichnogenus *Ramosulcichnus* Hillmer & Schulz, 1973

Type ichnospecies – *Polydora biforans* Gripp, 1967.

Diagnosis – (Translation from the original German; after Hillmer & Schulz, 1973, p. 9.) "Long, blindly ending, slightly curved, tubular boring. Cross-section of the distal end is weakly dumbbell to oval-shaped. At the proximal end (mouth) 2 or 4 very narrow, deeply notched, outward diverging furrows may occur."

Ramosulcichnus biforans Hillmer & Schulz, 1973
Pl. 4, fig. 4.

Material – Four specimens, RGM 211 611.4, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Translation from the original German; after Hillmer & Schulz, 1973, p. 10) "Long, blindly ending, slightly curved, tubular boring. Cross-section of the distal end is weakly dumb-bell to oval-shaped. At the proximal end of the trace four parallel rows of dimple-shaped chambers may occur."

Description – Borings Y-shaped with circular apertural openings. The diameter of each aperture on individual specimens is constant. For the figured specimen the diameter is *c*. 110 µm. The borings are perpendicular to the substrate surface.

Remarks – The distal extremities of the borings were not observed, preventing a description of these areas, as no vertical sections were available. However, this has not prevented confident identification because it is clear that both apertures do connect and the borings are Y-shaped.

Ichnogenus *Reticulina* Radtke, 1991

Type ichnospecies – *Reticulina elegans* Radtke, 1991.

Diagnosis – (Translation from the original German; after Radtke, 1991, p. 68.) "Closely meshed, complex network system parallel to the substrate surface consisting of dichotomous vertical and zigzag branching tunnels."

Reticulina elegans Radtke, 1991
Fig. 5.

Material – A single specimen, UWIGM 2005.35, locality *b* (Fig. 1), Moneague Formation and three specimens, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Translation from the original German; after Radtke, 1991, p. 68.) "Thin linear tunnels parallel to the substrate's surface having multiply dichotomous branches. Swelling occurs at or near the branching nodes."

Description – *Reticulina* is characterized by multibranched, 2-4 branches per canal, linear canals that are parallel to the substrate surface. These canals form

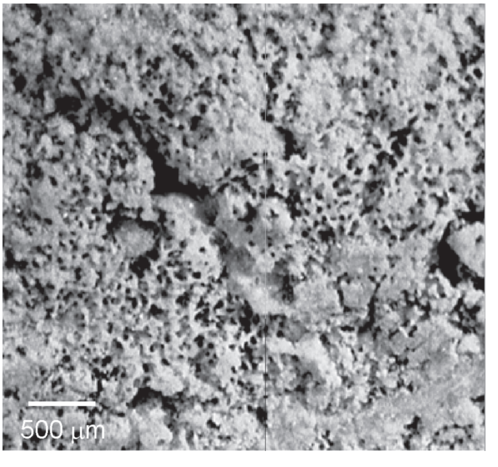

Fig. 5. *Reticulina elegans* Radtke, 1991, UWIGM 2005.35, locality *b*.

a mesh-like network. Vertical branching is sporadic and swelling occurs at a majority of the branching nodes.

Ichnogenus *Scolecia* Radtke, 1991

Type ichnospecies – *Scolecia maeandria* Radtke, 1991.

Diagnosis – (Emended after translation from the original German; after Radtke, 1991, p. 70.) Boring characterized by a complex network of predominantly curved to highly contorted or straight tubules that are either branched or unbranched. Constriction along the tubules and tiering of the tubules may or may not occur.

Remarks – The translated diagnosis is herein emended to exclude Radtke's (1991) inclusion of the temporal term *sic* "gelegentlichen" (= occasional) and to include options such as branching and tiering as diagnostic features of the ichnospecies that would best be incorporated in the diagnosis of the ichnogenus.

Scolecia filosa Radtke, 1991

Pl. 4, fig. 5.

Material – Single specimen, RGM 211 616, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Emended after translation from the original German; after Radtke, 1991, p. 72.) Thin, branched or unbranched, slightly curved to vermiform boring lying beneath the substrate's surface. Tiering may or may not occur.

