Soft-sediment ichnotaxa from the Cenozoic White Limestone Group, Jamaica, West Indies

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Blissett, D.J. & Pickerill, R.K. Soft-sediment ichnotaxa from the Cenozoic White Limestone Group, Jamaica, West Indies. *Scripta Geologica*, **127**: 341-378, 3 figs, 11 pls, 1 table, Leiden, May 2004.
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Key words – systematics, burrows, West Indies, Jamaica, Cenozoic, Eocene-Miocene.
Jamaica, the third largest of the Greater Antillean islands, exposes various lithological units that are dominated by Cenozoic carbonate rocks including those of the mid-Cenozoic White Limestone Group. This Group is comprised of six formations, the Troy, Swanswick, Somerset, Moneague, Montpelier and Pelleu Island formations. An uncommon but moderately diverse, poorly to moderately preserved soft-sediment ichnofauna is described herein from several of these, namely the Moneague, Montpelier and Pelleu Island formations, which have yielded 15 ichnogenera represented by 27 ichnospecies. These are: *Bergaueria hemispherica*? Crimes, Legg, Marcos & Arboleya; *Chondrites furcatus* Sternberg; *Chondrites* isp.; *Circulichnus montanus* Vialov; *Dactyloidites ottoi* (Geinitz); *Dactyloidites peniculus* D'Alessandro & Bromley; *Diplocraterion* isp. cf. *D. parallelum* Torell; *Glockerichnus parvula* (Książkiewicz); *Helminthopsis hieroglyphica* Wetzel & Bromley; *Ophiomorpha nodosa* Lundgren; *Palaeophycus herberti* (Saporta); *Palaeophycus tubularis* Hall; *Palaeophycus* isp.; *Planolites beverleyensis* (Billings); *Planolites montanus* Richter; *Planolites* isp.; *Schaubcylindrichnus coronus* Frey & Howard; *Scolicia prisca* Quatrefages; *Scolicia strozzii* Savi & Meneghini; *Taenidium cameronensis* (Brady); *Taenidium serpentinum* Heer; cf. *Taenidium barretti* (Bradshaw); *Thalassinoides horizontalis* Myrow; *Thalassinoides paradoxicus* (Woodward); *Thalassinoides* isp.; *Trichichnus linearis* Frey; and *Trichichnus simplex* Fillion & Pickerill. Various processes such as dolomitization, lack of bedding plane surfaces, lack of contrasting lithologies precluding toponomic preservation, case hardening and chertification may, individually or in combination, be responsible for the variable ichnofaunal diversity within and between the various formations of the White Limestone Group.

Contents

Introduction

Jamaica, the third largest of the Greater Antillean islands, West Indies, lies in the Caribbean Sea south of the island of Cuba and west of the island of Hispaniola (Fig. 1). Geologically, Cenozoic carbonate rocks, including the Middle Eocene to Middle Miocene White Limestone Group, dominate the island. This sequence overlies the Middle Eocene Yellow Limestone Group and underlies the Middle Miocene to Pleistocene Coastal Group (Fig. 2), and represents between 60-65% of the surface outcrop of Jamaica (Robinson, 1994; Mitchell, 2004).

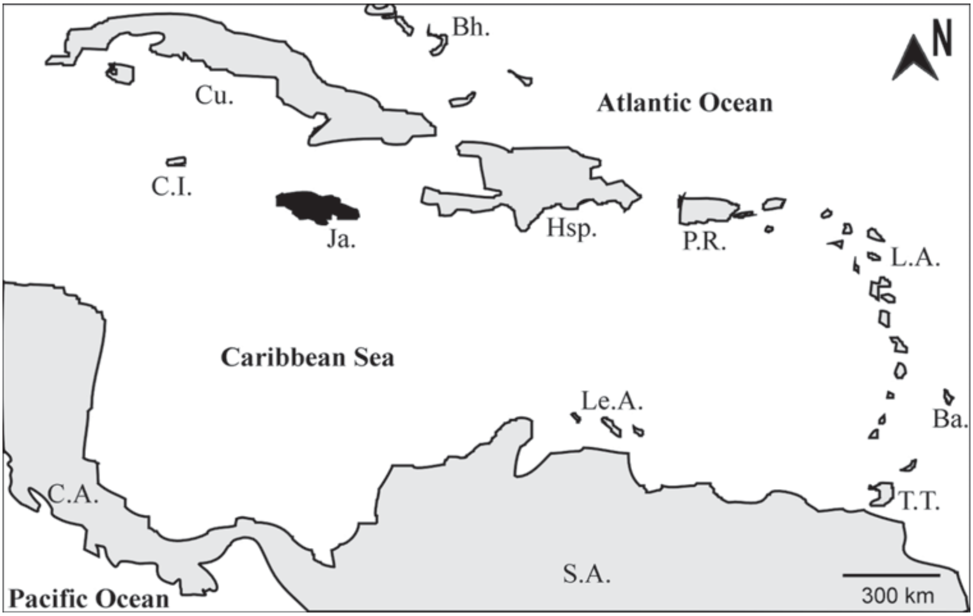

Fig. 1. Geographical map of the West Indies. Key to the land masses: Ba.=Barbados; Bh.=Bahamas; C.A.=Central America; C.I.=Cayman Islands; Cu.=Cuba; Hsp.=Hispaniola; Ja.=Jamaica (in black); L.A.=Lesser Antilles; Le.A.=Leeward Antilles; P.R.=Puerto Rico; S.A.=South America; T.T.=Trinidad and Tobago. (Modified after Pindell, 1994, fig. 2.1).

The White Limestone Group comprises six formations, namely the Troy, Swanswick, Somerset, Moneague, Montpelier and Pelleu Island formations, as defined by Mitchell (2004). Of these, the Montpelier and Pelleu Island formations are essentially deep water in origin, whereas the remainder were deposited in shallow water (Mitchell, 2004). The lithologies of these formations are summarized in Figure 2.

Localities and lithologies

The exposure labelled *a* (Fig. 3A, B) is located in the parish of Portland, approximately 4.5 km south of the town of Buff Bay, on the western bank of the Buff Bay River which parallels the Buff Bay to Newcastle mainroad. There, the exposure occurs within the upper Lower to Middle Miocene Pelleu Island Formation (Steineck, 1974), and consists of mottled, compact, medium-bedded (100-300 mm thick), fine- to medium-grained, bioclastic, cream-coloured, chalky limestones interbedded with poorly consolidated, thinly bedded (30-100 mm), cream-coloured calcareous mudstones that lack macrofossils.

Exposure *b* (Fig. 3A, C) is located in the parish of St. Ann, approximately 8 km south of Brown's Town along the Brown's Town to Alexandria mainroad in a disused bauxite pit. At this locality, the Lower Oligocene to Middle Miocene Moneague Formation is exposed as massive beds comprising sparsely fossiliferous micrites and sparry calcite (Mitchell, 2004).

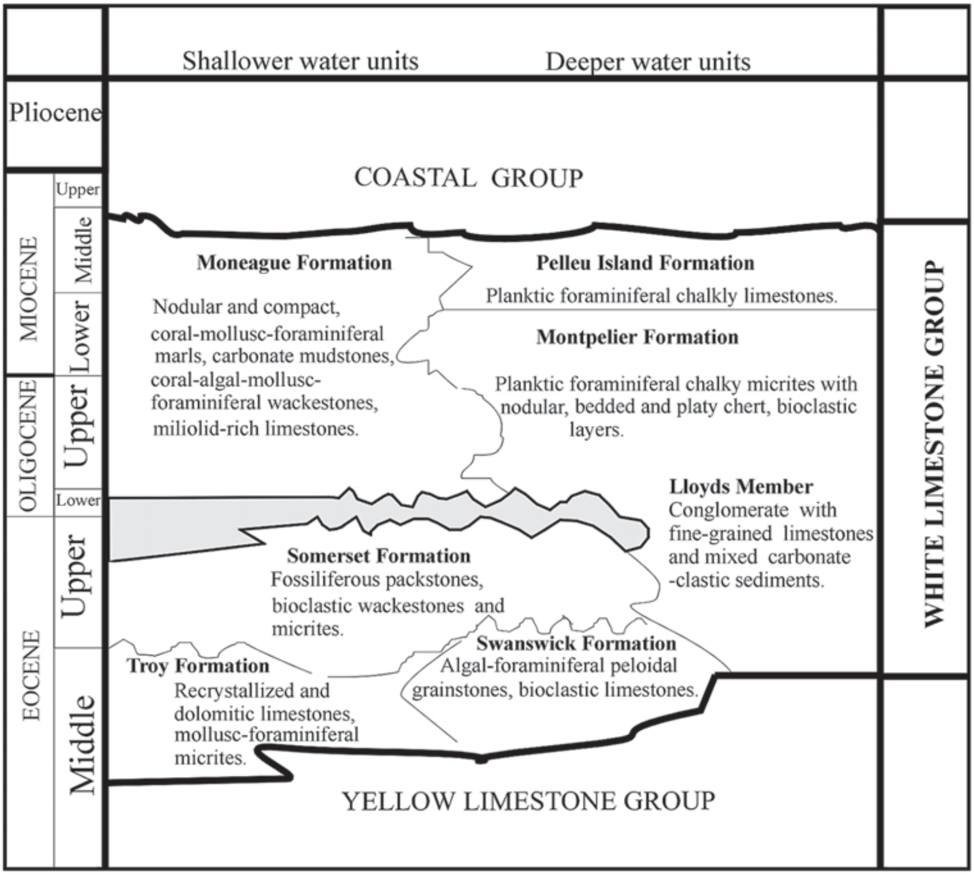

Fig. 2. Middle Eocene to Middle Miocene lithostratigraphic units of the White Limestone Group, Jamaica (adapted from Blissett & Pickerill, 2003b), also showing the relationship of the overlying Coastal Group and the underlying Yellow Limestone Group.

Exposure *c* (Fig. 3A, D) is located in the parish of Trelawny, approximately 5 km west of the town of Duncans, along the Duncans to Montego Bay mainroad in a disused quarry. This locality exposes the Lower Miocene Montpelier Formation (Steineck, 1974; Robinson & Mitchell, 1999). The lithologies consist of 0.5-2.0 m thick layers of fine- to very coarse-grained chalky limestones interbedded with greyish calcareous mudstones and bedded chert, thin bioclastic limestones, and extraclastic coral-rich rudstones-floatstones (Blissett & Pickerill, 2004).

Exposure *d* (Fig. 3A, E) is located in the parish of Westmoreland, along the roadside in the town of Dundee below the Dundee all-age school. There, the Middle Eocene to Lower Miocene Montpelier Formation (Steineck, 1974; Robinson & Mitchell, 1999; Mitchell, 2004) consists of unconsolidated and consolidated, white to cream coloured, fine- to medium-grained chalky limestones interbedded with nodular and bedded cherts.

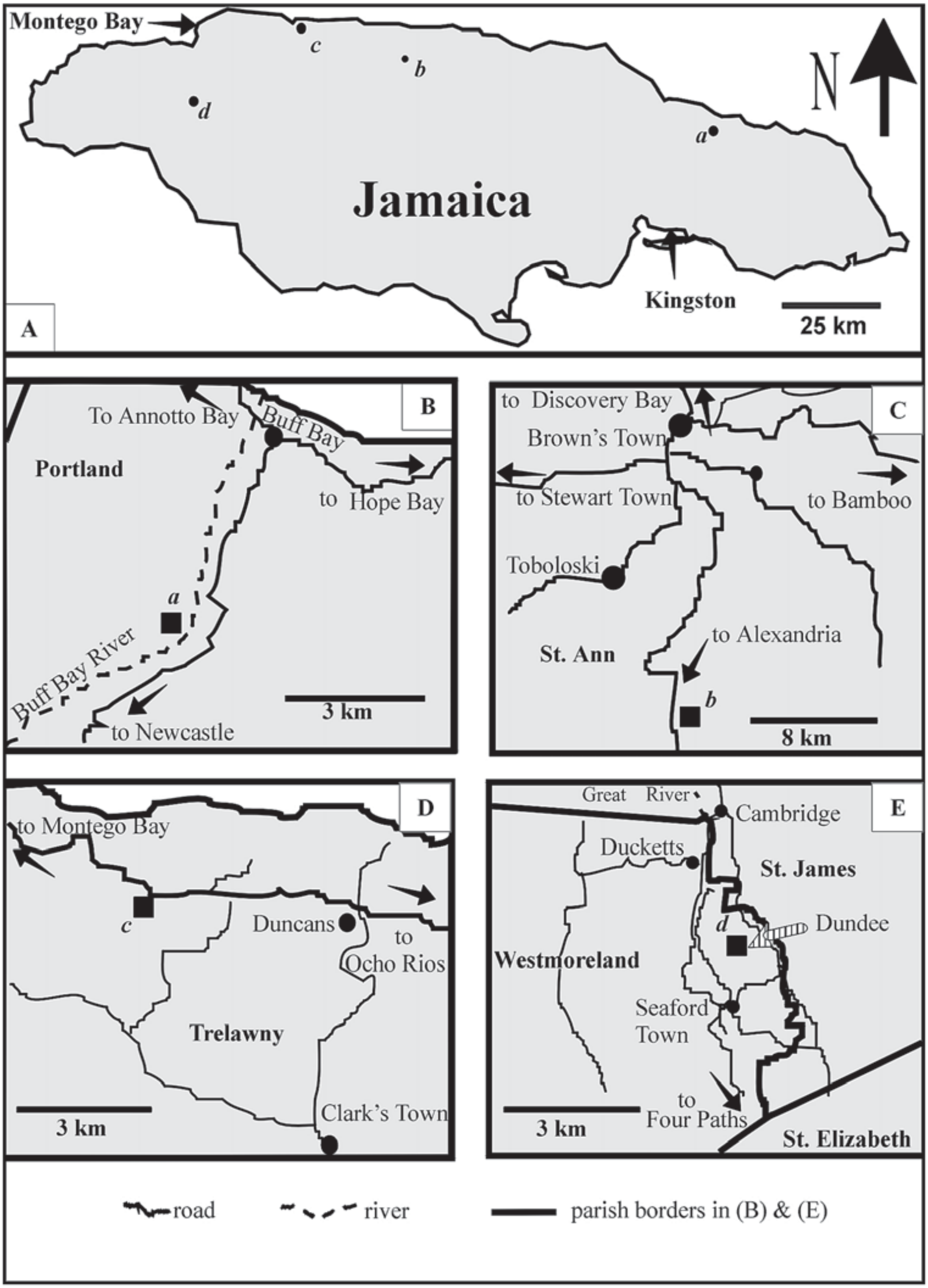

Fig. 3. (A) An outline map of Jamaica depicting the location of four sites within the White Limestone Group labelled *a-d*. (B-E) Detailed road maps of these four areas within which the sites labeled *a-d* are located. Key: shading=land; blank=Caribbean Sea.

