Gordia nodosa isp. nov. and other trace fossils from the Cass Fjord Formation (Cambrian) of North Greenland

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A new ichnospecies, *Gordia nodosa* isp. nov., is figured and described from member D of the Cass Fjord Formation of Daugaard-Jensen Land, western North Greenland. Strata of Member D are Dresbachian in age and thus the new trace fossil is from the latest Middle Cambrian or earliest Late Cambrian. Two additional slabs from underlying members B and C of the Formation contain, respectively, the ichnotaxa *Diplichnites* Dawson, 1873, cf. *Monocraterion* Torell, 1870 and *Palaeophycus tubularis*, Hall, 1847, and *Cruziana problematica* (Schindewolf, 1921). These ichnotaxa are figured and described briefly.

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The study of Lower Palaeozoic trace fossils from Greenland is still in its infancy (cf. Pickerill & Peel, 1990). Documentation of most ichnotaxa has essentially relied on material collected on a random basis, commonly over a period of several years by different workers, and with no view to a thorough ichnological analysis. Yet despite the restricted size of many of the previously described collections (e.g. Bergström & Ineson, 1988; Bergström & Peel, 1988; Pickerill & Harland, 1988; Bryant & Pickerill, 1990; Pickerill & Peel, 1990), study of the often well preserved material has proven to be extremely rewarding. Such is also the case herein, where four slabs collected from the Cass Fjord Formation of Daugaard-Jensen Land, western North Greenland (Figs 1, 2), contain a variety of generally well preserved ichnotaxa. Among these is a new ichnospecies, *Gordia nodosa* isp. nov., which is figured and described in detail. Other trace fossils include the ichnotaxa *Cruziana problematica* (Schindewolf, 1921), *Diplichnites* Dawson, 1873, cf. *Monocraterion* Torell, 1870 and *Palaeophycus tubularis* Hall, 1847. For the sake of completeness, these are also briefly described and figured. The four slabs each possess a Geological Survey of Greenland collection number (GGU prefix, Grønlands Geologiske Undersøgelse) and appropriate specimen numbers prefixed by MGUH; all are housed in the Geological Museum, University of Copenhagen.

Location and stratigraphy

Poulsen (1927) gave the name Cass Fjord Formation to a unit in the Cass Fjord area of Daugaard-Jensen Land, western North Greenland which yielded Early Ordovician faunas from its highest beds. Formal proposal was accomplished by Koch (1929), while Henriksen & Peel (1976) gave a brief re-description. Palmer & Peel (1981) described the lower part of the formation in more detail, recording trilobites of late Middle Cambrian (Dresbachian) and younger age; the formation thus ranges from the Middle Cambrian to the Early Ordovician. The Cass Fjord Formation outcrops throughout Daugaard-Jensen Land (Fig. 1), from Humboldt Gletscher in the south-west to Petermann Gletscher in the north-east (cf. Palmer & Peel, 1981; Peel & Christie, 1982).

The Cass Fjord Formation (400–470 m) is dominated by greenish grey, nodular and lenticularly bedded micritic limestones, with frequent thin beds (5–50 cm) of intraformational flat-pebble conglomerates. A variety of other lithologies are represented, however, including yellowish finely recrystallised dolomites, anhydritic shales and lime grainstones; white quartzites (1–30 m) near the top of the formation are referred to the Kap Coppinger Member (Bryant & Smith, 1990). The formation forms part of a Cambrian aggradational platform succession assigned to the Ryder Gletscher Group and widely distributed throughout western North

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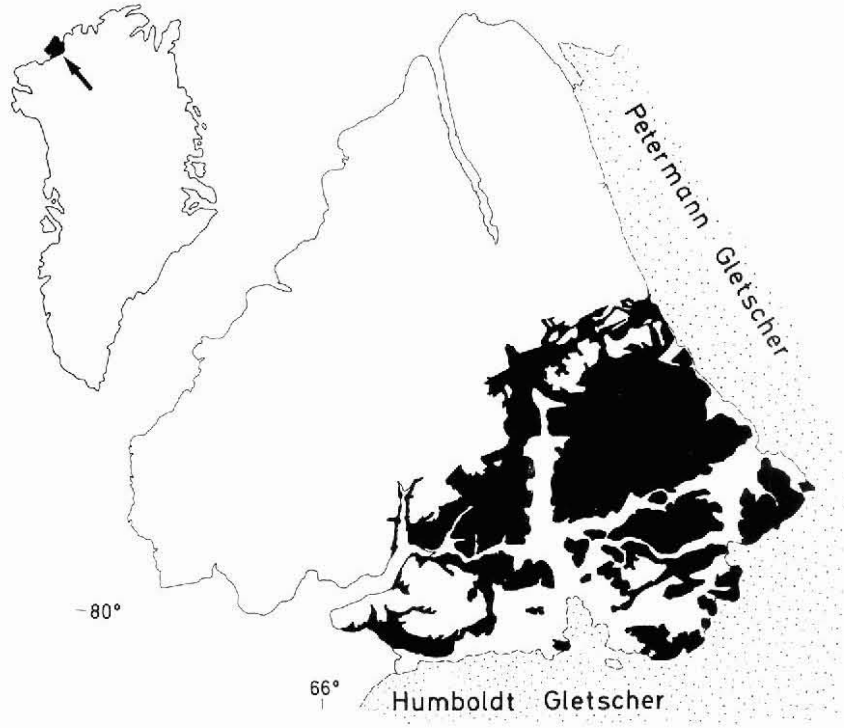

Fig. 1. Outcrop of the Cass Fjord Formation (black) between Humboldt Gletscher and Petermann Gletscher, corresponding almost exactly to the land area known as Daugaard-Jensen Land.

Greenland (cf. Higgins *et al.*, in press). Ryder Gletscher Group strata are principally carbonates; in Daugaard-Jensen Land they overlie siliciclastic shelf sediments of the Humboldt Formation (Fig. 2).

Palmer & Peel (1981) recognised four informal members within the lower part of the Cass Fjord Formation. A basal member A (20–40 m) is characterised by the micritic limestones typical of the formation as a whole, and silty interbeds. Overlying cliff-forming carbonates assigned to member B (30–45 m) lack the silty interbeds and, in addition to the micritic limestones, also include grainstones with trilobites, and infrequent oolites. *Diplichnites* isp., cf. *Monocraterion* isp. and *Palaeophycus tubularis* have been collected from this interval, where the associated trilobites indicate a late Middle Cambrian age from possibly pre-Dresbachian to the earliest Dresbachian *Cedaria* Zone (Palmer & Peel, 1981).

Member C consists of about 45 m of recessive micritic limestones, finely recrystallised dolomites and some reddish shales and siltstones. *Cruziana problematica* was collected from this interval which lies within the *Cedaria* Zone, as indicated by trilobites occurring in the underlying and overlying members.

Member D of the Cass Fjord Formation is a prominent-weathering unit (about 45 m) of similar lithology to member B, although the thin grainstone beds are less prominent. *Gordia nodosa* and *Palaeophycus tubularis* were collected from this member in beds yielding *Cedaria* Zone, or possibly younger, Dresbachian trilobites (Palmer & Peel, 1981).

Systematic ichnology

Ichnogenus *Gordia* Emmons, 1844

Type ichnospecies. Gordia marina Emmons, 1844

Diagnosis. Unbranched, predominantly horizontal trails or burrows that wind or loop but do not regularly meander, with a marked tendency to level crossing. Burrow-fill structureless (after Książkiewicz, 1977; Fillion & Pickerill, 1990).