Description – Multitiered, multibranched, complex network system having straight to slightly curved, thin tubules with average diameter of 116 μm. The total length of the network system is 3·5 mm with a thickness of 900 μm. Branching nodes do not show sign of swelling. Constriction is sporadic and only occurs close to the branching nodes.

Scolecia maeandria Radtke, 1991

Pl. 4, fig. 6.

Material – Two specimens, including RGM 211 615, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Emended after translation from the original German; after Radtke, 1991, p. 71.) Densely packed, curved to sinuous, vein-like network system that is parallel to the substrate surface. Constriction along the tunnels is sporadic.

Description – Complex network systems having curved to slightly contorted branching filaments that do not intersect. Average diameter of these filaments is 170 μm and the length of the network systems averages 3·3 mm. At branching nodes slight swellings occur.

Remarks – Diagnoses of the ichnospecies *S. filosa* and *S. maeandria* are emended to remove temporal and ambiguous terminologies.

Ichnogenus *Stellatichnus* Nielsen & Nielsen, 2001

Type ichnospecies – *Stellatichnus radiatus* Nielsen & Nielsen, 2001.

Diagnosis – (After Nielsen & Nielsen, 2001, p. 112.) "Biogenic holes having a star-shaped outline and situated in skeletal substrate."

***Stellatichnus radiatus* Nielsen & Nielsen, 2001**
Pl. 5, fig. 1.

Material – Single specimen, RGM 211 608.2, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (After Nielsen & Nielsen, 2001, p. 112.) "Biogenic hole characterized by a multi-radiate star-shaped outline. External opening equal to or slightly larger than internal opening. Both openings sharp in outline. Margin of hole perpendicular to external test surface or converging slightly inward in a straight manner."

Description – Five pointed star-shaped boring featuring a prominent (longer than the other four) elongate ray. Largest dimension of boring measured from longest to opposite ray is *c*. 380 µm. The margin of the boring is perpendicular to the substrate surface.

Ichnogenus *Trypanites* Mägdefrau, 1932

Type ichnospecies – *Trypanites weisei* Mägdefrau, 1932.

Diagnosis – (Modified after Bromley & D'Alessandro, 1987, p. 403.) Single entrance, cylindrical or sub-cylindrical, unbranched boring in lithic or biogenic substrates having circular cross-section throughout length. The axes of the boring may be straight, curved or irregular.

***Trypanites fimbriatus* (Stephenson, 1952)**
Pl. 5, fig. 2.

Material – Nine specimens, including RGM 211 612.3, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – Single, slightly club-shaped borings having the distal portion a little swollen; axes are straight or gently curved, generally perpendicular to the surface from which the borings originate, but in thin substrates they are forced to run parallel to it. They neither cross each other nor interpenetrate, but show avoidance growth strategies.

Description – Single, slightly curved, club-shaped, unbranched borings each parallel to the substrate surfaces. Lengths average 2·5 mm. The distal portions are swollen and taper to form semicircular terminations. The thicknesses of the borings are consistent and average 520 μm proximally; the diameter of each neck is abruptly reduced to an average diameter of 200 μm.

Remarks – No diagnosis was included in the formulation of the ichnospecies *Specus fimbriatus* Stephenson, 1952. Subsequently, we are unaware of any formal diagnosis (e.g., Bromley & D'Alessandro, 1987). Therefore, we recommend the diagnosis given above which is a summary of the descriptions provided by Stephenson (1952) and Bromley & D'Alessandro (1987).

Trypanites solitarius (Hagenow, 1840)
Pl. 5, fig. 3.

Material – Fifty two specimens, including RGM 211 617, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Emended after Bromley 1972, p. 96.) Simple, more or less cylindrical *Trypanites* with straight or gently curving course generally following close beneath the substrate surface.

Description – Essentially cylindrical, straight to curved borings oriented parallel to the substrate surfaces. Rare examples exhibit single apertural openings. The dimensions of each specimen vary with lengths ranging from 0·9-6·0 mm and diameters ranging from 60-500 μm. The distal portions taper to a blind end.

Trypanites weisei Mägdefrau, 1932
Pl. 5, fig. 4.

Material – Five specimens, including RGM 211 608.3, locality *a* (Fig. 1), Somerset Formation.

Diagnosis – (Emended after Bromley, 1972, p. 95.) More or less straight and vertical *Trypanites* penetrating hard substrates.