Table 1. Distribution of soft-sediment ichnotaxa in the White Limestone Group. Key: MoF=Moneague Formation; MpF=Montpelier Formation; PeF=Pelleu Island Formation; X=present.

	MoF	**MpF**	**PeF**
Bergaueria hemispherica? Crimes *et al.*		X	
Chondrites furcatus Sternberg		X	
Chondrites isp.		X	
Circulichnus montanus Vialov		X	
Dactyloidites ottoi (Geinitz)		X	
Dactyloidites peniculus D'Alessandro & Bromley		X	
Diplocraterion isp. cf. *D. parallelum* Torell			X
Glockerichnus parvula (Książkiewicz)		X	
Helminthopsis hierogyphica Wetzel & Bromley		X	
Ophiomorpha nodosa Lundgren	X		
Palaeophycus herberti (Saporta)		X	
Palaeophycus tubularis Hall		X	X
Palaeophycus isp.			X
Planolites beverleyensis (Billings)	X	X	X
Planolites montanus Richter		X	X
Planolites isp.			X
Schaubcylindrichnus coronus Frey & Howard			X
Scolicia prisca Quatrefages			X
Scolicia strozzii Savi & Meneghini			X
Taenidium cameronensis (Brady)		X	
Taenidium serpentinum Heer		X	X
cf. *Taenidium barretti* (Bradshaw)			X
Thalassinoides horizontalis Myrow		X	X
Thalassinoides paradoxicus (Woodward)		X	
Thalassinoides isp.		X	
Trichichnus linearis Frey			X
Trichichnus simplex Fillion & Pickerill			X

Systematic ichnology

The White Limestone Group contains an uncommon but moderately diverse, poor to moderately preserved soft-sediment ichnofauna (Blissett & Pickerill, 2003a, b) and also uncommon but relatively diverse, bioerosional structures (borings) (see Blissett & Pickerill, 2003c, 2004 for details). Prior to this contribution the only other soft-sediment ichnotaxon documented in detail from the White Limestone Group of Jamaica was *Schaubcylindrichnus coronus* Frey & Howard, 1981 (Blissett & Pickerill, 2003b). Further observations on the soft-sediment ichnotaxa have indicated the presence of 14 additional ichnogenera represented by 26 ichnospecies distributed among three of the six formations, namely the Pelleu Island, Montpelier and Moneague formations (Table 1). Detailed systematics of these ichnospecies are documented below.

For ease of reference, the descriptions of each ichnospecies are arranged alphabetically, (cf. Osgood, 1970; Pickerill & Donovan, 1991), rather than in morphological (cf. Uchman, 1995; Schlirf, 2000) or ethological (cf. Seilacher, 1964) groups. The figured material, other than that specified as field photographs, is housed in the National Natuurhistorisch Museum, Leiden (RGM 283550-283564).

To preclude unnecessary repetition, discussion on preserved ichnotaxa described herein is collectively made following the descriptions of individual ichnogenera, whether or not there are more than one ichnospecies relevant to a specific ichnogenus.

Ichnogenus *Bergaueria* Prantl, 1945

Type ichnospecies — *Bergaueria perata* Prantl, 1945, by original designation.

Diagnosis — (After Pemberton *et al*., 1988, p. 877.) "Cylindrical to hemispherical, vertical burrows possessing smooth, unornamented walls, circular to elliptical in cross-section, infillings essentially structureless, rounded base, with or without shallow central depression and radial ridges."

Bergaueria hemispherica? Crimes, Legg, Marcos & Arboleya, 1977
Pl. 1, fig. A.

Material — Ten specimens including RGM 283550.1 from locality *c* (Fig. 3D), preserved as positive semireliefs on bedded chert. Montpelier Formation.

Description — Small vertical, unornamented, plug-shaped, hemispherical, typically, circular traces without a central depression. Their diameter varies from 1-2 mm and the hemispherical forms between 1×2 - 15×30 mm.

Discussion — These plug-shaped traces are tentatively referred to as *B. hemispherica.* Definitive identification is precluded as a result of the inability to demonstrate whether or not they are preserved in hyporelief. This, as stated by Pemberton *et al*. (1988) and Uchman (1995), is necessary for positive assessment. Indeed, it is possible that these traces are distal extremities of *Thalassinoides* ispp. or alternative ichnogenera.

Ichnogenus *Chondrites* Sternberg, 1833

Type ichnospecies — *Fucoides antiquus* (Brongniart, 1828), by subsequent designation (Miller, 1889, p. 14).

Diagnosis — (After Osgood, 1970, p. 328.) "Tunnel systems possessing a small number of master shafts open to the surface, which ramify with depth to form a dendritic network. The individual branches may or may not cross over and interpenetrate."

***Chondrites furcatus* Sternberg, 1833**
Pl. 1, fig. B.

Material — One specimen, RGM 283551.1, locality *c* (Fig. 3D), preserved in positive semirelief on bedded chert. Montpelier Formation.

Description — The burrow system is preserved on bedded chert in positive semirelief. The specimen comprises a mastershaft, 0.4 mm in width, which branches into a dendritic pattern. The branches bifurcate and their thickness is similar to that of the mastershaft. The span of the burrow system is 10 mm and angle of branching is up to 40°. The branches do not cross nor are they recurved; no swellings occur at branching sites and the lengths of the branches are irregular.

Diagnosis — (After the description by Crimes & Crossley, 1991, p. 34.) Tunnel systems comprising a dendritic pattern and a prominent mastershaft. Branches do not cross, interpenetrate or curve back onto themselves. Branch angles range between 25-40°.

Remarks — Despite having being described on several occasions, both historically (e.g., Tauber, 1949; Książkiewicz, 1977) and more recently (e.g., Crimes & Crossley, 1991), Sternberg's description was never accompanied by a formal diagnosis, and indeed, to our knowledge none has subsequently been presented. We therefore propose that presented above, based on the detailed description by Crimes & Crossley (1991), as appropriate at least until a more detailed ichnotaxonomic review is undertaken.

***Chondrites* isp.**
Pl. 2, fig. A.

Material — Four specimens, including RGM 283552, locality *c* (Fig. 3D), preserved in positive semirelief on bedded chert. Montpelier Formation.

Description — Straight to slightly curved, simple branching systems consisting of a prominent mastershaft. Thickness of the branches and the mastershaft ranges between 0.4-0.5 mm. The lengths of the branches are approximately 3 mm and the branching angles range between 30-50°. Second-order branching is evident.

Discussion — The ichnogenus *Chondrites* has been the subject of a number of controversies, the latest a revision and detailed synonymy by Uchman (1999). Prior to this Fu (1991) distinguished four ichnospecies (*C. targionii* (Brongniart, 1828), *C. intricatus* (Brongniart, 1823), *C. patulus* Fischer-Ooster, 1858, and *C. recurvus* (Brongniart, 1823)). Uchman (1999), while essentially agreeing with Fu (1991), noted that not all of the nominal ichnotaxa could be synonymized within four ichnospecies. He retained *C. caespitosus* (Fischer-Ooster, 1858) and introduced *C. stellaris* Uchman, 1999. Speciation of the various ichnospecies of *Chondrites* depends on the following significant criteria; the presence or absence of a mastershaft, the angle of branching and the presence or otherwise of recurved branches (Osgood, 1970; Fu, 1991; Uchman, 1999).

Contrary to Fu (1991) and Uchman (1999), who placed *C. furcatus* in synonymy with *C. intricatus*, we have retained *C. furcatus* as a distinct ichnospecies. This is based on the lack of recurved branches as described and discussed in Crimes and Crossley (1991). The specimen of *C. furcatus*, described herein, is very similar to that of Crimes & Crossley (1991) and other authors (as noted above). It differs from *C. intricatus* Brongniart that does not exhibit a distinct mastershaft and from *C. targionii* Brongniart that has larger branching angles. The system also differs from *C. stellaris* Uchman, which is star-like; from *C. recurvus*, that exhibits branches arising on only one side of its masterbranch; and from *C. patulus* that has simpler branches at an obtuse angle to its mastershaft. *Chon-*

drites isp. exhibit a tunnel size similar to *C. intricatus*, but lack its density of branches (see Uchman, 1999), while differing from *C. targionii* whose tunnels are usually a few millimetres wide. Both *C. furcatus* and *Chondrites* isp. show no similarity to *C. caespitosus*, that possesses winding branches, and *C. aequalis*, that exhibits a larger tunnel size.

Ichnogenus *Circulichnus* Vialov, 1971 (nom. correct)

Type ichnospecies — *Circulichnis montanus* Vialov, 1971, by monotypy.

Diagnosis — (After Vialov, 1971, p. 91.) "Annular track of almost round (or oval) shape, formed by one cylinder" (*trans. litt.* from Russian).

***Circulichnus montanus* Vialov, 1971 (nom. correct)**
Pl. 2, fig. B.

Diagnosis — As for the ichnogenus.

Material — Three specimens, including RGM 283553, locality *c* (Fig. 3D), two preserved in positive semirelief and the other in negative semirelief on bedded chert. Montpelier Formation.

Description — Three unlined, unbranched specimens lacking internal structures, oval in shape and comprising well-defined connected rings that vary in thickness. The outer ring dimensions range between 10-15 mm (short diameter), and 15-19 mm (long diameter). The inner ring dimensions range between 7-12 mm (short diameter), and 10-15 mm (long diameter). They are preserved on bedded chert, two in positive and the other in negative semirelief. The infill of the former is finer in grain size than the host rock.

Discussion — Based on the ovate shape, their connectivity and preclusion of 3-dimensional examination, the specimens are included within *C. montanus* to which they best accord. Originally termed *Circulichnis* by Vialov (1971), the correct orthography is actually *Circulichnus*, as discussed by Keighley & Pickerill (1997).

Ichnogenus *Dactyloidites* Hall, 1886

Type ichnospecies — *Dactyloidites asterioides* (Fitch, 1850), by original designation.

Diagnosis — (After Fürsich & Bromley, 1985, p. 207.) "Vertical radial spreiten structure having central shaft."

***Dactyloidites ottoi* (Geinitz, 1849)**
Pl. 3, fig. A.

Diagnosis — (After Fürsich & Bromley, 1985, p. 207.) "*Dactyloidites* having branched radial to subradial protrusive spreiten."

Material — Four specimens, RGM 283554.1 from locality *c* (Fig. 3D), preserved in positive semirelief and in full relief (Pl. 3, fig. A) on bedded chert. Montpelier Formation.

Description — Partially preserved rosette-shaped burrows, comprising radial segments preserved in positive semirelief that radiate from a central shaft. The radial segments are slightly curved, branch and fan out to less than a half circle. The inter-radial spaces are widest at the distal extremities and taper as they approach the centre. The radial segments are more or less equal in diameter where no branching exists. Where branching occurs their diameter varies. The central shafts are cylindrical and protrude from the horizontal surface at an angle of approximately 40°. No sediment disturbance is present at or near their centre and it cannot be ascertained whether or not vertical spreiten are present.

***Dactyloidites peniculus* D'Alessandro & Bromley, 1986**
Pl. 3, fig. B.

Diagnosis — (After D'Alessandro & Bromley, 1986, pp. 79-80.) "A *Dactyloidites* having numerous, regular, symmetrically radiating branches, themselves apparently unbranched and containing a limited retrusive spreite."