Remarks. At the ichnogeneric level *Gordia* is a commonly occurring facies-crossing ichnotaxon ranging from the upper Vendian Redkino Horizon (Fedonkin, 1988) to the Holocene (Ratcliffe & Fagerstrom, 1980, pl. 1, fig. 1). As discussed more fully below, it has been confused historically with several morphologically similar burrow systems. In part this confusion, and the resultant taxonomic inconsistency, has resulted from the scanty description supplied with the original illustration of *Gordia* by Emmons (1844, p. 24, pl. 2, fig. 2). Additionally, the illustration of *Gordia* given by Häntzschel (1962, p. W196, fig. 2) in the first edition of the

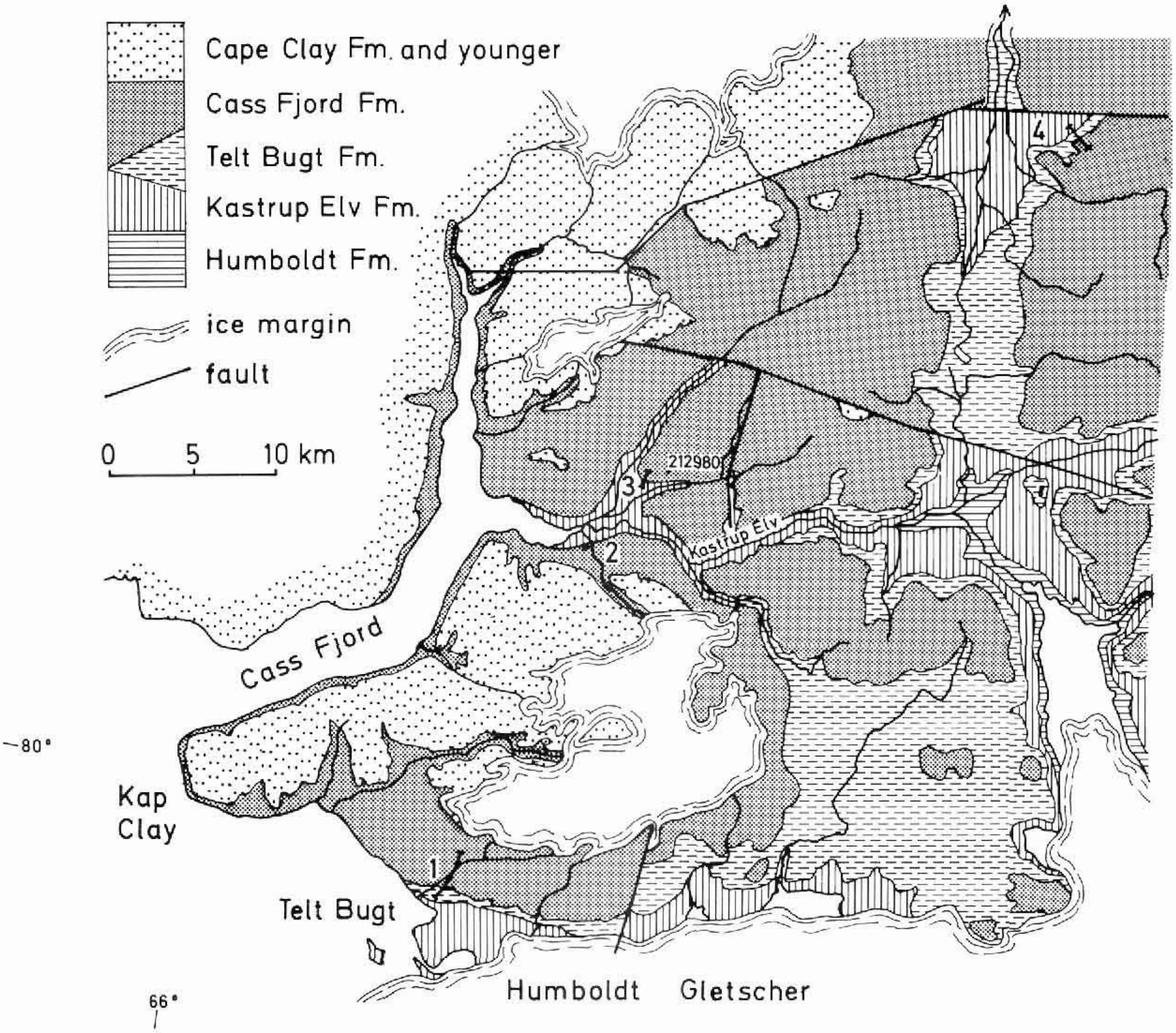

Fig. 2. Geological map of south-western Daugaard-Jensen Land with fossil localities in the Cass Fjord Formation, reproduced from Palmer & Peel (1981, fig. 3). Trace fossils were collected from localities 1 and 4. Locality 1, *Gordia nodosa, Palaeophycus tubularis, Diplichnites* isp. and cf. *Monocraterion* isp. Locality 4, *Cruziana problematica*.

Treatise on Invertebrate Paleontology and adopted by many subsequent authors, is clearly referable to the ichnogenus *Helminthopsis* Heer, 1877 (cf. Fillion & Pickerill, 1990). This illustration was subsequently reproduced in the revised edition of the *Treatise* (Häntzschel, 1975, p. W63, fig. 39, 1b) together with an additional specimen (Häntzschel, 1975, p. W63, fig. 39, 1a) which is a true *Gordia*, most probably *G. marina* Emmons, 1844.

Gordia nodosa isp. nov.

Figs 3,4,5

Diagnosis. *Gordia* characterised by regularly or irregularly positioned annulations throughout or sporadically developed along its course.

Material. Two slabs preserving over 50 specimens from GGU collection 242096 from talus material of Member D of the Cass Fjord Formation, at locality 4 in Fig. 2.

Types. Holotype, MGUH 20.637 (Figs 3a, 4a); selected paratypes MGUH 20.638–20.640.

Etymology. *Nodosus* (L.), *-a, -um* (full of knots) from *nodus* (L. knot).