Description – Essentially straight, simple cylindrical borings. The borings are normally inclined at approximately 30° from vertical. Dimensions vary between individual specimens. Lengths vary between 20-75 μm and width between 1-5 μm.

Remarks – In the redefinition of the ichnogenus *Trypanites*, Bromley (1972) included dimensions as a diagnostic feature; this is considered inappropriate (see Pickerill, 1994; Bertling *et al*., 2006) and, as such, is excluded from the diagnoses of both *T. solitarius* and *T. weisei*, hence the emendations.

Problematica

crescent-shaped boring
Fig. 6.

Material – Single specimen, RGM 211 618, locality *a* (Fig. 1), Somerset Formation.

Description – Crescent-shaped, non-penetrative depression parallel to substrate surface having sharp boundaries and a constant diameter, 360 µm, along its length. Overall length of specimen is 1·2 mm.

Remarks – This ichnofossil differs from its closest morphological analogue, *Curvichnus pediformis* isp. nov., in maintaining a constant diameter along its boundaries.

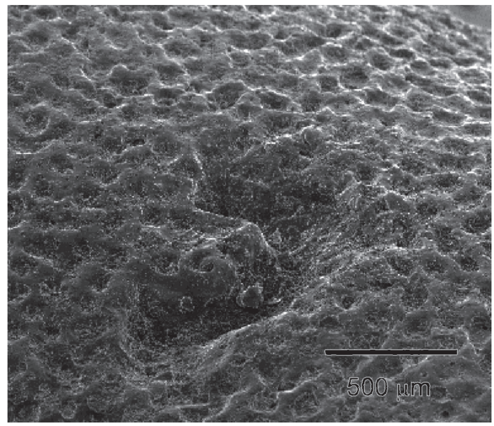

Fig. 6. Crescent-shaped boring, RGM 211 618, locality *a*.

sub-horizontal to undulatory boring
Fig. 7.

Material – Single specimen, RGM 211 619, locality *a* (Fig. 1), Somerset Formation.

Description – Sub-horizontal to undulatory horizontal boring, 1·3 mm in length, characterized by a proximal elliptical depression (to the left in Fig. 7) having dimensions of 500 µm in length, 275 µm in width and depth of *c*. 100 µm. From the distal extremity of the depression an etched 'tail' (not fully figured) arises, having a width consistent with that of the depression. The boring does not totally penetrate the substrate and the base of the proximal depression is concave.

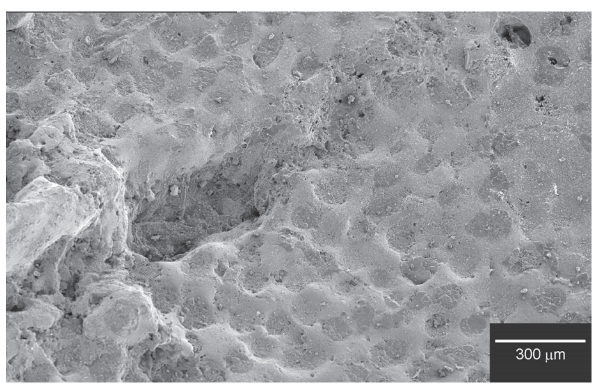

Fig. 7. Sub-horizontal to undulatory boring, RGM 211 619, locality *a*.

Remarks – We are unaware of any nominal ichnofossil that remotely resembles this specimen. With only a single specimen, formulation of a new epithet is considered inappropriate.

Acknowledgements

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Plate 1

Curvichnus pediformis isp. nov., locality *a*.
Fig. 1. Holotype, RGM 211 602.1. Figs 2-6. Paratypes, RGM 211 620, 211 621.1, 211 622, 211 623 and 211 607.1, respectively, depicting variations in shape. In (3), black and white arrows indicate *Oichnus paraboloides* Bromley, 1981, and *Oichnus simplex* Bromley, 1981, respectively.

All localities mentioned in the plates are localized in Figure 1.