Material — One specimen, RGM 283554.2, locality *c* (Fig. 3D), preserved in positive semirelief on bedded chert. Montpelier Formation.

Description — Penicilliform trace fossil, 30 mm in diameter, having curved spreiten that radiate from a common, indistinct, central point. The specimen is intersected by subsequent *Planolites* and *Palaeophycus* burrows, thus precluding detailed observation of spreiten.

Discussion — *Dactyloidites ottoi* differs from *D. asterioides* (Fitch, 1850), whose arrangement of spreiten is protrusive and with radial elements shaped like strongly recurved Js (Fürsich & Bromley, 1985), and from *D. canyonensis* (Bassler, 1941), whose spreiten arrangement is retrusive and with radial causative burrows that are widely spaced without branching (Fürsich & Bromley, 1985). *Dactyloidites peniculus* are penicilliform burrows with numerous, regular, symmetrically radiating branches containing limited retrusive spreite (D'Alessandro & Bromley, 1986). Although the radiating branches are not evident in this specimen, it is closely similar to the example figured in D'Alessandro & Bromley (1986, fig. 3, p. 95) and, accordingly, is identified as such.

Ichnogenus *Diplocraterion* Torell, 1870

Type ichnospecies — *Diplocraterion parallelum* Torell, 1870, by subsequent designation (Matthew, 1891, p. 163).

Diagnosis — (After Fürsich, 1974, p. 958.) "Vertical U-shaped spreiten burrows; dwelling burrows of suspension-feeders."

Diplocraterion isp. cf. *Diplocraterion parallelum* Torell, 1870
Pl. 4, fig. A.

Material — One specimen, RGM 283555.1, locality *a* (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Description — A vertical cross-section of an apparent J- or U-shaped burrow containing unidirectional spreiten with sediment fill darker in colour than the surrounding sediment type. The diameter of the vertical tube is constant at 4 mm with length of 35 mm. The lower extremity is curved with an abrupt termination on the vertical face. On the upper bedding plane surface the trace is oval-shaped with widest diameter 7 mm and narrowest 4 mm and possibly represents the burrow aperture.

Discussion — Ichnospeciation is based on the orientation of the long axis of the oval-shaped section of the J- or U-shaped burrow. This vertical section was unintentionally cut at a very acute angle; hence, its apparent vertical representation is not totally obvious. *Diplocraterion* isp. as described herein differs from *Diplocraterion helmerseni* (Öpik, 1929) and *Diplocraterion biclavatum* (Miller, 1875), as these latter ichnospecies exhibit features which deviate from the normal smooth U-tube (see Fürisch, 1974). It also differs from *Diplocraterion polyupsilon* Smith, 1893, that exhibits bi-directional spreiten, and *Diplocraterion habichi* (Lisson, 1904), that has diverging apertures. Therefore, as described above the only closest comparative ichnospecies to the specimen from Jamaica is *Diplocraterion parallelum*.

Ichnogenus *Glockerichnus* Pickerill, 1982

Type ichnospecies — *Glockeria glockeri* Książkiewicz, 1968, by original designation.

Diagnosis — (After Książkiewicz, 1977, p. 100.) "Hypichnial star-shaped form consisting of ribs radiating from a center, to which all or some of the ribs are joined. Small ribs may intercalate between the main ribs. Outline of the star is irregularly circular."

Remarks — Pickerill (1982) pointed out that the descriptor *Glockeria* was unavailable, having previously been utilized for a phacopid trilobite, and proposed *Glockerichnus* as an appropriate replacement name, particularly to retain the sense of Książkiewicz's etymology.

Glockerichnus parvula (Książkiewicz, 1970)
Pl. 4, fig. B.

Diagnosis — (After Książkiewicz, 1977, p. 102.) "Hypichnial small stellate cast, consisting of a central cone from which radiate a few short straight thin ribs. A tiny crater-like pit is situated at the top of the cone."

Material — Three specimens, RGM 283554.3, locality *c* (Fig. 3D), preserved in positive semirelief on bedded chert. Montpelier Formation. The specimens are at best only partially preserved.

Description — Star-shaped burrows comprising a central ring, having an outer diameter of between 2-3 mm and inner diameter ranging from 1-2 mm, with radiating elements which together outline an irregular circle. The radial elements are branched with varying thickness between each radiating element and lengths of up to 6 mm.

Discussion — Ichnospeciation of *Glockerichnus* is based on the shape, dimension and density of the ribbing (Książkiewicz, 1968). The forms described herein differ from its other ichnospecies as follows: *G. alata* (Seilacher, 1977) and *G. glockeri* (Książkiewicz, 1970) both possess U-shaped bifurcating ribs, the former also being large while the latter possesses numerous string-sized ribs; *G. dichotoma* (Seilacher, 1977) has branched V-shaped bifurcating ribs; *G. disordinata* (Książkiewicz, 1977) is characterized by winding riblets; and *G. sparsicostata* (Książkiewicz, 1968) is characterized by few ribs.

Ichnogenus *Helminthopsis* Heer, 1877

Type ichnospecies — *Helminthopsis magna* Heer, 1877, by subsequent designation (Ulrich, 1904, p. 144).

Diagnosis — (After Fillion & Pickerill, 1990, p. 36.) "Unbranched, irregularly winding or meandering, horizontal burrows or trails that do not touch or cross themselves. Only one order of meandering may be present. Burrow-fill massive."

***Helminthopsis hieroglyphica* Wetzel & Bromley, 1996**
Pl. 5, fig. A.

Diagnosis — (After Han & Pickerill, 1995, p. 109.) "*Helminthopsis* in which the windings, normally wide and low, comprise straight segments interspersed with irregularly sinous and variably developed segments. The tortuous segments may be bell-shaped but not horseshoe-shaped. The full course is commonly, though not exclusively, alternately winding and straight."

Material — Two specimens, RGM 283556, locality *c* (Fig. 3D), preserved in positive semirelief on bedded chert. Montpelier Formation.

Description — Horizontal, string-like, curved traces, approximately 0.5 mm wide, that exhibit straight segments, albeit only partially preserved. Each preserves alternating straight and curved segments throughout their course.

Discussion — Of the various ichnospecies of *Helminthopsis* distinguished by Han & Pickerill (1995) and Wetzel & Bromley (1996), the Jamaican material can clearly be assigned to *H. hieroglyphica*. *Helminthopsis abeli* Książkiewicz, 1977, possesses irregular open meanders and horseshoe-like turns, *H. tenuis* Książkiewicz, 1968, has irregular, high amplitude windings, but only with U-turns and no horseshoe-like turns, and *H. granulata* Książkiewicz, 1968, is variably and irregularly loosely meandering, but is also characterized by an external ornament of warts and ridges that parallel the burrow axis.

Ichnogenus *Ophiomorpha* Lundgren, 1891

Type ichnospecies — *Ophiomorpha nodosa* Lundgren, 1891, by monotypy.

Diagnosis — (After Frey *et al*., 1978, p. 222.) "Simple to complex burrow systems distinctly lined with agglutinated pelletoidal sediment. Burrow lining more or less smooth interiorly, densely to sparsely mamillated or nodose exteriorly. Individual pellets or pelletal masses may be discoid, ovoid, mastoid, bilobate, or irregular in shape. Characteristics of the lining may vary within a single specimen."

Remarks — There have been a number of debates as to the significance of the morphologically similar ichnogenera *Ophiomorpha*, *Thalassinoides* and *Spongeliomorpha*. Fürsich (1973) assigned *Thalassinoides* and *Ophiomorpha* to the ichnogenus *Spongeliomorpha.* Bromley & Frey (1974) suggested that *Spongeliomorpha* be abandoned because they considered it a synonym of *Thalassinoides***.** Uchman (1995), while noting that intergradation between *Ophiomorpha* and *Thalassinoides* was common, enigmatically still retained them as separate ichnotaxa. More recently, Schlirf (2000) synonymized *Ophiomorpha* and *Thalassinoides* with *Spongeliomorpha*, in part because he observed intergradation, which he interpreted as a result of substrate consistency. Notwithstanding these nomenclatural debates, for the purpose of this contribution *Ophiomorpha* and *Thalassinoides* are herein retained in agreement with Bromley & Frey (1974) and Uchman (1995, 1999).

Ophiomorpha nodosa **Lundgren, 1891**
Pl. 5, fig. B.

Diagnosis — (After Frey *et al*., 1978, p. 225.) "Burrow walls consisting predominantly of dense, regularly distributed discoid, ovoid or irregular polygonal pellets."

Material — One specimen, RGM 283557, locality *b* (Fig. 3C), preserved in full relief. Moneague Formation.

Description — Inclined, unbranched, cylindrical burrow having an ellipsoidal cross-section. The width along its longest diameter varies between 24-35 mm and is approximately 20 mm across its shortest diameter. The length of the specimen, albeit only partially exposed, is 75 mm. Varying sizes of irregular ovoid, nodose pellets are distributed regularly around the exposed surface. The opposite side of the sample does not preserve pellets or pellet-like structures and is relatively smooth.

Discussion — It is always difficult to identify an imperfectly preserved *Ophiomorpha*-like specimen, as it tends to lose its nodose morphology either when transitional with *Thalassinode*s ispp. (D'Alessandro & Bromley, 1986; Uchman, 1995) or as a result of extensive tropical weathering.

Ichnogenus *Palaeophycus* Hall, 1847

Type ichnospecies — *Palaeophycus tubularis* (Hall, 1847), by subsequent designation (Miller, 1889, p. 130).

Diagnosis — (Emended after Pemberton & Frey, 1982, p. 852; Fillion & Pickerill, 1984, pp. 19-20, 1990, p. 43; and recommendations by Keighley & Pickerill, 1995.) Essentially cylindrical, predominantly sub-horizontal, straight or slightly curved or slightly undulose, ornamented or smooth, branched or unbranched, lined burrows. Bifurcation is not systematic, nor does it result in swelling at the ramification points. The burrows do not systematically wind, meander or coil. Burrow fill typically massive, similar to host rock.

Remarks — The above citations represent a combination of the most recent diagnoses, or recommendations, of *Palaeophycus*. We have collectively combined the various criteria proposed by these authors, that individually include some but not all of these criteria. In so doing we provide a more comprehensive definition of the ichnotaxon than previously available.

Palaeophycus herberti (Saporta, 1872)
Pl. 6, fig. A.

Diagnosis — (After Pemberton & Frey, 1982, p. 861.) "Smooth, unornamented, thickly lined cylindrical burrows."

Material — Two specimens, including RGM 283558.1, locality *c* (Fig. 3D), preserved in full relief in bedded chert. Montpelier Formation.

Description — Unornamented, smooth and thickly lined cylindrical burrows preserved in full relief. The lining in one specimen comprises reddish-brown chert while the infill consists of chalky limestone, similar to the surrounding host rock. In the other specimen both the infill and the lining comprise reddish-brown chert with the infill having a lighter colouration than the lining. The thickness of the lining in each specimen (4 and 5 mm, respectively) is consistent, but varies between specimens with the total burrow diameters being 13 and 18 mm, respectively.

Palaeophycus tubularis Hall, 1847
Pl. 3, fig B; Pl. 4, fig. A; Pl. 6, fig. B.

Diagnosis — (After Pemberton & Frey, 1982, p. 859.) "Smooth, unornamented burrows of variable diameter, thinly but distinctly lined."

Material — Four specimens: three, including RGM 283554.7 and 283559, from locality *c* (Fig. 3D), preserved in positive semirelief and full relief. Montpelier Formation. A fourth specimen, RGM 283555.2, locality *a* (Fig. 3B), preserved in positive hyporelief. Pelleu Island Formation. Several further specimens at localities *a* and *c* could not be collected.

Description — Straight to slightly curved, subcylindrical to cylindrical, unornamented, smooth-walled burrows that are parallel to bedding or rarely slightly inclined. The diameters of each specimen are constant but vary between individuals from 10-19 mm, while lengths vary between 25-70.5 mm. The burrow fills are essentially similar to the surrounding host rock.

Palaeophycus isp.
Pl. 7.

Material — One specimen, RGM 283560.1, locality *a* (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Description — Distinctly lined, elongated, ovate burrow preserved in vertical section having dimensions 17 × 10 mm (outer and inner long diameters, respectively), and 4 × 2 mm (outer and inner short diameters, respectively). Burrow-fill similar to host rock with the lining exhibiting a darker colouration to that of the host rock and also a greater amount of bioclastic material.

Discussion — Classification of *Palaeophycus* ispp. requires longitudinal views in order to determine whether striations or branching are present. Therefore, determination of *Palaeophycus* isp. is precluded as the specimen is only preserved in vertical section. *Palaeophycus herberti* and *P. tubularis* differ from its other ichnospecies, namely *P. striatus* Hall, 1852, *P. sulcatus* (Miller & Dyer, 1878) and *P. alternatus* Pemberton & Frey, 1982, by being sculptured, distinctly lined and smooth-walled (Pemberton & Frey, 1982). *Palaeophycus herberti* is distinguished by having a very thick lining with respect to its infill as opposed to *P. tubularis* that is thinly lined (Pemberton & Frey, 1982).