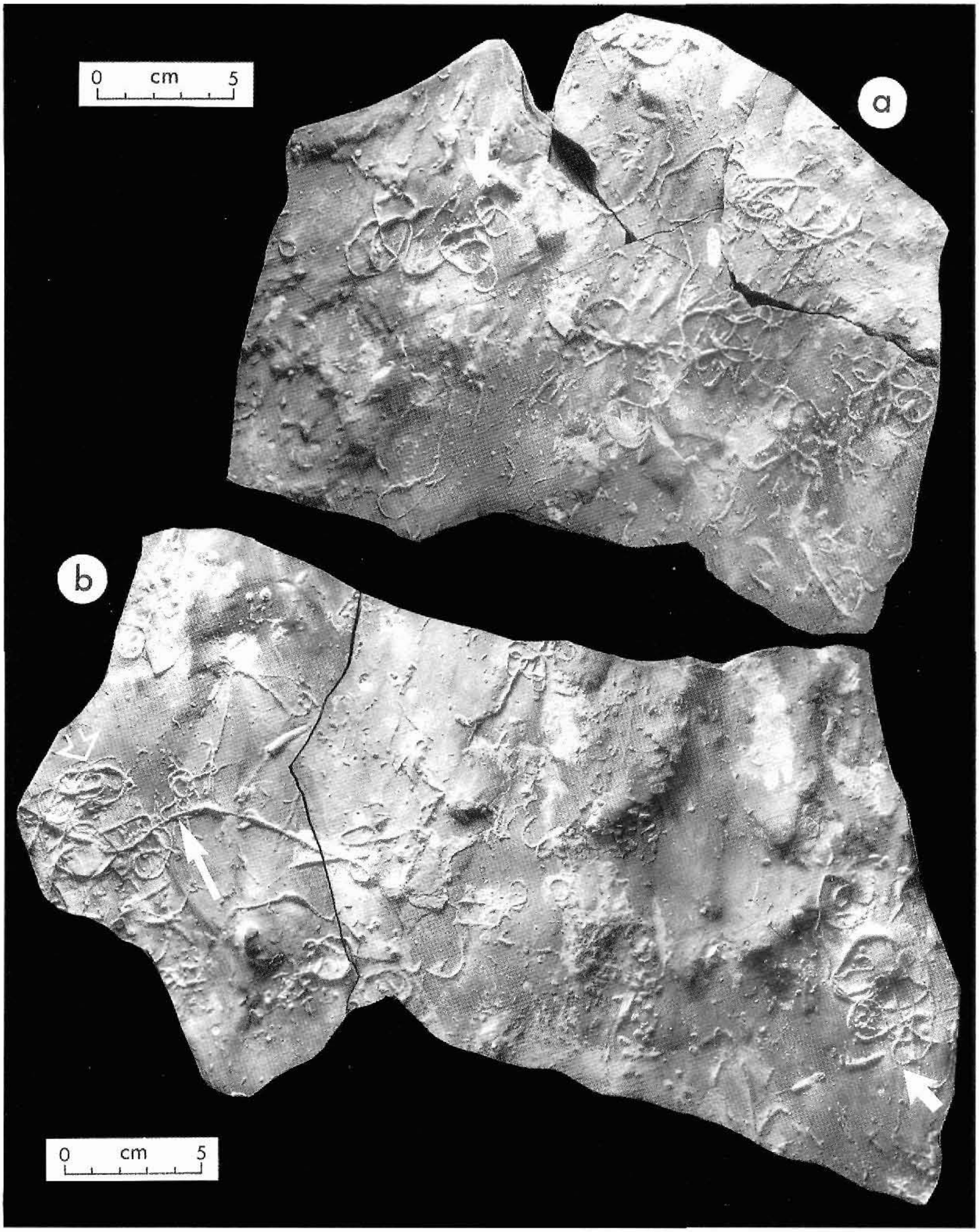

Fig. 3. Two slabs representing GGU collection 242096 exhibiting *Gordia nodosa* isp. nov. preserved in positive hyporelief. Solid arrow in a indicates the holotype, MGUH 20.637. Short solid arrow in b indicates paratype MGUH 20.638, long solid arrow points to paratype MGUH 20.639 and open arrow denotes paratype MGUH 20.640. All arrows are oriented approximately perpendicular to more detailed views seen in Figs 4 and 5.

Description. Specimens are preserved in positive relief on the soles of 2 cm thick, parallel or wavy laminated, calcisiltite. The soles exhibit flute marks and primary current lineations that clearly pre-date *G. nodosa,* thus attesting to a post-depositional origin of the ichnotaxon. Upper surfaces of the two slabs contain abundant examples of *Planolites* as described later.

The material is variably preserved but most examples

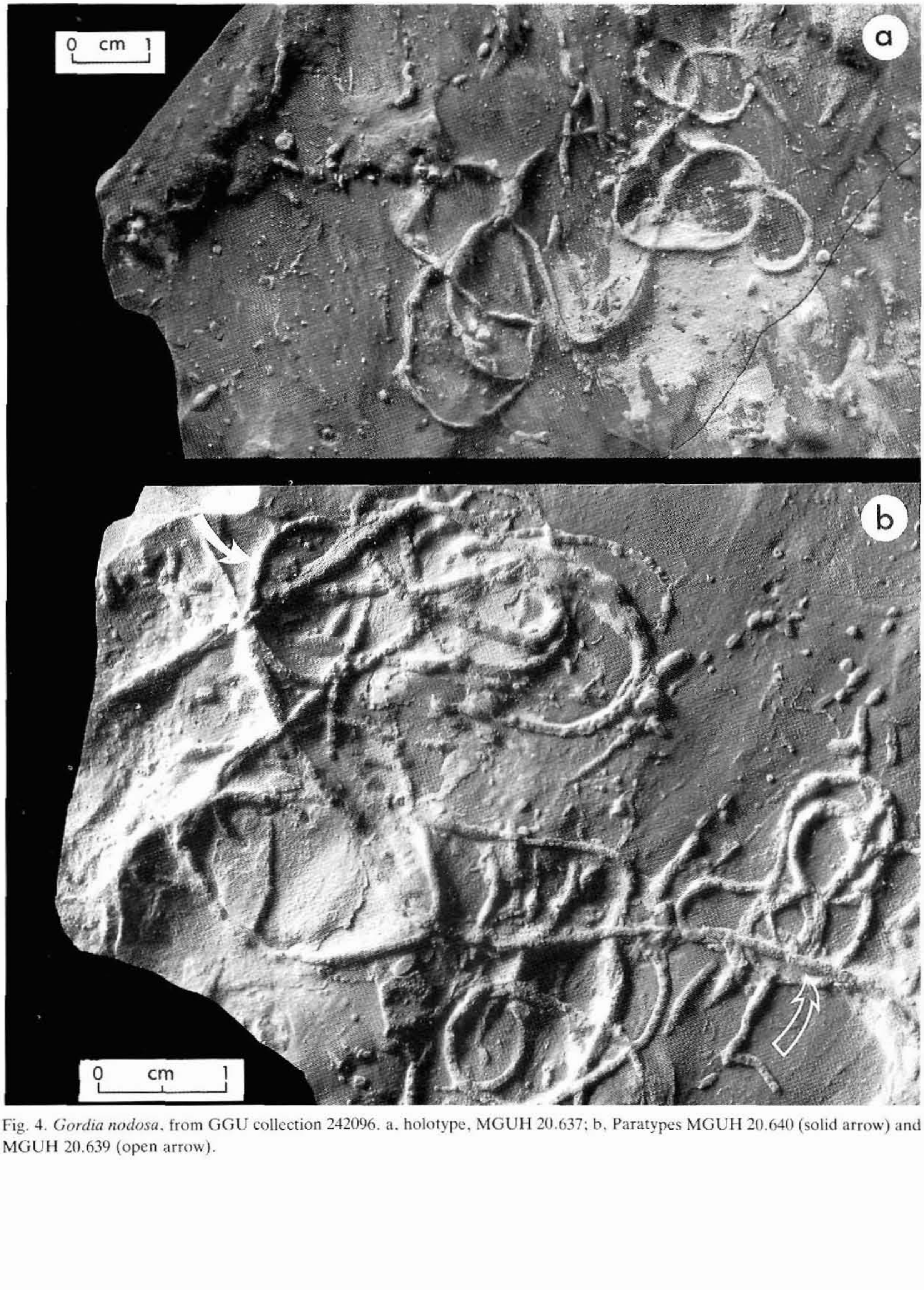

Fig. 4. *Gordia nodosa*, from GGU collection 242096. a, holotype, MGUH 20.637; b, Paratypes MGUH 20.640 (solid arrow) and MGUH 20.639 (open arrow).

comprise simple, long and slender, horizontal burrows, that wind or loop irregularly and exhibit a marked tendency to level crossing. Burrow diameter varies from 0.3 to 1.1 mm and is relatively constant in individual specimens. The full course of many individual burrows is difficult to ascertain as commonly they merge with, and apparently follow, the course of their own or pre-existing burrows. The selected holotype (Figs 3a, 4a) clearly demonstrates this phenomenon. Additionally, individual burrows are commonly crossed by separate burrow systems, which precludes a realistic assessment of the actual number of individual specimens. Less commonly an individual burrow purposely avoids true level crossing and, instead, crosses below, or more rarely above, itself. In such examples, however, true level crossing of the burrows is also typically developed, particularly where an extensive horizontal burrow course can be ascertained.