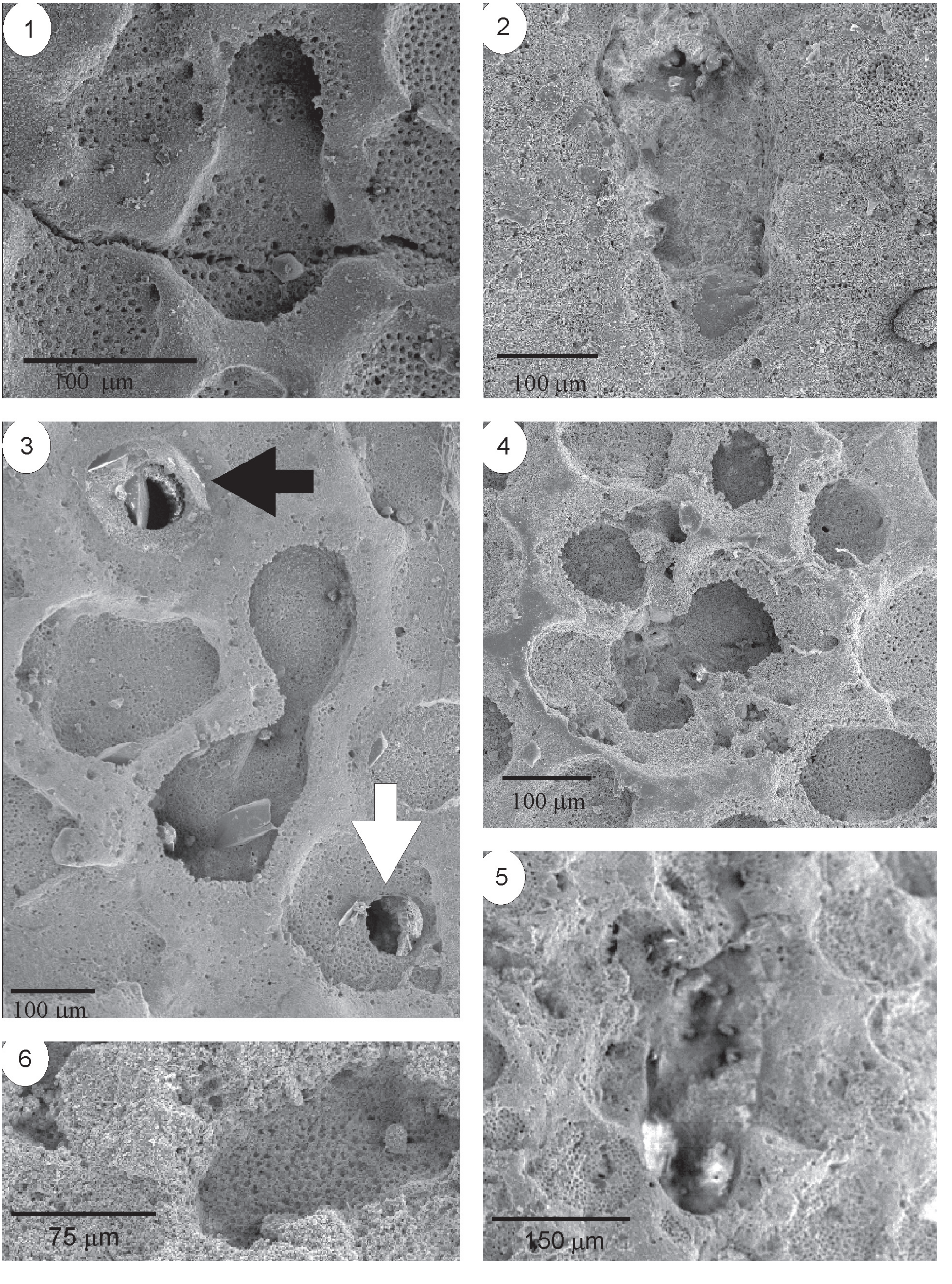
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Plate 2

Fig. 1. *Dipatulichnus rotundus* Nielsen & Nielsen, 2001, RGM 211 604.1, locality *a*.
Fig. 2. *Entobia volzi* Bromley & D'Alessandro, 1984, RGM 211 605, locality *a*.
Fig. 3. *Entobia* isp. cf. *E. ovula* Bromley & D'Alessandro 1984 (arrowed), RGM 211 606, locality *a*.
Fig. 4. *Entobia* isp. form A, UWIGM 2005.34, locality *a*.
Fig. 5. *Entobia* isp. form B, RGM 211 607.2, locality *a*.
Fig. 6. *Maeandropolydora elegans* Bromley & D'Alessandro, 1983, RGM 211 609, locality *a*.