Ichnogenus *Planolites* Nicholson, 1873

Type ichnospecies — *Planolites vulgaris* Nicholson & Hinde, 1874, by subsequent designation (Miller, 1889, p. 520).

Diagnosis — (Emended after Pemberton & Frey, 1982, p. 865; Fillion & Pickerill, 1990, p. 48; Stanley & Pickerill, 1994, p. 120.) Unlined, rarely branched, straight or tortuous, smooth or ornamented, irregularly walled or annulate burrows, circular to elliptical in cross-section, predominantly horizontal, but bedding penetrative. The dimensions and configurations are variable and the fill is essentially massive.

Remarks — We emend the diagnosis of *Planolites* to collectively include all the diagnostic characteristics of the ichnotaxon proposed by the above authors, which, individually, do not encompass its overall morphology.

Planolites beverleyensis (Billings, 1862)
Pl. 3, fig. B; Pl. 4, fig. A; Pl. 7, arrowed (Pb); Pl. 8, fig. A; Pl. 11, fig. B.

Diagnosis — (After Pemberton & Frey, 1982, p. 869.) "Relatively large, smooth, straight to gently curved or undulose cylindrical burrows."

Material — Numerous examples observed in the field. Thirty specimens collected, including RGM 283554.4 and 283554.5, locality *c* (Fig. 3D), preserved in positive semirelief with the majority on bedded chert. Montpelier Formation. Three specimens, including RGM 283555.3, 283560.2 and 283564.4 locality *a* (Fig. 3B), preserved in positive hyporelief. Pelleu Island Formation.

Description — Horizontal, unlined, unbranched, straight to gently curving, unornamented cylindrical burrows. The diameters vary and range from 2-15 mm. Burrow crowding and cross-cutting are commonplace. Burrow diameters are constant along exposed length and infill is typically massive and similar to the host rocks.

Planolites montanus Richter, 1937
Pl. 8, fig. B.

Diagnosis — (After Pemberton & Frey, 1982, p. 870.) "Relatively small, curved to contorted burrows."

Material — Numerous examples observed in the field. Forty two specimens collected. Forty, including RGM 283551.2, locality *c* (Fig. 3D), preserved in positive semirelief on bedded chert. Montpelier Formation. Two, locality *a* (Fig. 3B), preserved in positive hyporelief. Pelleu Island Formation.

Description — Horizontal, unlined, unbranched, unornameted, relatively small, contorted burrows, averaging 14 mm in length and 1-2 mm in diameter. Each burrowfill is typically massive and similar in grain size to the host rock. Vertical components of these burrows were not observed.

Planolites isp.
Pl. 4, fig. A.

Material — Thirteen specimens, including RGM 283555.4, locality *a* (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Description — Unlined, unbranched, circular to elliptical burrows seen in vertical section. Their diameter ranges from 2-18 mm. Burrow-fill is typically massive and similar to the host rock, but essentially darker in colour.

Discussion — The major difference between *Planolites* ispp. and *Palaeophycus* ispp., its closest morphologically similar ichnogenus, is the distinct lining of the latter. Definitive determination of *Planolites* isp. is precluded due the absence of longitudinal views, which is essential in determining ornamentation. Within the ichnospecies of *Planolites*, *Planolites annularius* Walcott, 1890 (characterized by transverse annulations), *P. reinecki* Książkiewicz, 1977 (characterized by both longitudinal striations and transverse annulations) and *P. terraenovae* Fillion & Pickerill, 1990 (that exhibits continuous longitudinal striations) are ornamented, while *P. montanus* and *P. beverleyensis* are unornamented. *Planolites montanus* differs from *P. beverleyensis* by its smaller size and contorted morphology (Pemberton & Frey, 1982). Keighley & Pickerill (1997) suggested that these latter ichnospecies were synonymous with *P. beverleyensis* having priority.

However, this suggestion has not been followed by subsequent authors (e.g., Uchman, 1999). We therefore follow the recommendation of Fillion & Pickerill (1990) to include simple burrows of this type with diameters of less than 5 mm within *P. montanus.*

Ichnogenus *Schaubcylindrichnus* Frey & Howard, 1981

Type ichnospecies — *Schaubcylindrichnus coronus* Frey & Howard, 1981, by monotypy.

Diagnosis — (After Frey & Howard, 1981, p. 801.) "Distinct, isolated groups or bundles of congruent, lined tubes that ordinarily do not branch or interconnect. Preserved as endichnia."

***Schaubcylindrichnus coronus* Frey & Howard, 1981**
Pl. 7; Pl. 8, fig. C; Pl. 11, fig. B.

Diagnosis — (After Frey & Howard, 1981, p. 802.) "Schaubcylindrichnians in which the tubes are thickly lined and gently curved, their upper extremities approximately vertical and their lower ones approaching the horizontal."

Material — One slab, initially measuring 400 × 270 × 50 mm, subsequently vertically sectioned, RGM 283560.3, 283561.2 and 283564.2 locality *a* (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Description — Lined, circular to ovate tubes in cross-section, bundled collectively in groups of between three and twelve. The diameter of individual tubes varies from 4-13 mm (outer diameter) with the inner diameter between 3-5 mm. The tubes do not intersect, but, because of their tight bundling, especially in groups having a large number, the linings of adjacent tubes intermingle and uncommonly, where this occurs, are very faint. The lining of individual tubes consists of well-sorted, black, generally bioclastic grains (predominantly foraminifers) that vary from very thin and faint up to approximately 1 mm in thickness. The linings are thickest basally and laterally. The infill consists of cream-coloured, micritic grains.

Remarks — The only two ichnospecies of *Schaubcylindrichnus*, *S. coronus* and *S. freyi* Miller, 1995, differ on the basis of the tightness of the bundles (*S. coronus* is tightly bundled while *S. freyi* is loosely bundled). Ichnospecific assignment of the material documented herein is based on this criterion. For further details as to similarities and the significance of this ichnospecies to this region, see Blissett & Pickerill (2003b).

Ichnogenus *Scolicia* Quatrefages, 1849

Type ichnospecies — *Scolicia prisca* Quatrefages, 1849, by monotypy.

Diagnosis — (Emended after Uchman, 1995, p. 34.) Variably and commonly selectively preserved, simple, winding, meandering to coiled bilobate or trilobate, essentially horizontal meniscate structures with two parallel, locally discontinuous, sediment strings along their lower side. Cross-section is approximately oval. The upper side possesses composite laminae which may be biserial.

Remarks — The revised diagnosis of *Scolicia* provided by Uchman (1995, p. 34) included interpretive considerations, which should not enter into any ichnotaxonomic definition. We therefore emend his diagnosis to remove these from further consideration. Additionally, in his revised diagnosis, Uchman (1995) did not include orientation of the structures, a consideration of paramount importance with respect to trace fossil nomenclature.

***Scolicia prisca* Quatrefages, 1849**
Pl. 7; Pl. 8, fig. C.

Diagnosis — (After Uchman, 1995, p. 36.) "*Scolicia* preserved usually as an epichnial trilobate furrow with concave, semicircular bottom and oblique slopes, densely packed fine transverse ribs at the bottom, and more loose, asymmetrical and thicker ribs on the slopes. Two parallel strings may occur along the edges of the bottom. Proportion of bottom to slopes may vary in different specimens."

Material — Two specimen, RGM 283560.4 and 283561.1, locality *a* (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Description — Slightly curved, 20 mm wide, burrows each having a relatively flat lower surface. Two parallel ridges, 3 mm thick, that are parallel to the bedding plane surface, characterize the outer extremities of their lower surface. A cross-section of the burrow (RGM 283561.1; Pl.8, fig. C), albeit normal to its exposed width and at an angle to its longitudinal axis, exhibits thin transverse ribs along its length. The shape of the burrow, on this surface, is semicircular, but skewed with an approximate radius of 7 mm.

***Scolicia strozzii* (Savi & Meneghini, 1850)**
Pl. 4, fig. A; Pl. 7; Pl. 9, fig. A; Pl. 11, fig. C.

Taphonomic expression — *Laminites kaitiensis* Ghent & Henderson, 1966.

Diagnosis — (After Uchman, 1995, p. 37.) "Straight to tightly meandering hypichnial bilobate ridge, preserved in semirelief. Median grooves separate the prominent zones of the ridge. The prominent zones and the groove are more or less semi-circular in cross-section."

Material — Several examples observed in the field. Seven specimens, including RGM 283555.5, 283562, 283560.5 and 283564.3, locality *a* (Fig. 3B), preserved in both positive hyporelief and in full relief. Pelleu Island Formation.

Description — Straight to slightly curved laminate burrows preserved in both positive hyporelief and full relief. Those preserved in hyporelief consist of bilobate ridges with poorly developed furrows that separate the ridges on the horizontal plane. The width of these burrows average, where fully preserved, 40 mm with each lamina, evenly spaced, approximately 1 mm apart. The only specimen preserved in full relief is semi-ovate in shape, tapering from a height of 1-20 mm. Along its length, approximately 45 mm, are evenly spaced (1 mm apart) curved, thin laminations that consist of fine–grained chalky limestone sedimentary rocks darker in colour than the surrounding host rock.

Discussion — *Scolicia strozzii* (Savi & Meneghini, 1850) differs from *Scolicia prisca* Quatrefages, 1849, and *Scolicia plana* Książkiewicz, 1970, as both the latter are trilobate and preferentially preserved as epichnial burrows (Uchman, 1999). The major difference between *S. prisca* and *S. plana* is the occurrence of a parallel string on the bottom edges of the former. The samples of *S. strozzii* resemble *Laminites kaitiensis* Ghent & Henderson, 1966, illustrated in Plaziat & Mahmoudi (1988, fig. 4, p. 213), but Uchman (1995) demonstrated that *Laminites* ispp. lack diagnostic features and are preservational expressions of differing burrows. Ichnospeciation of these burrows, herein, is as recommended by Uchman (1995) and Goldring *et al*. (1997).

Ichnogenus *Taenidium* Heer, 1877

Type ichnospecies — *Taenidium serpentinum* Heer, 1877, by subsequent designation (Häntzschel, 1962, p. W218).

Diagnosis — (After Keighley & Pickerill, 1994, p. 322.) "Variably oriented, unwalled, straight, winding, curved, or sinuous, essentially cylindrical, meniscate backfilled trace fossils. Secondary successive branching may occur, but true branching is absent."

Taenidium cameronensis (Brady, 1947)
Pl. 9, fig. B.

Diagnosis — (After Keighley & Pickerill, 1994, p. 325.) "Unwalled meniscate burrows, secondary successive branching and intersections may be present. Meniscate packets usually longer than wide, with the deeply concave meniscate interfaces resulting in a nested appearance."

Material — One specimen, RGM 283563, locality *c* (Fig. 3D), preserved in full relief. Montpelier Formation.

Description — Unbranched, unlined, slightly curved, tightly packed *Taenidium* having crescentic-shaped menisci, each 8 mm in overall length. Spacing of each intermeniscate segments are approximately 1 mm and their arcs are deep with each successive menisci nested around each other. An exposed vertical section of the trace shows that the menisci are conical, but with the apices sub-rounded.

Taenidium serpentinum Heer, 1877
Pl. 9, fig. C.

Diagnosis — (After D'Alessandro & Bromley, 1987, p. 752.) "Serpentiform *Taenidium* having well-spaced, arcuate menisci; distance between menisci about equal to or a little less than burrow width. External moulds may show slight annulation corresponding to menisci, or fine transverse wrinkling. Secondary subsequent branching and intersections occur. Boundary sharp, lining lacking or insignificant."

Material — Approximately 40 specimens, including RGM 283354.6, locality *c* (Fig. 3D), preserved in positive semirelief on bedded chert. Montpelier Formation. Two specimens, locality *a* (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Description — Straight burrows with sharp boundaries, parallel to slightly inclined with respect to bedding, having infill similar to the host strata. Burrow width varies from 2-12 mm, but is consistent within individual specimens. Menisci are arcuate and the distance between them varies, but remains more or less equal to the burrow width. The burrows are slightly wrinkled and exhibit no true branching.

cf. *Taenidium barretti* (Bradshaw, 1981)
Pl. 8, fig. C.

Material — One specimen, RGM 283561.3, locality a (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Descripition — Slightly inclined, and curved, cylindrical, unbranched, unwalled, vertically oriented, meniscate burrow having irregular, but sharp, boundaries. Menisci are arcuate, but vary in distinctiveness. The burrow-fill is homogenus, bioclastic and darker in colour than the host rock. Burrow diameter is approximately 10 mm while the lengths of the few clearly defined menisci average 15 mm. The height of the burrow is 35 mm.