Burrow-fill is structureless and of the same grain size as the host rock. Burrow linings are absent; cross-sectional shape, where discernible, is circular. Individual burrows are characterised by the development of nodes or annulations thus giving them a beaded appearance. The annulations are irregularly developed; several burrows are annulate throughout their entire course, but more commonly the annulations are interspersed so that annulate sections alternate with non-annulate sections. Typically, the annulations are extremely small with a density of 1 or 2 per mm. Surfaces of the annuli are smooth.

The holotype exhibits the typical irregular winding, looping and level crossing of the ichnotaxon; only portions of this specimen exhibit annulations. The three selected paratypes exhibit winding, looping, and to a lesser degree, self-crossing, but are considerably more annulate.

Remarks. At the ichnogeneric level these structures resemble a number of ichnotaxa, most notably *Helminthoidichnites* Fitch, 1850, *Helminthopsis* Heer, 1877 and *Mermia* Smith, 1909. *Helminthoidichnites* was considered a junior synonym of *Gordia* by Häntzschel (1962, 1975) but was utilised by Hofmann & Patel (1989) and more recently by Narbonne & Aitken (1990). As noted by these authors, it differs from *Gordia* in that level crossing of an individual burrow system is only rarely, if ever, developed. Instead, *Helminthoidichnites* is characterised by irregularly sinuous to meandering burrows with common random crossings of different individuals. *Helminthopsis,* particulary *Helminthopsis tenuis* Książkiewicz, 1968, which Häntzschel (1975) also assigned to *Gordia,* is an irregularly meandering or sinuous form that consistently avoids level crossing. As such it is clearly different from *Gordia* and must not be considered its junior synonym. *Mermia*, an ichnogenus not considered by Häntzschel (1962, 1975), is also comparable to *Gordia,* as also noted by Walker (1985). Although *Mermia* is much thinner (typically <0.5 mm wide) and supposedly possesses more intense looping (see also Pollard & Walker, 1984), the figured neotype of these authors (Walker, 1985, fig. 8a, p. 294; Pollard & Walker, 1984, pl. 2, fig. 6) very closely resembles *G. marina* and a case could reasonably be made to regard it as a junior synonym.

Thus, the material described here is regarded as *Gordia* even though the original scanty description has resulted in general confusion and taxonomic inconsistencies. We adopt *Gordia* for burrows or trails that exhibit a marked tendency to level crossing (cf. Miller, 1889; Narbonne & Hofmann, 1987; Narbonne & Aitken, 1990; Fillion & Pickerill, 1990), as is evident in Emmons' (1847) original illustration and in topotype material subsequently figured by Hall (1847).

We are currently aware of five previously described ichnospecies assigned to *Gordia,* namely *G. marina* Emmons, 1844, *G. molassica* (Heer, 1864), *G. arcuata* Książkiewicz, 1977, *G. hanyagensis* Yang & Hu *in* Yang *et al.* (1987), and *G. maeandria* Jiang *in* Jiang *et al.* (1982). As noted by Pickerill (1981) and reiterated by Narbonne & Hofmann (1987) and Fillion & Pickerill (1990), *G. molassica* should be regarded as a junior synonym of *G. marina* since their respective sizes are unknown and their course is virtually identical. *G. hanyagensis* also agrees in all respects with *G. marina* and was also regarded by Fillion & Pickerill (1990) as a junior synonym. *G. maeandria* is characterised by loose or even guided meanders (e.g. Crimes & Jiang, 1986, p. 646, fig. 4h) with no level crossings, and as noted by Pickerill & Peel (1990), should be assigned to an alternative ichnogenus. *G. arcuata* is an ichnospecies in which only the apical arcuate bends are developed (see Książkiewicz, 1977) and it clearly differs from the material described here.

Irrespective of the acceptance or otherwise of these ichnospecies, the one characteristic common to them all is their smoothness, relatively constant diameter and lack of the annulations which characterise the material described herein as *G. nodosa.*

The nodes or annulations of *Gordia nodosa* are reminiscent of those present in the ichnotaxa *Torrowangea rosei* Webby, 1970, and to some extent *Planolites annularius* Walcott, 1890 and *Palaeophycus tortuosus* Hall, 1847 (questionably regarded as a junior synonym of *Palaeophycus tubularis* Hall, 1847 by Pemberton & Frey, 1982). The annulations perhaps reflect peristaltic movement (cf. Pemberton & Frey, 1982) or small scale

Fig. 5. Paratype MGUH 20.638 of *Gordia nodosa*, GGU collection 242096.

sinuous and undulose motion (cf. Narbonne & Aitken, 1990) by the producing organisms. The absence of internal structure in longitudinal section suggests that the pinch-and-swell appearance does not result from backfill of the burrows (cf. Webby, 1970). It is also worthwhile noting that in similar fashion to *Helminthoidichnites* and *Helminthopsis*, none of these ichnospecies exhibit self level crossing, though they may form irregular meshworks of crossing and branching strands produced as a result of intersections by adjacent burrow systems (see Webby, 1970; Pemberton & Frey, 1982). Thus, these ichnotaxa clearly differ from *G. nodosa* as described herein.

The nature of the producing organisms is of course enigmatic. Fillion & Pickerill (1990) proposed that some *Gordia marina* were produced by a slender bilaterally symmetrical arthropod-like or vermiform organism, and a similar origin for *G. nodosa* cannot be ruled out. The remarkable size and morphological similarity to the burrows and trails produced under laboratory conditions by the foraminifer *Quinqueloculina impressa* Reuss by Severin *et al.* (1982) also suggests the possibility of production by similar organisms, particularly as the fossil record of benthic foraminifera extends well into the Cambrian (Buzas *et al.*, 1987). Interestingly, the examples figured by Severin *et al.* (1982) also exhibit sections where the foraminifer follows its own or previously existing burrows or trails similar to that observed in *G. nodosa*. Trail following (at least in the Gastropoda) may be related to predation (Paine, 1963) or homing (Cook, 1979) as a response to mechano-reception or chemoreception.

Additional trace fossils

Additional ichnotaxa from the available material from the Cass Fjord Formation are figured but only briefly described.

Ichnogenus *Cruziana* d'Orbigny, 1842

Cruziana problematica (Schindewolf, 1921)

Fig. 6

Material. Minimum of 51 specimens from GGU collection 212827 from locality 1 (Fig. 2), Member C, of the Cass Fjord Formation (see Palmer & Peel, 1981).

Description. Specimens are variably preserved in convex relief on the sole of a 1 cm thick calcisiltite. They consist of essentially bilobed, horizontal, symmetrical burrows that follow a straight, curved or slightly flexuous course. Several examples are undulatory, disappearing up into the host stratum and reappearing at a different location. When this undulatory behaviour is conspicuously developed the resultant segments commonly reveal short burrow sections that superficially resemble *Rusophycus* Hall, 1852, particularly *R. didymus* (Salter, 1856), though assignment to this ichnotaxon would obviously be unsatisfactory. The undulatory behaviour of the producing organisms makes an accurate assessment of the number of specimens present on the slab extremely difficult, as commonly the complete burrow course of an individual specimen cannot be ascertained. More rarely, the bilobed burrows extend horizontally into unilobed segments particularly where such segments are more deeply impressed.