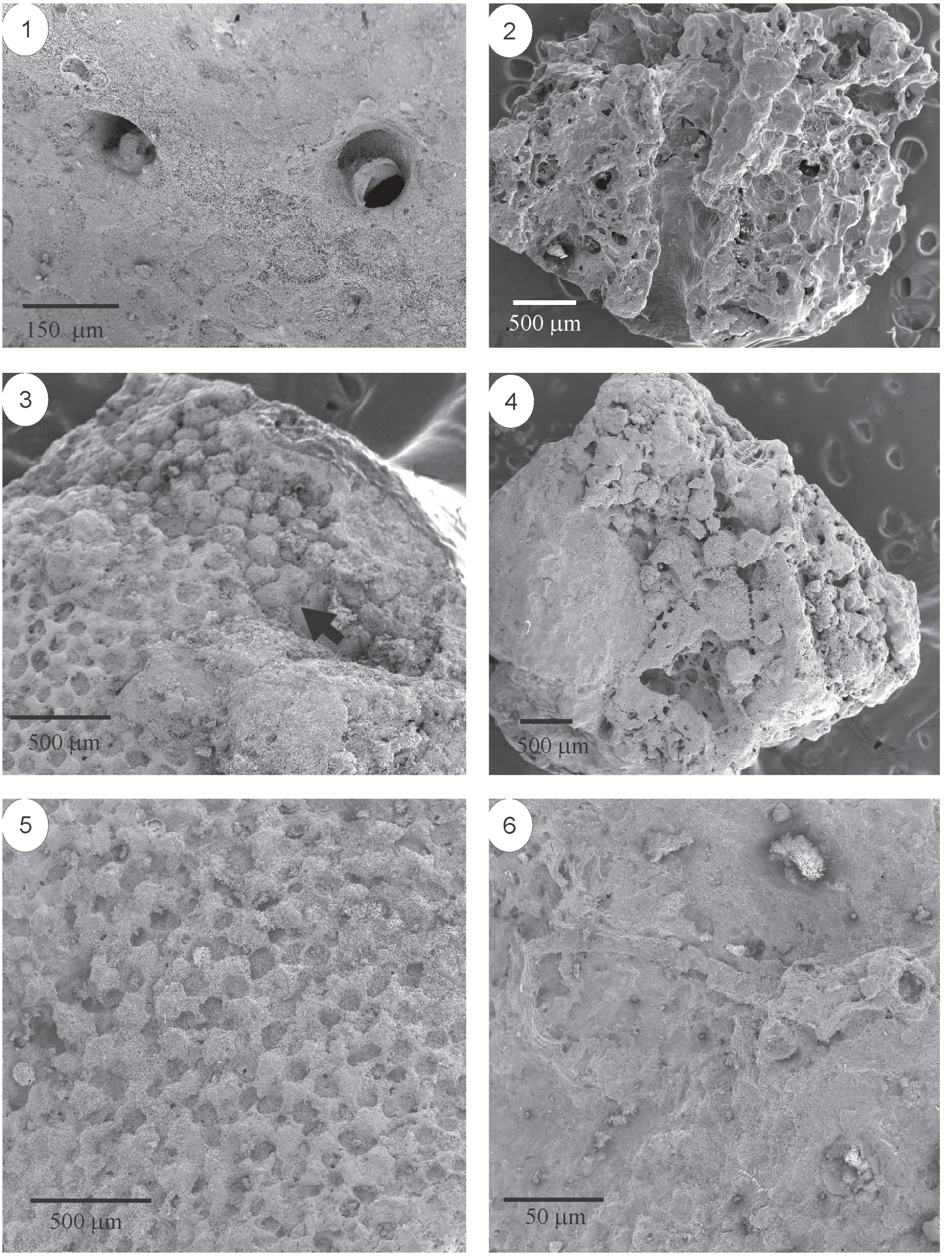
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Plate 3