Discussion — A lack of wall linings and the presence of menisci within a burrow are sufficient criteria for it to be included in the ichnogenus *Taenidium*. *Taenidium cameronensis* differs from *T. serpentinum*, *T. dieslingi* (Unger, 1850) and *T. barretti* (Bradshaw, 1981) by having menisci longer than the burrow width. *Taenidium serpentinum* differs from *T. satanassi* D'Alessandro & Bromley, 1987, as the latter consists of meniscate packets containing two types of sediment. *Taenidium barretti* (Bradshaw, 1981) also has a similar heterogeneous fill, but packeting is not distinct (Keighley & Pickerill, 1994). *Taenidium serpentinum* also differs from *T. cameronensis* (Brady, 1947) that has deeply concave meniscate packets longer than wide and a nested appearance of its meniscate interfaces (D'Alessandro & Bromley, 1987).

Ichnogenus *Thalassinoides* Ehrenberg, 1944

Type ichnospecies — *Thalassinoides callianassae* Ehrenberg, 1944, by original designation.

Diagnosis — (After Kennedy, 1967, p. 32.) "Extensive burrow systems with both vertical and horizontal elements. Burrows cylindrical, between 2 and 20 cm. in diameter. Branching regular, characterized by Y-shaped bifurcations, swollen at point of branching. Horizontal systems connecting to surface by vertical or steeply inclined shafts, widely associated with callianassid remains."

Thalassinoides horizontalis **Myrow, 1995**
Pl. 10, fig. A.

Diagnosis — (Emended after Myrow, 1995, p. 72.) Horizontal, branching framework of smooth-walled, unlined burrows, lacking vertically oriented offshoots. Burrow diameter consistent within individual specimens; constrictions or swellings at both junctions and inter-junction segments are notably absent.

Remarks — We emend the diagnosis of Myrow (1995) to exclude his inclusion of size constraints (inner tube diameter of less than 5 mm) with respect to this ichnospecies, an ichnotaxonomic criterion fraught with several difficulties (see Pickerill, 1994).

Material — Two specimens. One, RGM 283550.2, locality *c* (Fig. 3D), preserved in positive semirelief on bedded chert. Montpelier Formation. The other is preserved in positive hyporelief. Pelleu Island Formation.

Description — The burrows, preserved on the lower surface of a chalk layer and on bedded chert, are smooth-walled, unlined, unornamented and branched. Branching is characterized by T-shaped bifurcations with slight swelling at their junctions. The burrows, as a result of their preservation style, do not exhibit vertical components of either boxwork or polygonal networks. Burrow diameters are constant within each specimen at 7 and 10 mm.

Thalassinoides paradoxicus **(Woodward, 1830)**
Pl. 10, fig. B.

Diagnosis — (After Howard & Frey, 1984, p. 213.) "Sparsely to densely but irregularly branched, subcylindrical to cylindrical burrows oriented at various angles with respect to bedding; T-shaped intersections are more common than Y-shaped bifurcations, and offshoots are not necessarily the same diameter as the parent trunk."

Material — Hundreds of field examples preserved in full relief, in chalks of locality *d* (Fig. 3E), but because of their incomplete and fragile nature none collected. Montpelier Formation.

Description — Complex, subcylindrical burrow systems that irregularly branch forming complex boxwork patterns and are oriented at various angles to bedding. The diameter of the burrows varies and ranges from 5 to 30 mm. Y-shaped intersections predominate. Burrow-fill is darker in colour than the surrounding rock.

Thalassinoides isp.
Pl. 6, fig. A; Pl. 11, fig. A.

Material — Several examples including RGM 283551.2 and 283558.2, locality *c* (Fig. 3D), preserved in full relief in bedded chert. Montpelier Formation.

Description — Circular, irregularly ovate- to oval-shaped trace fossils preserved within bedded chert. Diameters range from 10 to 50 mm (long diameter) and 5 to 20 mm (short diameter) in the vertical plane. With respect to bedding, the angles of the tubes varied randomly and branching was rarely observed. The lengths, where obvious, did not exceed 40 mm and the density of these tubes varied between samples.

Discussion — Classification of the ichnogenus *Thalassinoides* is essentially based on the presence of horizontal elements and branching characteristics. Six ichnospecies are currently recognised, namely: *T. saxonicus* (Geinitz, 1842) (characterized by its large form with tunnels; Kennedy, 1967); *T. ornatus* Kennedy, 1967 (consisting of smaller ovate, horizontal to gently inclined burrows; Kennedy, 1967); *T. paradoxicus* (that branches forming complex boxwork patterns, generally irregular in geometry; Howard & Frey, 1984); *T. suevicus* (Rieth, 1932) (which is predominantly a horizontal form consisting of enlarged Y-shaped bifurcations; Howard & Frey, 1984); *T. horizontalis* (a strictly horizontal form); and *T. foedus* Mikuláš, 1990 (that forms polygonal frameworks). *Thalassinoides* isp. as described herein does not exhibit any of the aforementioned attributes, which therefore precludes definitive ichnospecific identification.

Ichnogenus _Trichichnus_ Frey, 1970

Type ichnospecies — *Trichichnus linearis* Frey, 1970, by monotypy.

Diagnosis — (After Fillion & Pickerill, 1990, p. 61.) “Branched or unbranched, hair-like, cylindrical, straight to sinuous burrows distinctly <1 mm in diameter, oriented at various angles (mostly vertical) with respect to bedding. Burrow walls distinct or indistinct, lined or unlined.”

Trichichnus linearis Frey, 1970
Pl. 7.

Diagnosis — (After Frey, 1970, p. 20.) “Rarely branched, dominantly vertical, thread-like, cylindrical trichichnid burrows having distinct walls, commonly lined with diagenetic minerals.”

Material — One specimen, RGM 283560.6, locality *a* (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Description — Slender, hair-like, unbranched, distinctly lined, slightly curved, cylindrical burrow that is oriented essentially vertical with respect to bedding. Burrow length is 8 mm and width is approximately 1 mm. The lining contains an abundance of bioclastic fragments and is darker in colour than the host rock. The burrow-fill is similar to the host rock.

Trichichnus simplex Fillion & Pickerill, 1990
Pl. 7; Pl. 11, fig. B.

Diagnosis — (After Fillion & Pickerill, 1990, p. 62.) "Unlined *Trichichnus.*"

Material — Twelve specimens, including RGM 283560.7 and 283564.1, locality *a* (Fig. 3B), preserved in full relief. Pelleu Island Formation.

Description — Cylindrical, unlined, vertical to inclined (>45°), branched and unbranched, hair-like burrows with distinct boundaries. Burrow diameters average 0.6 mm with lengths up to 7 mm.

Discussion — *Trichichnus* differs from the morphologically similar ichnogenus *Skolithos* Haldman by its smaller size (an unsatisfactory criterion, but beyond discussion in this contribution; see Pickerill, 1994 for discussion), variable orientation with respect to stratification and the presence or otherwise of branching. The major difference between *Trichichnus simplex* and *T. linearis* is that the latter is typically lined whereas the former is not. *T. appendicus* Uchman, 1999, the only other formally defined ichnospecies, displays short lateral appendages and is essentially oblique or horizontal.

Discussion and conclusions

The six lithostratigraphic units of the White Limestone Group exhibit varying degrees of ichnofaunal diversity. Although the group has yielded a moderately diverse, poor to moderately preserved soft-sediment ichnofauna (Blissett & Pickerill, 2003a), these have only been observed in the Montpelier and Pelleu Island formations, and to a lesser degree within the Moneague Formation. The Montpelier Formation exhibits the most abundant diversity in comparison to the Pelleu Island Formation (Table 1).

We consider that one or a combination of several factors, as outlined below, influence the presence or absence and variations in the soft-sediment ichnofaunal diversity exhibited in the Group.

Weathering/lithification — This factor has a dual effect on the taphomony of trace fossils. Extreme tropical weathering, especially on subaerially exposed carbonate rocks, will cause case hardening (Illing, 1954) which, potentially, can destroy any biosedimentary structures that may have formed. This phenomenon has been observed to occur extensively in the Moneague Formation and to varying degrees within several other formations of the White Limestone Group. This factor can also enhance or aid in the preservation of soft-sediment structures as, for example, observed in the Moneague Formation where *Ophiomorphia nodosa* and *Planolites beverleyensis*, albeit single specimens, have been recorded.

Toponomy — With the exception of the Pelleu Island Formation and several exposures in the Montpelier Formation, there is a lack of exposed bedding plane surfaces that precludes observation of bedding-parallel ichnofossils.

Dolomitization — Dolomitization and dedolomitization processes, especially observable in strata of the Troy Formation, could potentially have also been a factor in the destruction of any biogenic sedimentary structures that may have been present prior to the onset of these processes.

Contrast — One of the additional factors considered to affect the ability to observe soft-sediment structures is contrasting lithologies. The Troy, Swanswick, Somerset and Moneague formations lack colour contrast and, as such, discernible biogenic sedimentary structures cannot be distinguished.

Chertification — Chertification, which is only observed in the Montpelier Formation, also contributed to the preservation of soft-sediment ichnotaxa. The majority of the ichnotaxa described herein are directly related to the presence or otherwise of bedded chert, the former being conducive to their preservation.

Acknowledgements

We thank Jermaine Blissett and Aundrae Gayle for field assistance, and Anthony Mundell and the University of the West Indies Geography and Geology Department for assisting in logistics. A Natural Sciences Engineering Research Council Discovery Grant to R.K.P. provided financial support, which is gratefully acknowledged. This report constitutes part of D.J.B.'s Ph.D. thesis. Critical reviews by S.K. Donovan and D.G. Keighley were much appreciated, and greatly assisted in improving the content of the contribution.

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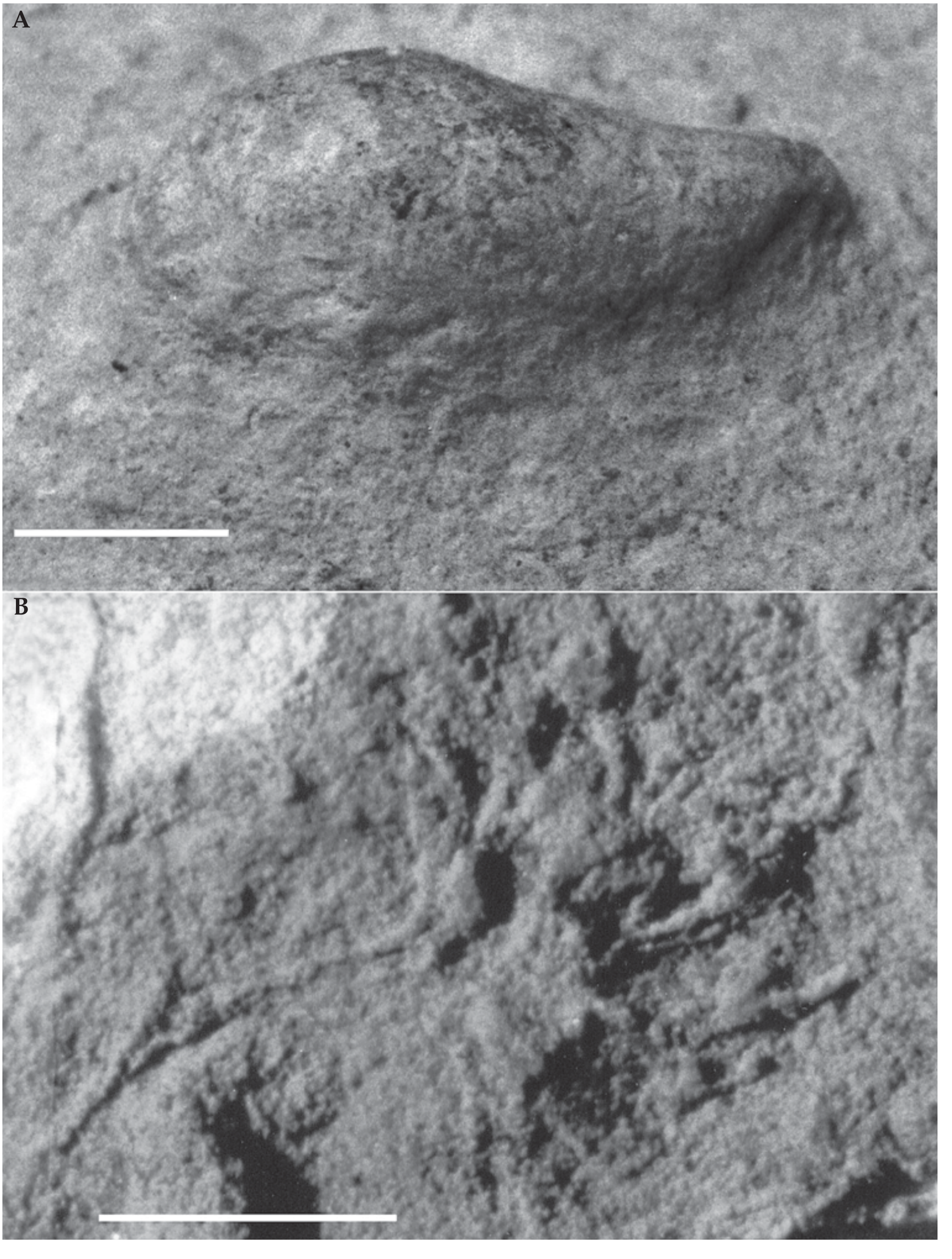

Plate 1

Fig. A. *Bergaueria hemispherica*?, RGM 283550.1, in positive semirelief on bedded chert. Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. B. *Chondrites furcatus* Sternberg, RGM 283551.1, in positive semirelief on bedded chert. Scale bar represents 5 mm. Locality *c* (Fig. 3D). Montpelier Formation.