Burrows vary in diameter from 0.6 to 3 mm and up to a maximum length of approximately 6 cm. In bilobed sections, the central groove is well developed. Individual burrows commonly cross previously formed examples but never intersect themselves. Lobes are either smooth or possess closely spaced, transverse or highly obtuse unifid scratch marks that extend from the central furrow to the margins of the lobes. Commonly, and for reasons not completely understood, the narrower burrows preserve obvious scratch markings whereas the wider burrows are either smooth or possess poorly preserved scratch markings and exhibit a more obvious development of unilobed segments.

Remarks. We follow the reasoning of Bromley & Asgaard (1979) and Romano & Whyte (1987) to include this material within the ichnogenus *Cruziana* d'Orbigny, 1842 rather than the morphologically similar ichnogenus *Isopodichnus* Bornemann, 1889. The suggestion of Pollard (1981, 1985) to separate these ichnogenera on the basis of age, facies association and nature of producer is considered inappropriate; trace fossil nomenclature should be based on morphology alone, or behaviour as evidenced in morphology rather than other considerations.

Ichnogenus *Diplichnites* Dawson, 1873

Diplichnites isp.

Fig. 7

Material. Six, possibly seven specimens from GGU collection 242103 from locality 4 (Fig. 2), Member B, of the Cass Fjord Formation (see Palmer & Peel, 1981).

Description. Specimens are preserved in negative epirelief on a 1 cm-thick, parallel laminated, calcisiltite. Following the terminology of Osgood (1970), each specimen comprises a set of paired unifid imprints; the width of each set ranges from 2 to 4 cm and length from 2 to 5 cm. Imprints of individual specimens number between six and eleven and are oriented approximately normal to the trace axes. Length of opposing individual imprints is the same but length within a series is variable, the more elongate pairs typically being centrally located. Withdrawal markings occur in association with a single set (Fig. 7a, upper left).

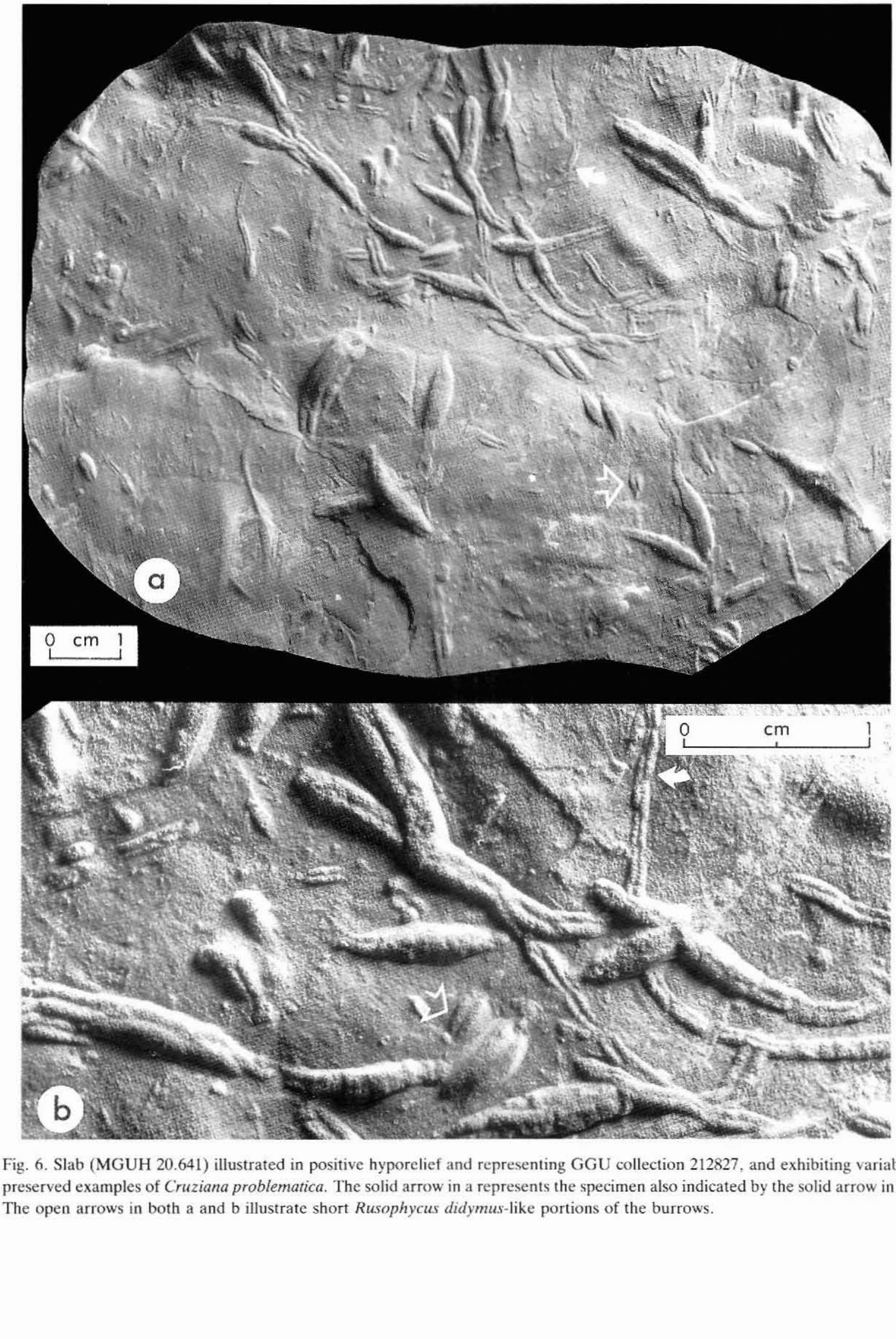

Fig. 6. Slab (MGUH 20.641) illustrated in positive hyporelief and representing GGU collection 212827, and exhibiting variably preserved examples of *Cruziana problematica*. The solid arrow in a represents the specimen also indicated by the solid arrow in b. The open arrows in both a and b illustrate short *Rusophycus didymus*-like portions of the burrows.