Fig. 1. *Maeandropolydora sulcans* Voigt, 1965, RGM 211 610, locality *a*.
Fig. 2. *Oichnus asperus* Nielsen & Nielsen, 2001 (black arrow), RGM 211 611.1; *Oichnus ovalis* Bromley, 1993 (top right hand corner), RGM 211 611.2; and *Oichnus paraboloides* Bromley, 1981 (white arrow), RGM 211 611.3, locality *a*.
Fig. 3. *Oichnus excavatus* Donovan & Jagt, 2002, RGM 211 612.1, locality *a*.
Fig. 4. *Oichnus gradatus* Nielsen & Nielsen, 2001, RGM 211 612.2, locality *a*.
Fig. 5. *Oichnus ovalis* Bromley, 1993, RGM 211 602.3, locality *a*.
Fig. 6. *Oichnus simplex* Bromley, 1981, RGM 211 613, locality *a*.

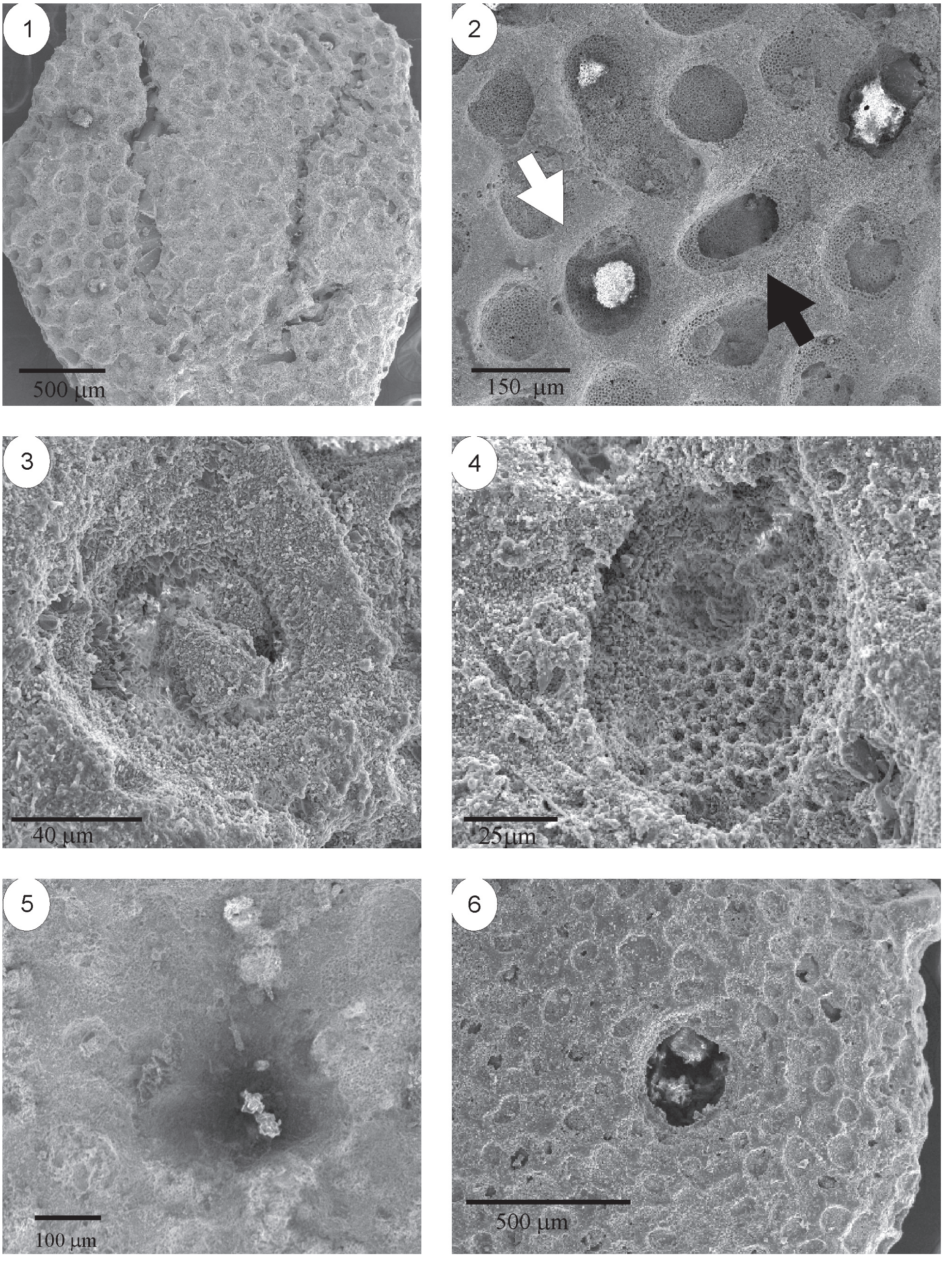
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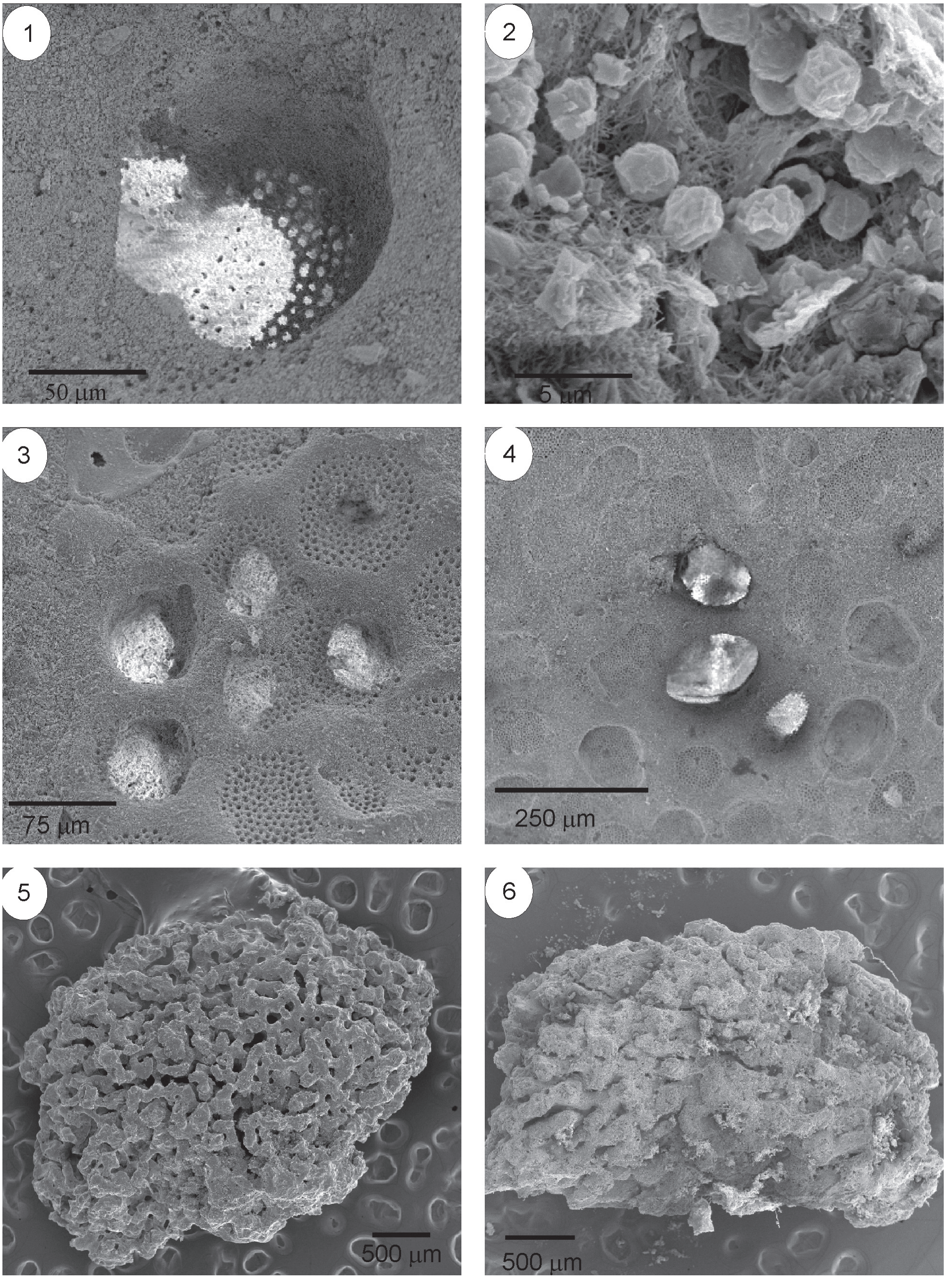
Plate 4