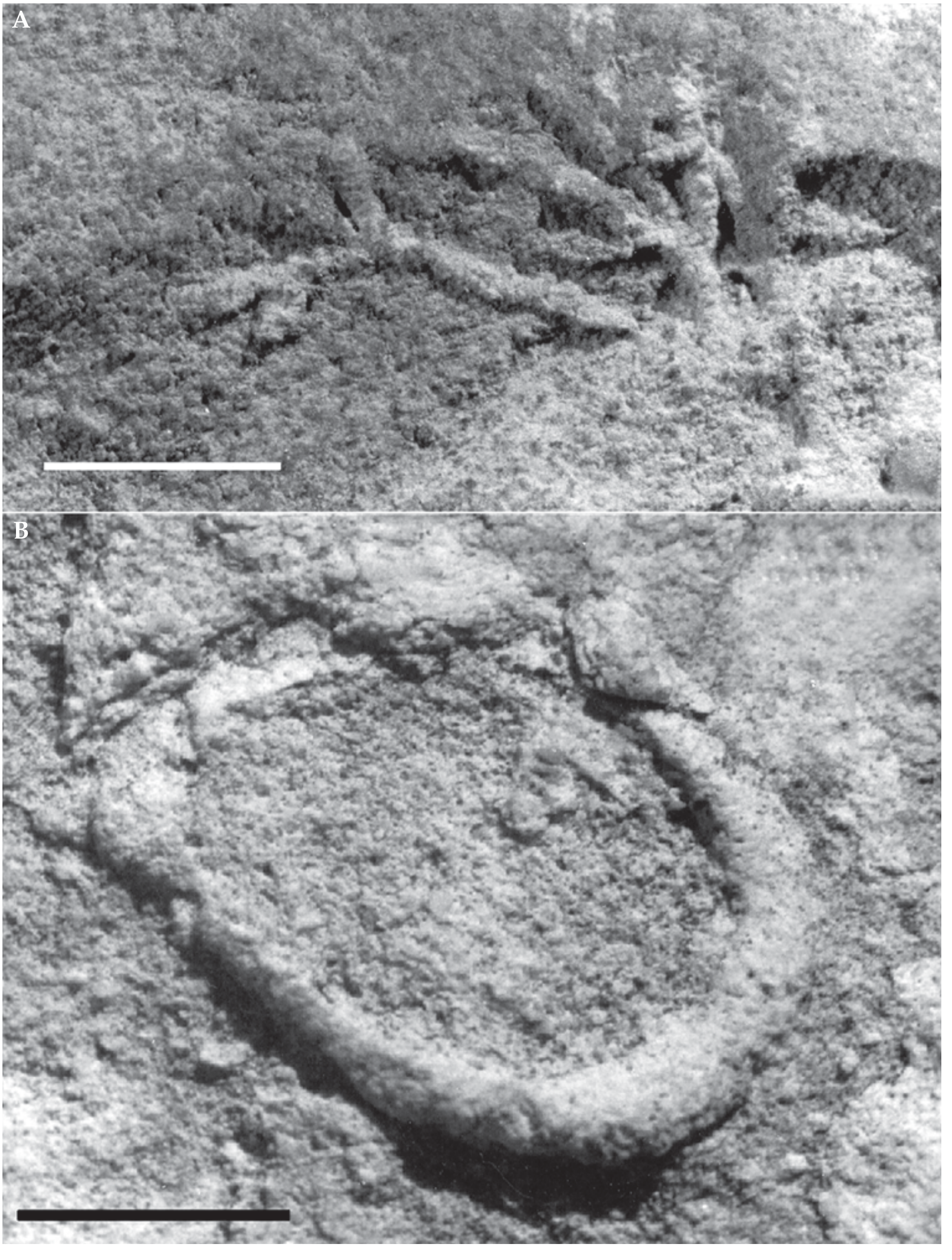

Plate 2

Fig. A. *Chondrites* isp., RGM 283552, in positive semirelief on bedded chert. Scale bar represents 3 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. B. *Circulichnus montanus* Vialov, RGM 283553, in positive semirelief on bedded chert. Scale bar represents 5 mm. Locality *c* (Fig. 3D). Montpelier Formation.

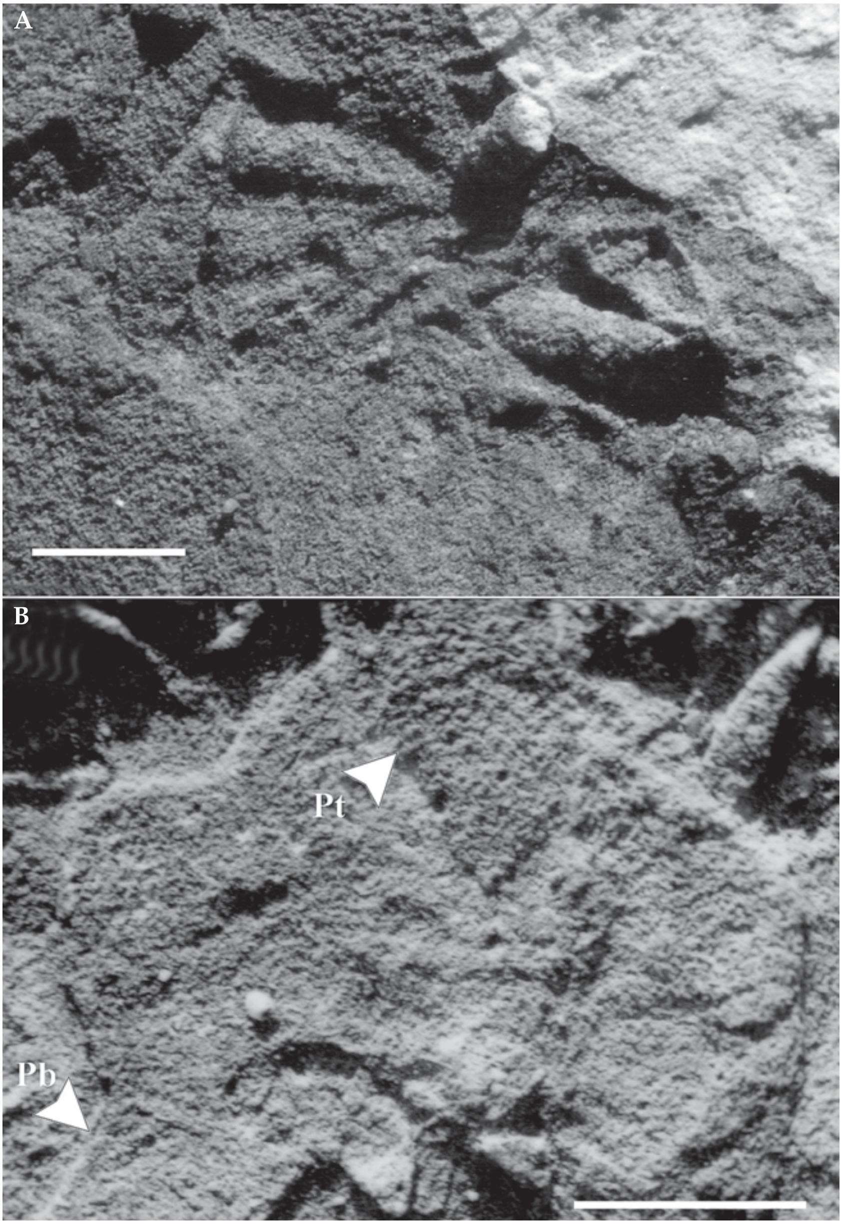

Plate 3

Fig. A. *Dactyloidites ottoi* (Geinitz), RGM 283554.1, in full relief on bedded chert. Scale bar represents 5 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. B. *Dactyloidites peniculus* D'Alessandro & Bromley, RGM 283554.2, in positive semirelief on bedded chert, including *Palaeophycus tubularis* Hall (Pt), RGM 283554.7 and *Planolites beverleyensis* (Billings) (Pb), RGM 283554.4. Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.

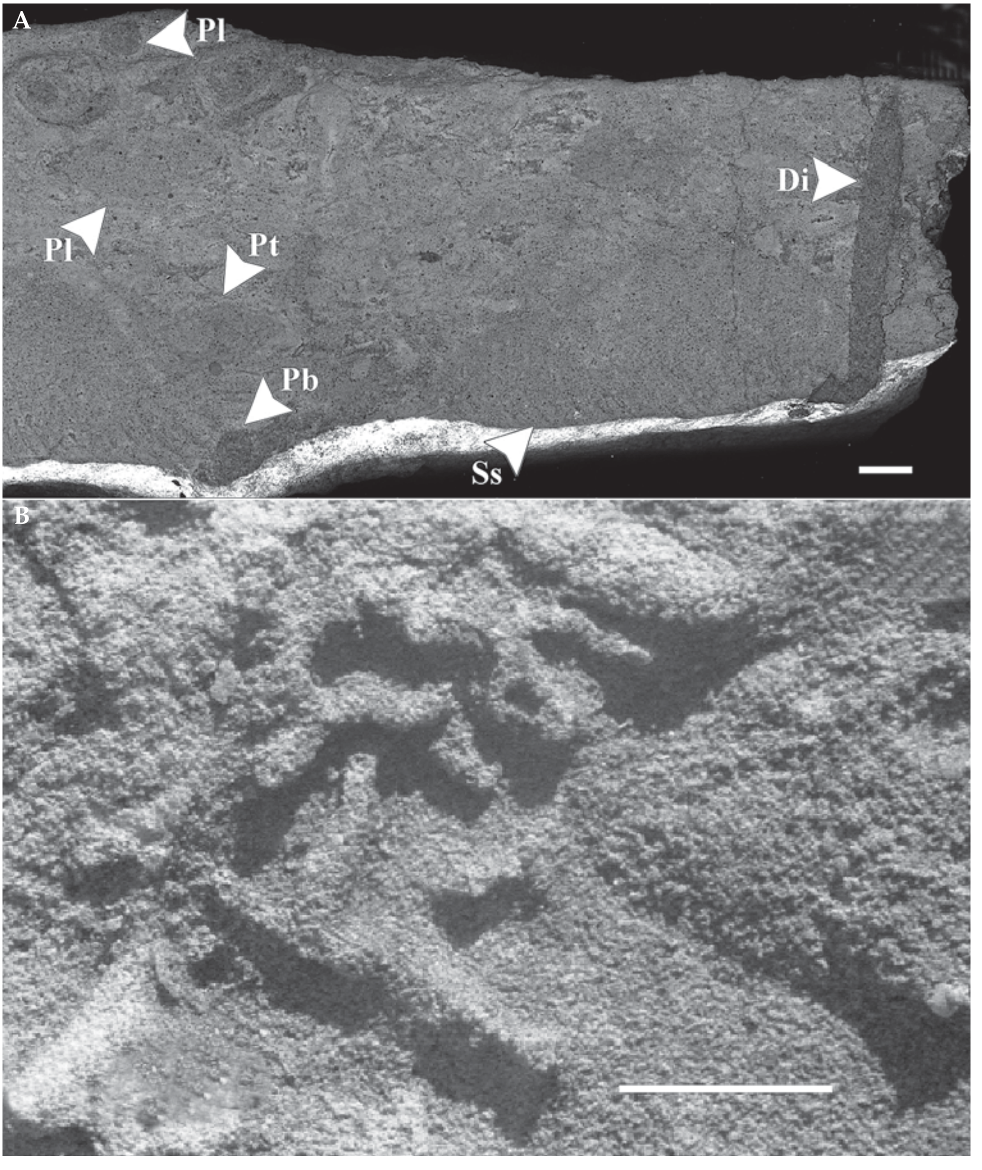

Plate 4

Fig. A. Vertical section depicting, *Diplocraterion* isp. cf. *D. parallelum* (Di), RGM 283555.1; *Palaeophycus tubularis* Hall (Pt), RGM 283555.2; *Planolites* isp. (Pl), RGM 283555.4; *Planolites beverleyensis* (Billings) (Pb), RGM 283555.3; and *Scolicia strozzii* Savi & Meneghini (Ss), RGM 283555.5 in full relief. Scale bar represents 5 mm. Locality *a* (Fig. 3B). Pelleu Island Formation.
Fig. B. *Glockerichnus parvula* (Książkiewicz), RGM 283554.3, in positive semirelief on bedded chert. Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.