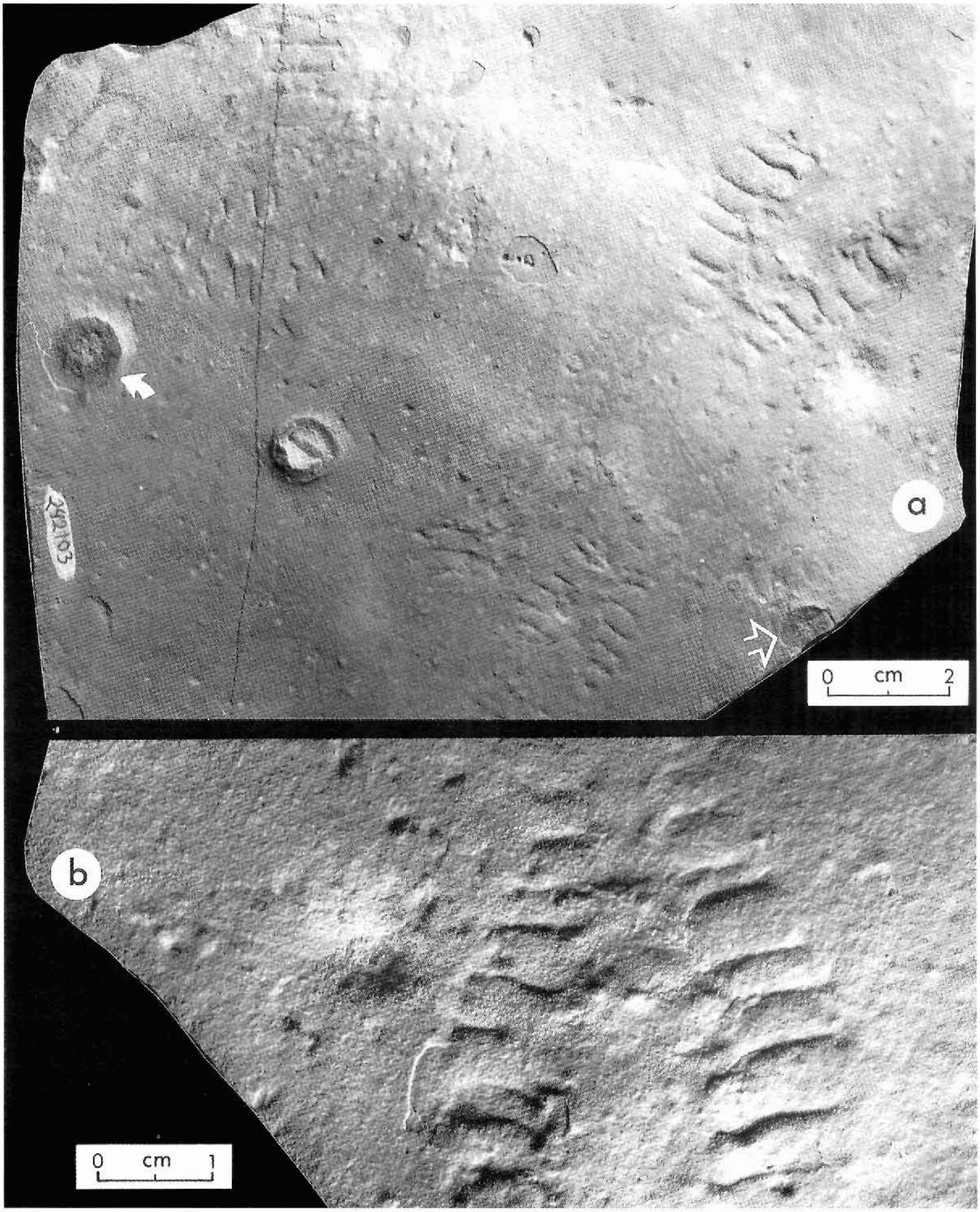

Fig. 7a. Upper surface of GGU collection 242103 illustrating several examples of *Diplichnites* isp. and three specimens in transverse section of cf. *Monocraterion* isp. Arrowed *Diplichnites* isp. is MGUH 20.642, also illustrated in b. Short solid arrow is cf. *Monocraterion* isp., MGUH 20.643, also illustrated in Fig. 8b; open arrow is cf. *Monocraterion* isp., MGUH 20.644, also illustrated in Fig. 8a.

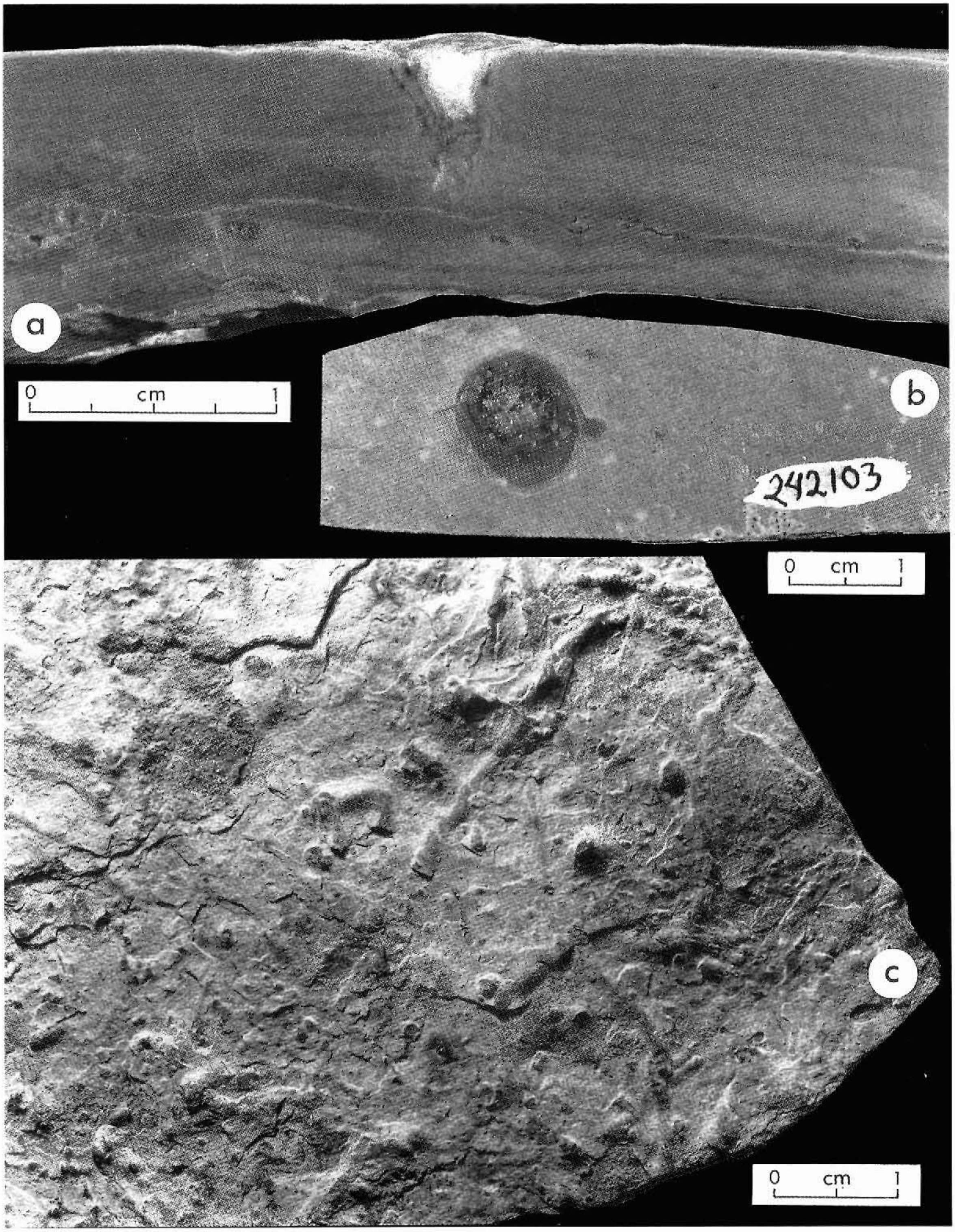

Fig. 8a, longitudinal section of cf. *Monocraterion* isp., MGUH 20.644 from GGU collection 242103. b, Transverse section of cf. *Monocraterion* isp., MGUH 20.643 from GGU collection 242103. c, *Palaeophycus tubularis* preserved on the upper surface of a slab from GGU collection 242096; MGUH 20.645.

Remarks. Fillion & Pickerill (1990) discussed the taxonomic confusion currently existing in ichnological literature with respect to the arthropod-produced trackways of *Diplichnites.* Until a thorough study of the ichnogenus and its possible synonyms is undertaken we prefer to identify the Greenland material only to the ichnogeneric level.

Ichnogenus *Monocraterion* Torell, 1870

cf. *Monocraterion* isp.