Fig. 1. *Oichnus* isp., RGM 211 604.2, locality *a*.
Fig. 2. *Planobola microgota* Schmidt, 1992, RGM 211 614, locality *a*.
Fig. 3. *Podichnus centrifugalis* Bromley & Surlyk, 1973, RGM 211 602.2, locality *a*.
Fig. 4. *Ramosulcichnus biforans* Hillmer & Schulz, 1973, RGM 211 611.4, locality *a*.
Fig. 5. *Scolecia filosa* Radtke, 1991, RGM 211 616, locality *a*.
Fig. 6. *Scolecia maeandria* Radtke, 1991, RGM 211 615, locality *a*.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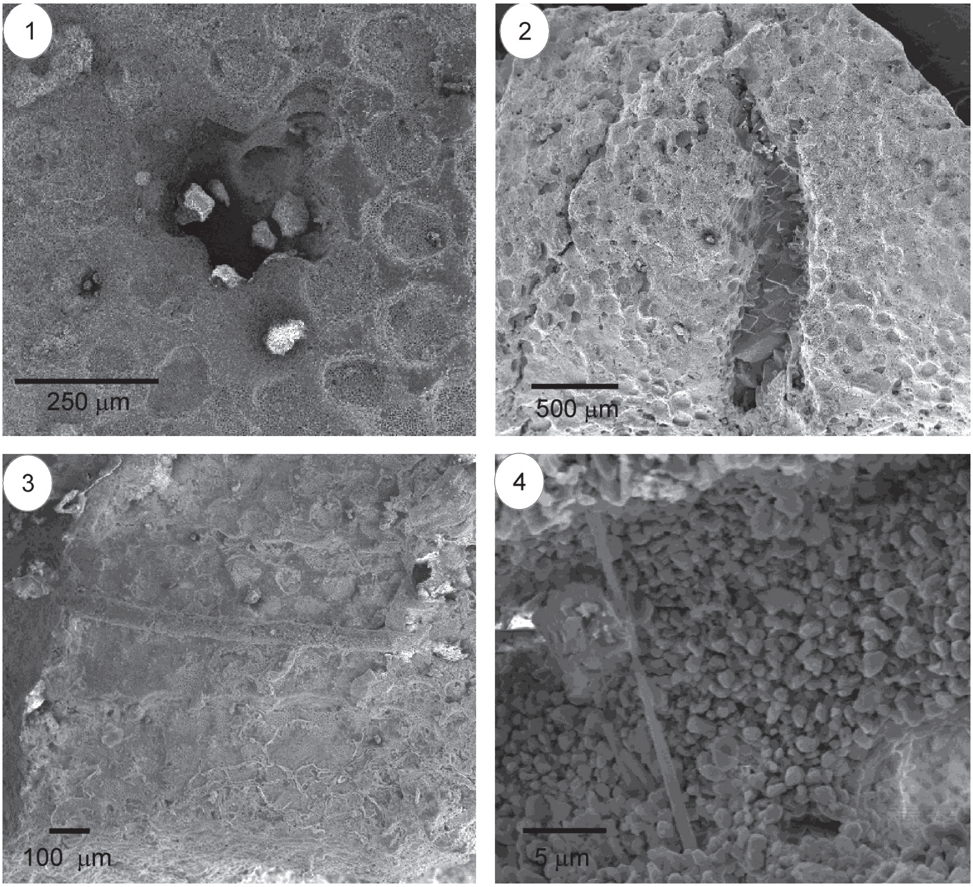

Plate 5

Fig. 1. *Stellatichnus radiatus* Nielsen & Nielsen, 2001, RGM 211 608.2, locality *a*.
Fig. 2. *Trypanites fimbriatus* (Stephenson, 1952), RGM 211 612.3, locality *a*.
Fig. 3. *Trypanites solitarius* (Hagenow, 1840), RGM 211 617, locality *a*.
Fig. 4. *Trypanites weisei* Mägdefrau, 1932, RGM 211 608.3, locality *a*.