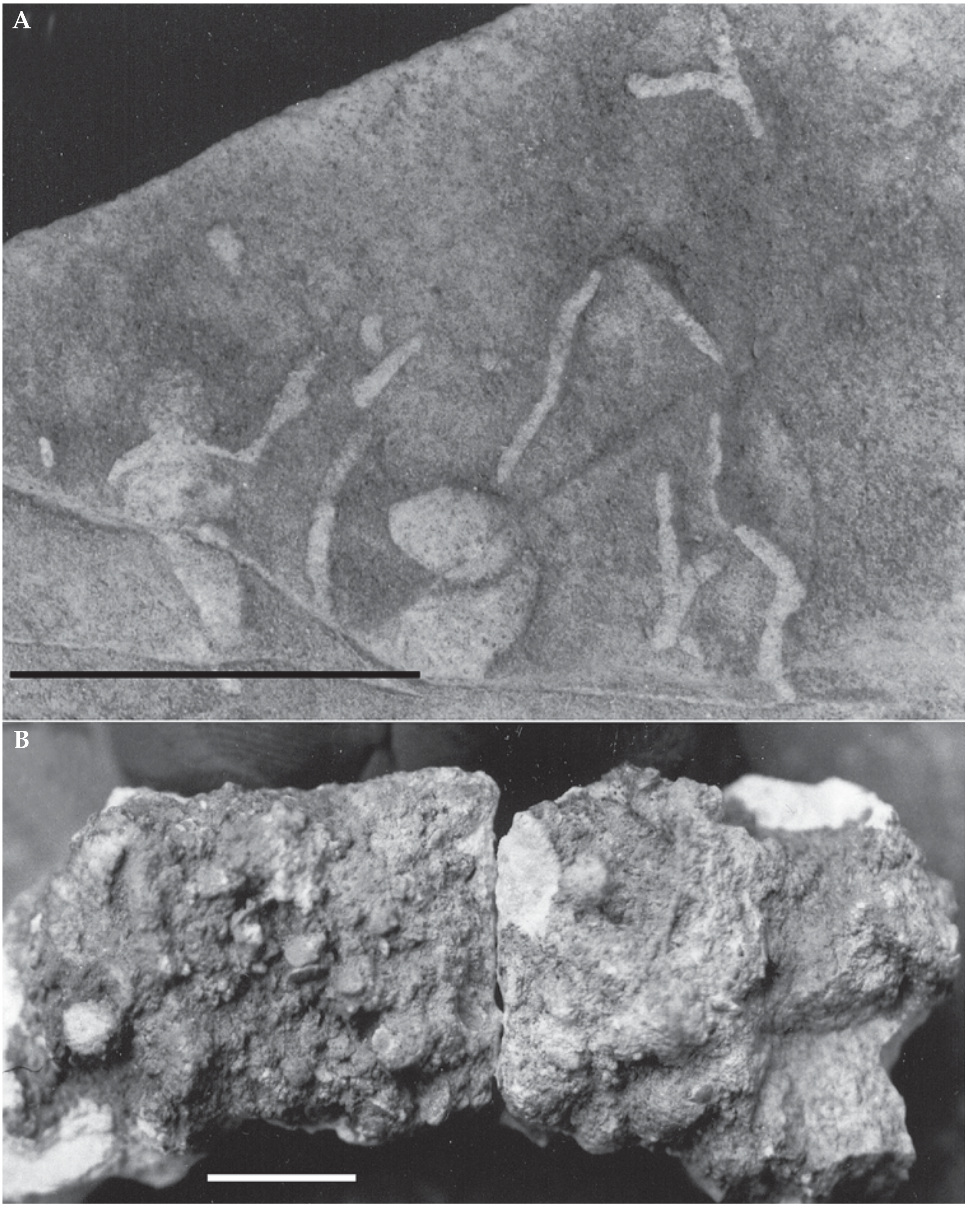

Plate 5

Fig. A. *Helminthopsis hieroglyphica* Wetzel & Bromley, RGM 283556, in positive relief on bedded chert. Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. B. *Ophiomorpha nodosa* Lundgren, RGM 283557, in positive relief on bedded chert. Scale bar represents 10 mm. Locality *b* (Fig. 3C). Moneague Formation.

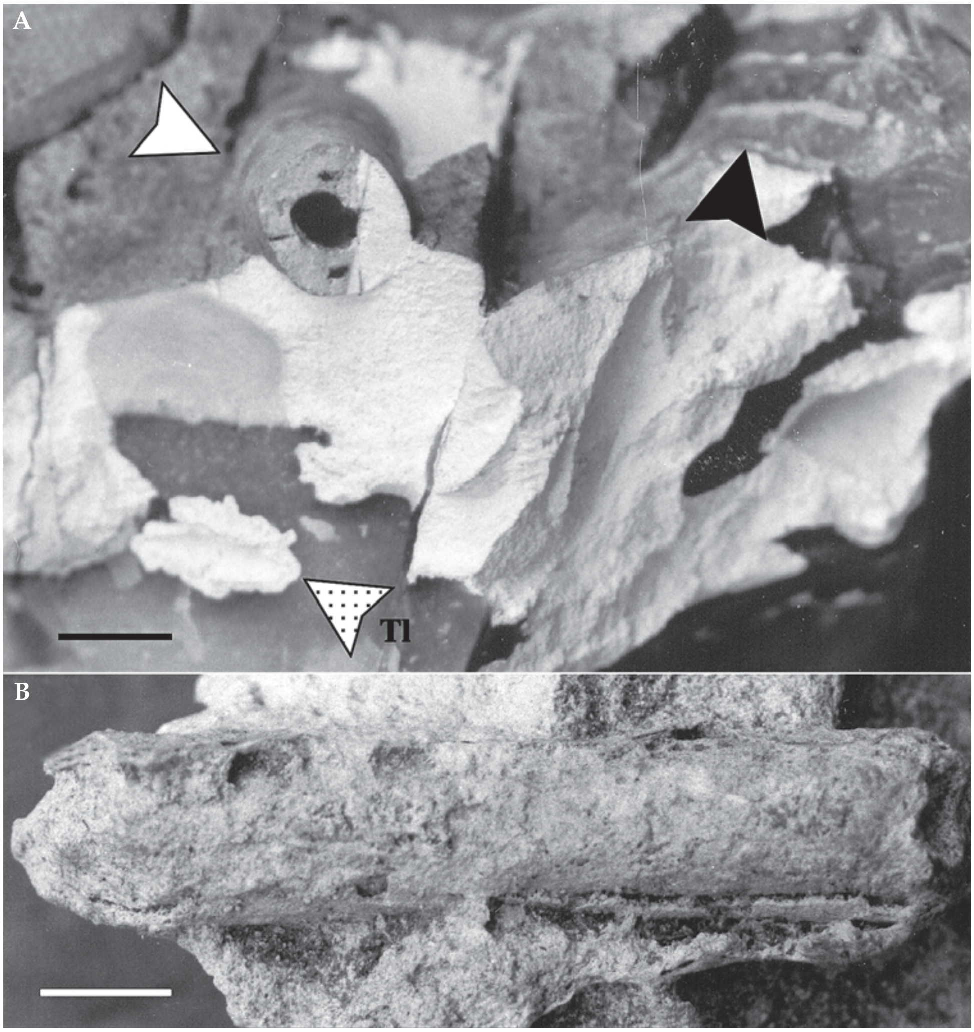

Plate 6

Fig. A. *Palaeophycus herberti* (Saporta), RGM 283558.1 (plain arrow), in full relief within bedded chert (black arrow depicts totally chertified example). *Thalassinoides* isp. (Tl), RGM 283558.2 (stippled arrow) is also depicted. Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. B. *Palaeophycus tubularis* Hall, RGM 283559, in full relief. Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.

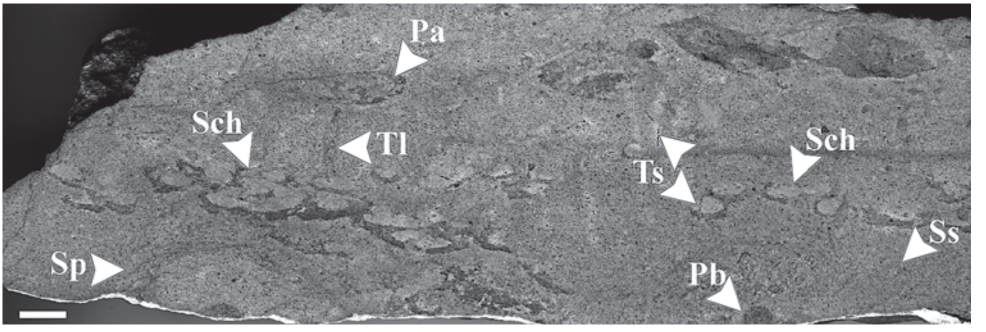

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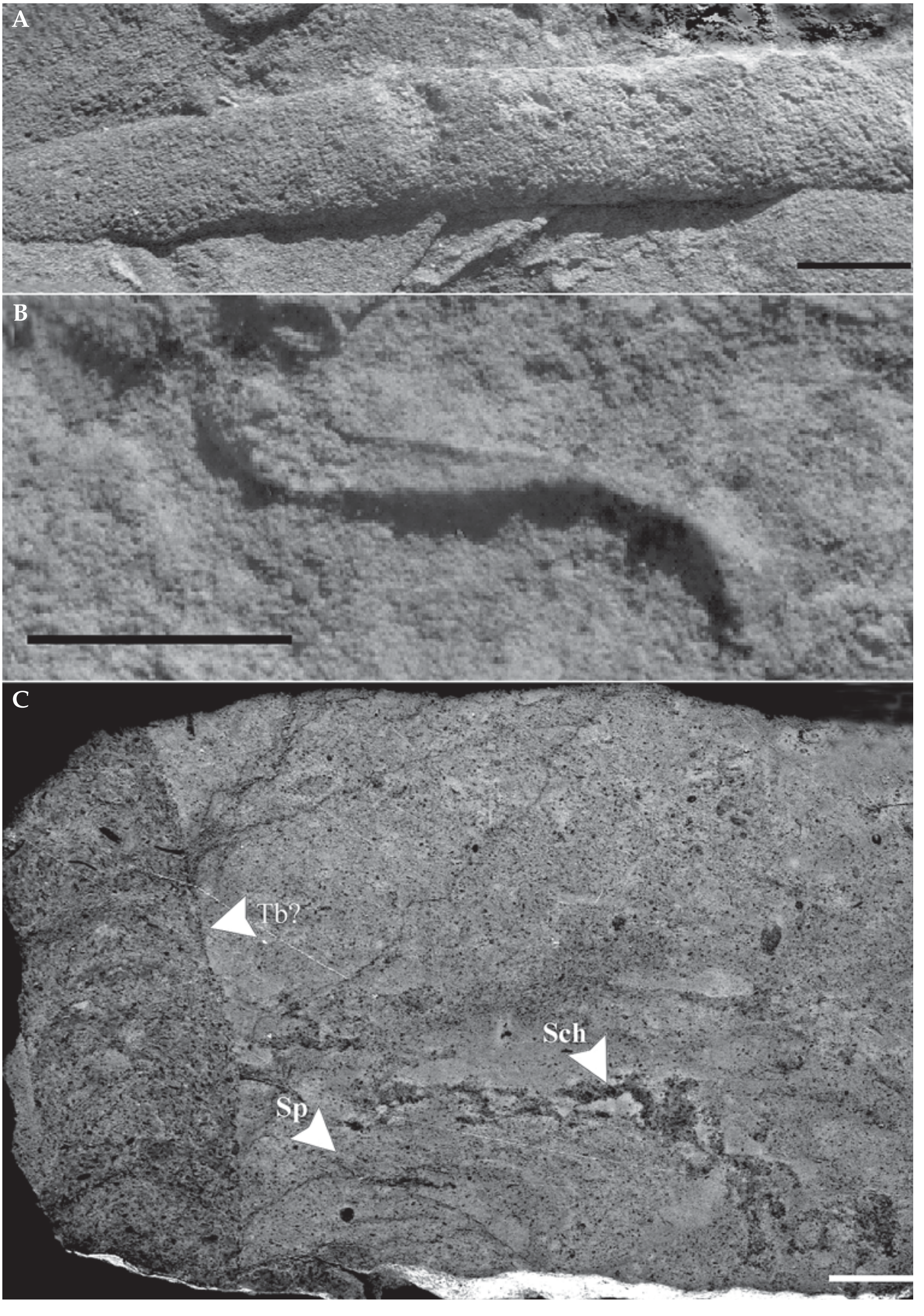
Plate 7

Vertical section depicting *Palaeophycus* isp. (Pa), RGM 283560.1, in association with *Scolicia prisca* Quatrefages (Sp), RGM 283560.4; *Scolicia strozzii* Savi & Meneghini (Ss), RGM 283560.5; *Schaubcylindrichnus coronus* Frey & Howard (Sch), RGM 283560.3; *Trichichnus linearis* Frey (Tl), RGM 283560.6; *Trichichnus simplex* Fillion & Pickerill (Ts), RGM 283560.7; and *Planolites beverleyensis* (Billings) (Pb), RGM 283560.2. Scale bar represents 5 mm. Locality *a* (Fig. 3B). Pelleu Island Formation.