Figs 7a; 8a, b

Material. Three specimens from GGU Collection 242103 from locality 4 (Fig. 2), Member B of the Cass Fjord Formation (see Palmer & Peel, 1981).

Description. Specimens are preserved as circular, concentrically lined structures on the upper surface of the slab containing the previously described *Diplichnites.* Two structures are 1.2 cm in diameter, the third 1.0 cm. Each possesses a central sparite-filled core. Rims of the structures are turned slightly upwards. Longitudinal sectioning of the smaller specimen (Fig. 8a) illustrates the linings, the sparite fill and the marked downward tapering of the burrow. Upward deflection of laminae on one side of the burrow is also apparent.

Remarks. The exact nature of these specimens is enigmatic and we are uncertain whether they represent biogenic or physical (water or gas escape) sedimentary structures despite application of the differentiating criteria comprehensively discussed by Ekdale *et al.* (1984). Tentatively, however, we regard them as biogenic. This conclusion is based on the fact that both upper and lower surfaces of the slab containing the specimens possess abundant ichnofossils and personal experience that water and gas escape structures typically occur in more abundant concentration, are accompanied by considerably more bedding deformation, are larger in scale and, on the whole, are morphologically dissimilar to the structures here (cf. Wnuk & Maberry, 1990). Assuming that the specimens are biogenic, they are tentatively compared to *Monocraterion* which we regard as the closest morphological analogue. They also resemble the ichnogenus *Rosselia* Dahmer, 1937 which, however, is a concentric cone-shaped or funnel-shaped burrow produced by active back-filling. The fact that the described structures were originally open, as indicated by their sparite-filled cores, suggests that they are therefore best compared to *Monocraterion.*

Ichnogenus *Palaeophycus* Hall, 1847

Palaeophycus tubularis Hall, 1847

Fig. 8c

Material. Over 50 specimens from GGU collections 242096 and 242103 from, respectively, Member D and Member B of the Cass Fjord Formation at locality 4 (Fig. 2; see Palmer & Peel, 1981).

Description. Simple, straight to slightly curved, rarely slightly sinuous, smooth, horizontal, unbranched burrows preserved in positive hyporelief (GGU collection 242103) or positive and negative epirelief (GGU collection 242096). Burrows are typically 2 to 5 mm in diameter, of variable length, lined or apparently unlined, with a structureless fill of similar grain size to the enclosing host rock.

Remarks. Pemberton & Frey (1982), and more recently Fillion (1989) and Fillion & Pickerill (1990), have discussed in detail the distinction between *Palaeophycus* and the other relatively simple horizontal burrow systems of the ichnogenus *Planolites* Nicholson, 1873. Following their recommendations, these specimens can be confidently diagnosed as *P. tubularis.*

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References

Bergström, J. & Ineson, J. R. 1988: The arthropod trail *Multipodichnus* from the upper Middle Cambrian (Holm Dal Formation) of central North Greenland. *In* Peel, J. S. (ed.) Stratigraphy and palaeontology of the Holm Dal Formation (late Middle Cambrian), central North Greenland. *Meddr Grønland Geosci.* **20,** 113–117.

Bergström, J. & Peel, J. S. 1988: Lower Cambrian trace fossils from northern Greenland. *Rapp. Grønlands geol. Unders.* **137,** 43–53.

Bornemann, J. G. 1889: Über den Buntsandstein in Deutschland und seine Bedeutung für die Trias. *Beiträge Geol., Palaeontol.* **1,** 61 pp.

Bromley, R. G. & Asgaard, U. 1979: Triassic freshwater ichnocoenoses from Carlsberg Fjord, east Greenland. *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **28,** 39–80.

Bryant, I. D. & Pickerill, R. K. 1990: Lower Cambrian trace fossils from the Buen Formation of central North Greenland: preliminary observations. *Rapp. Grønlands geol. Unders.* **147,** 44–62.

Bryant, I. D. & Smith, M. P. 1990: A composite tectonic-eustatic origin for shelf sandstones at the Cambrian–Ordovician boundary in North Greenland. *J. geol. Soc. Lond.* **147,** 795–809.

Buzas, M. A., Douglass, R. C. & Smith, C. C. 1987: Kingdom Protista. *In* Boardman, R. S., Cheetham, A. H. & Rowell, A. J. (ed.) *Fossil Invertebrates,* 67–106. Palo Alto, Oxford, London, Edinburgh, Boston, Melbourne: Blackwell Scientific Publications.

Cook, A. 1979: Homing in the Gastropoda. *Malacologia* **18,** 315–318.

Crimes, T. P. & Jiang Zhiwen 1986: Trace fossils from the Precambrian–Cambrian boundary candidate at Meischucun, Jinning, Yunnan, China. *Geol. Mag.* **123,** 641–649.

Dahmer, G. 1937: Lebensspuren aus dem Taunusquarzit und den Siegener Schichten (Unterdevon). *Preuss. Geol. Landesant, Jahrb.* **57,** 523–539.

Dawson, J. W. 1873: Impressions and footprints of aquatic animals and imitative markings on Carboniferous rocks. *Amer. J. Sci. Arts* **105,** 16–24.

Emmons, E. 1844: *The Taconic System, based on observations in New York, Massachusetts, Maine, Vermont and Rhode Island,* 68 pp. Albany: Caroll & Cook.

Fedonkin, M. A. 1988: Paleoichnology of the Precambrian–Cambrian transition in the Russian Platform and Siberia. *In* Landing, E., Narbonne, G. M. & Myrow, P. (ed.) Trace fossils, small shelly fossils and the Precambrian–Cambrian boundary. *N.Y. State Univ., N.Y. State Museum/Geol. Surv. Bull.* **463,** 12 (only).

Fillion, D. 1989: Les critères discriminants à l'intérieur du triptyque *Palaeophycus–Planolites–Macaronichnus.* Essai de synthèse d'un usage critique. *C. r. Acad. Sci. Paris* **309,** 169–172.

Fillion, D. & Pickerill, R. K. 1990: Ichnology of the Upper Cambrian? to Lower Ordovician Bell Island and Wabana groups of eastern Newfoundland. *Palaeontogr. canadiana* **7,** 119 pp.

Fitch, A. 1850: A historical, topographical and agricultural survey of the county of Washington. Pt. 2–5. *N.Y. Agric. Soc. Trans.* **9,** 753–944.

Hall, J. 1847. *Palaeontology of New York, Volume I. Containing descriptions of the organic remains of the Lower Division of the New York System, (equivalent of the Lower Silurian rocks of Europe),* 338 pp. Albany: C. van Benthuysen.

Hall, J. 1852: *Palaeontology of New York, Volume II. Containing descriptions of the organic remains of the Lower Middle Division of the New York System, (equivalent in part to the Middle Silurian rocks of Europe),* 362 pp. Albany: C. van Benthuysen.

Häntzschel, W. 1962: Trace fossils and Problematica. In Moore, R. C. (ed.) *Treatise on Invertebrate Paleontology* W, W177–W245. New York, Lawrence: Geol. Soc. Am. and Kansas Univ. Press.

Häntzschel, W. 1975: Trace fossils and problematica. *In* Teichert, C. (ed.) *Treatise on Invertebrate Paleontology* W. *Miscellanea, Supplement* 1, 269 pp. Boulder, Lawrence: Geol. Soc. Am. and Kansas Univ. Press.

Heer, O. 1864–1865: *Die Urwelt der Schweiz. Mit sieben landschaftlichten Bildern, elf Tafeln, einer geologischen uebersichtskarte der Schweitz und zahlreichen in den Text eingedruckten Abbildungen,* 622 pp. Zürich: Friedrich Schulthess.