Plate 8 ▶

Fig. A. *Planolites beverleyensis* (Billings), RGM 283554.5, in positive semirelief on bedded chert. Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. B. *Planolites montanus* Richter, RGM 283551.2, in positive semirelief on bedded chert. Scale bar represents 5 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. C. Vertical section depicting *Scolicia prisca* Quatrefages, RGM 283561.1, in full relief in association with *Schaubcylindrichnus coronus* Frey & Howard (Sch), RGM 283561.2 and cf. *Taenidium barretti* (Tb?), RGM 283561.3. Scale bar represents 5 mm. Locality *a* (Fig. 3B). Pelleu Island Formation.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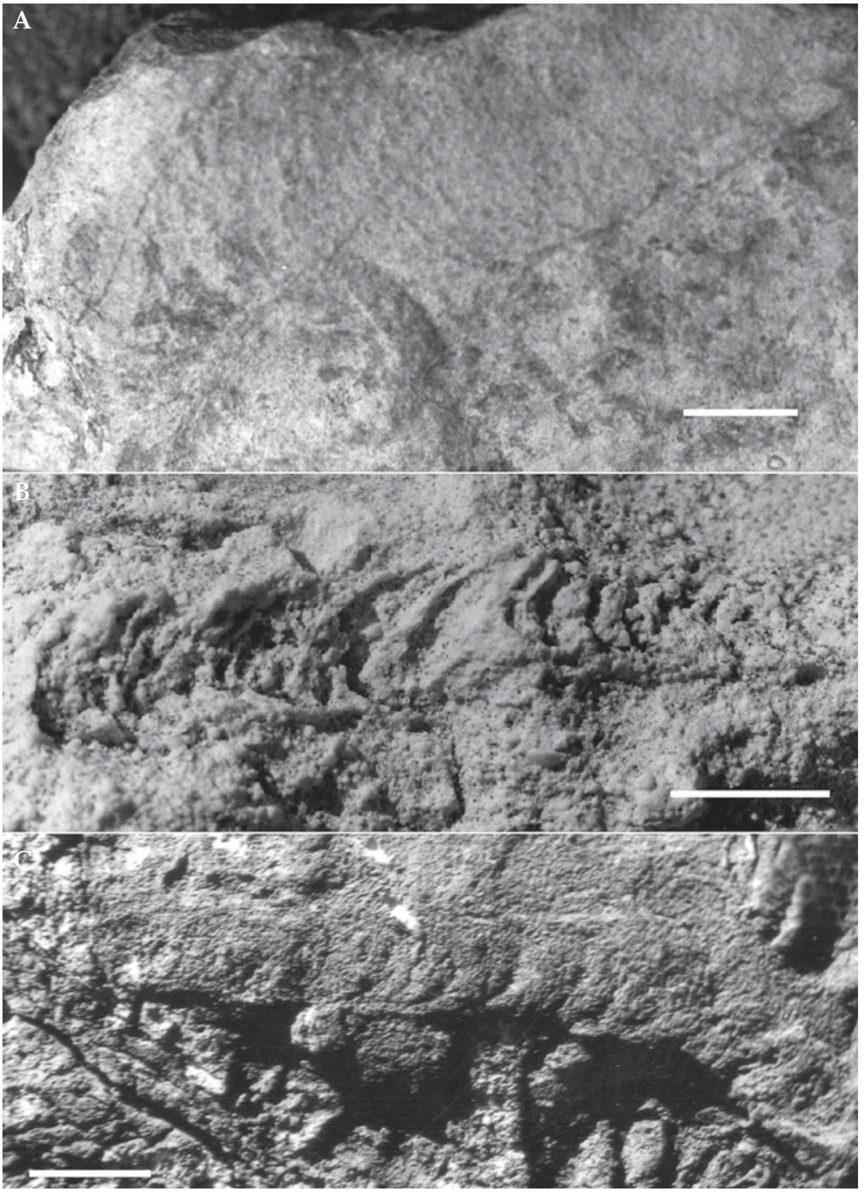

Plate 9

Fig. A. *Scolicia strozzii* Savi & Meneghini, RGM 283562, in positive hyporelief. Scale bar represents 10 mm. Locality *a* (Fig. 3B). Pelleu Island Formation.
Fig. B. *Taenidium cameronensis* (Brady), RGM 283563, in full relief. Scale bar represents 5 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. C. *Taenidium serpentinum* Heer, RGM 283554.6, in positive semirelief on bedded chert. Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.

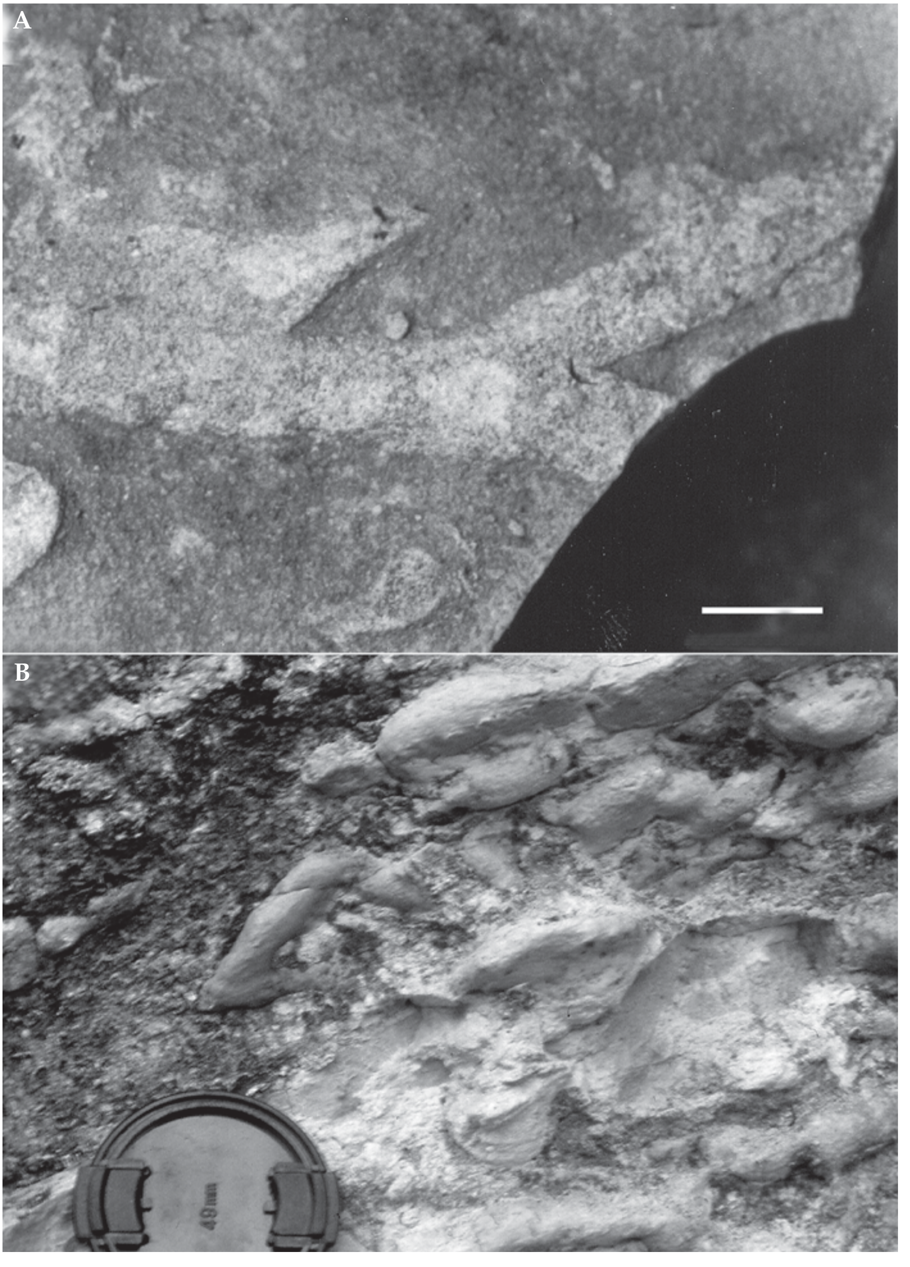

Plate 10

Fig. A. *Thalassinoides horizontalis* Myrow, RGM 283550.2, in positive hyporelief. Scale bar represents 10 mm. Locality *a* (Fig. 3B). Pelleu Island Formation.
Fig. B. Field photograph of *Thalassinoides paradoxicus* (Woodward) in full relief. Diameter of lens cap is 50 mm. Locality *d* (Fig. 3E). Montpelier Formation.

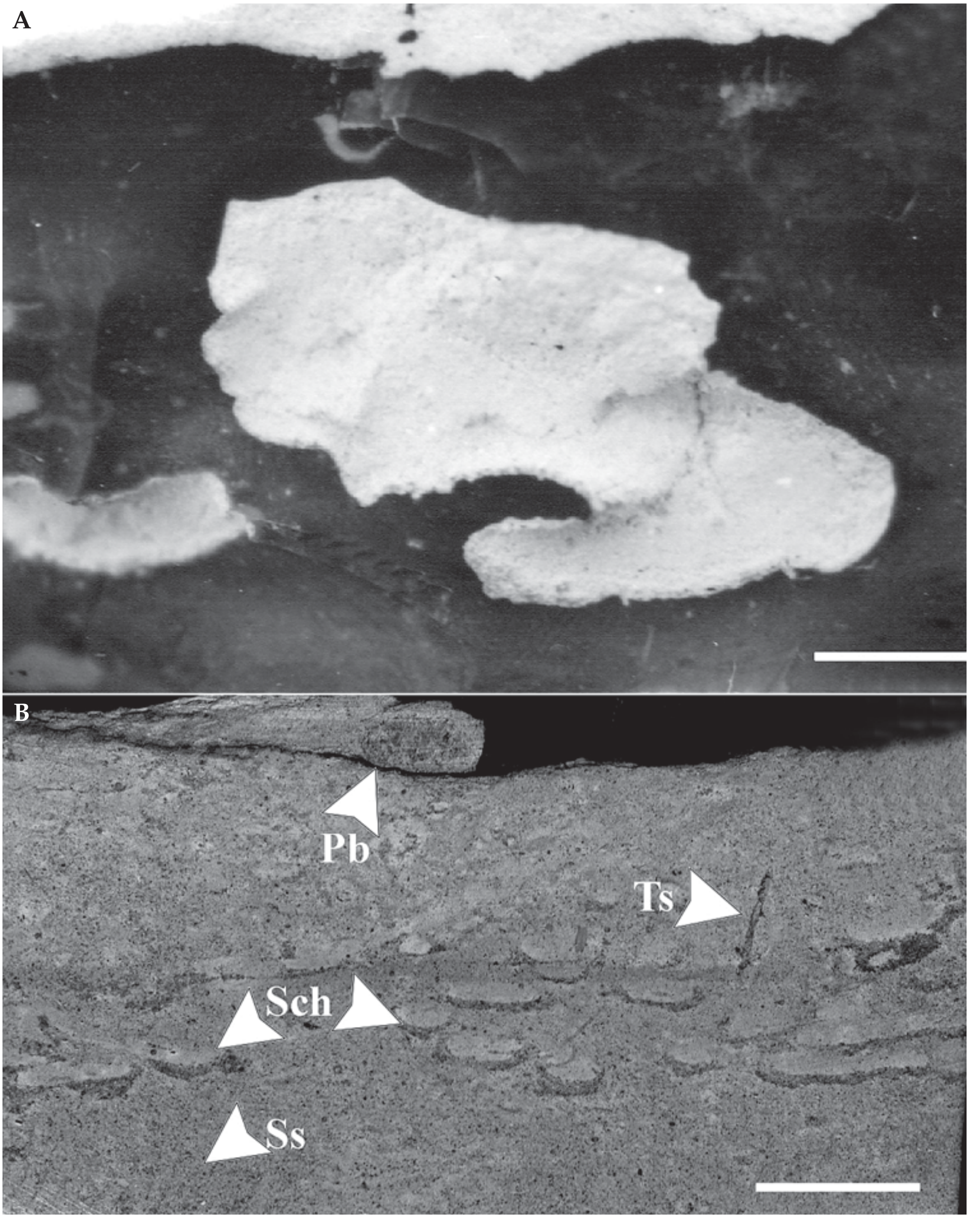

Plate 11

Fig. A. *Thalassinoides* isp., RGM 283551.2, in full relief in a chert layer (dark) interbedded with chalk (lighter). Scale bar represents 10 mm. Locality *c* (Fig. 3D). Montpelier Formation.
Fig. B. Vertical section of *Trichichnus simplex* Fillion & Pickerill (Ts), RGM 283564.1, in full relief, in association with *Schaubcylindrichnus coronus* Frey & Howard (Sch), RGM 283564.2; *Scolicia strozzii* (Ss), RGM 283564.3; and *Planolites beverleyensis* (Billings) (Pb), RGM 283564.4. Scale bar represents 10 mm. Locality *a* (Fig. 3B). Pelleu Island Formation.