Heer. O. 1876–1877: *Flora fossilis Helvetiae. Die vorweltliche Flora der Schweitz,* 182 pp. Zürich: J. Wurster & Co.

Henriksen, N. & Peel, J. S. 1976: Cambrian – Early Ordovician stratigraphy in south-western Washington Land, western North Greenland. *Rapp. Grønlands geol. Unders* **80,** 17–23.

Higgins, A. K., Ineson, J. R., Peel, J. S., Surlyk, F. & Sønderholm, M. in press: Lower Palaeozoic Franklinian Basin of North Greenland. *In* Peel, J. S. & Sønderholm, M. (ed.) Sedimentary basins of North Greenland. *Bull. Grønlands geol. Unders.*

Hofmann, H.J. & Patel, I. M. 1989: Trace fossils from the type 'Etcheminian Series' (Lower Cambrian Ratcliffe Brook Formation), Saint John area, New Brunswick, Canada. *Geol. Mag.* **126,** 139–157.

Jiang Zhiwen, Luo Huilin & Zhang Shishan 1982: Trace fossils of the Meishucun Stage (lowermost Cambrian) from the Meishucun Section in China. *Geol. Rev.* **28,** 7–13.

Koch. L. 1929: The geology of the south coast of Washington Land. *Meddr Grønland* **73**(1),1, 39 pp.

Książkiewicz, M. 1968: O niektórych problematykach z fliszu Karpat Polskich. III. *Roczn. Pol. Tow. Geol.* **38,** 3–17.

Książkiewicz, M. 1977: Trace fossils in the flysch of the Polish Carpathians. *Palaeontol. pol.* **36,** 208 pp.

Miller, A. A. 1889: *North American geology and palaeontology for the use of amateurs, students and scientists,* 664 pp. Cincinnati: Western Methodist Book Concern.

Narbonne, G. M. & Aitken. J. D. 1990: Ediacaran fossils from the Sekwi Brook area, MacKenzie Mountains, northwestern Canada. *Palaeontology* **33,** 945–980.

Narbonne, G. M. & Hofmann, H. J. 1987: Ediacaran biota of the Wernecke Mountains, Yukon, Canada. *Palaeontology* **30,** 647–676.

Nicholson, H. A. 1873: Contributions to the study of the errant annelides of the older Palaeozoic rocks. *Proc. Roy. Soc. Lond.* **21,** 288–290 (also *Geol. Mag.* **10,** 309–310).

Orbigny, A. 'd. 1842: *Voyages dans l'Amérique méridionale (le Brésil, la république orientale de l'Uruguay, la république Argentine, la Patagonie, la république du Chili, la république de Bolivie, la république du Pérou), exécuté pendant les années 1826–1833,* 188 pp. Paris-Strasbourg: Pitois-Levrault, Levrault.

Osgood, R. G. Jr. 1970: Trace fossils of the Cincinnati area. *Paleontogr. americana* **6,** 277–444.

Paine, R. T. 1963: Food recognition and predation on opisthobranches by *Navanax ineris* (Gastropoda: Opisthobranchia). *Veliger* **6,** 1–9.

Palmer, A. R. & Peel, J. S. 1981: Dresbachian trilobites and stratigraphy of the Cass Fjord Formation, western North Greenland. *Bull. Grønlands geol. Unders* **141,** 46 pp.

Peel, J. S. & Christie, R. L. 1982: Cambrian–Ordovician platform stratigraphy: correlations around Kane Basin. *In* Dawes, P. R. & Kerr. J. W. (ed.) Nares Strait and the drift of Greenland: a conflict in plate tectonics. *Meddr Grønland Geosci.* **8,** 117–135.

Pemberton, S. G. & Frey, R. W. 1982: Trace fossil nomenclature and the *Planolites-Palaeophycus* dilemma. *J. Paleont.* **56,** 843–881.

Pickerill, R. K. 1981: Trace fossils in a Lower Palaeozoic submarine canyon sequence – the Siegas Formation of northwestern New Brunswick, Canada. *Mar. Seds. Atl. Geol.* **17,** 37–58.

Pickerill, R. K. & Harland, T. L. 1988: Trace fossils from Silurian slope deposits, North Greenland. *Rapp. Grønlands geol. Unders.* **137,** 119–133.

Pickerill, R. K. & Peel, J. S. 1990: Trace fossils from the Lower Cambrian Bastion Formation of North-East Greenland. *Rapp. Grønlands geol. Unders.* **147,** 5–43.

Pollard, J. E. 1981: A comparison between the Triassic trace fossils of Cheshire and south Germany. *Palaeontology* **24,** 555–588.

Pollard, J. E. 1985: *Isopodichnus,* related arthropod trace fossils and notostracans from Triassic fluvial sediments. *Trans. Roy. Soc. Edinburgh* **76,** 273–285.

Pollard, J. E. & Walker, E. F. 1984: Reassessment of sediments and trace fossils from Old Red Sandstone (Lower Devonian) of Dunure, Scotland, described by John Smith (1909). *Geobios* **17,** 567–576.

Poulsen, C. 1927: The Cambrian, Ozarkian and Canadian faunas of northwestern Greenland. *Meddr Grønland* **70,** 239–343.

Ratcliffe, B. C. & Fagerstrom, J. A. 1980: Invertebrate lebensspuren of Holocene floodplains: their morphology, origin and paleoecological significance. *J. Paleontol.* **54,** 614–630.

Romano, M. & Whyte, M. A. 1987: A limulid trace fossil from the Scarborough Formation (Jurassic) of Yorkshire; its occurrence, taxonomy and interpretation. *Proc. Yorkshire geol. Soc.* **46,** 85–95.

Salter, J. W. 1856: On fossil remains in the Cambrian rocks of the Longmynd and north Wales. *Quart. J. geol. Soc. Lond.* **12,** 246–252.

Schindewolf, O. H. 1921: Studien aus dem Marburger Buntsandstein, I, II. *Senckenbergiana* **3,** 33–49.

Severin, K. P., Culver, S. J. & Blanpied, C. 1982: Burrows and trails produced by *Quinqueloculina impressa* Reuss, a benthic foraminifer, in fine-grained sediment. *Sedimentology* **29,** 897–901.

Smith, J. 1909: *Upland fauna of the Old Red Sandstone Formation of Carrick, Ayrshire.* 60 pp. Kilwinning: Cross.

Torell, O. M. 1870: Petrifica Suecana Formationis Cambricae. *Lunds Univ. Årssk.* **6,** 1–14.

Walcott, C. D. 1890: Descriptive notes of new genera and species from the Lower Cambrian or *Olenellus* Zone of North America. *Proc. U.S. Nat. Mus.* **12,** 33–46.

Walker, E. F. 1985: Arthropod ichnofauna of the Old Red Sandstone at Dunure and Montrose, Scotland. *Trans. Roy. Soc. Edinburgh* **76,** 287–297.

Webby, B. D. 1970: Late Precambrian trace fossils from New South Wales. *Lethaia* **3,** 79–109.

Wnuk, C. & Maberry, J. O. 1990: Enigmatic eight-meter trace fossils in the Lower Pennsylvanian Lee Sandstone, Central Appalachian Basin, Tennessee. *J. Paleontol.* **64,** 440–450.

Yang Shipu, Hu Changming & Sun Yongchuan 1987: Discovery of Late Devonian trace fossils from Guodingshan district, Hanyang, China and its significance. *Jour. Earth Sci. Wuhan College of Geol.* **12,** 1–8.