Lower Cambrian trace fossils from northern Greenland

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Rusophyciform and cruzianaeform trace fossils are described from Lower Cambrian siliciclastic shelf deposits in North-West and North Greenland. *Cruziana* cf. *C. dispar* Linnarsson, 1869 is reported from the Dallas Bugt Formation of Inglefield Land while a new ichnospecies, *Rusophycus marginatus,* occurs in the Buen Formation of Peary Land and in the equivalent Humboldt Formation of Daugaard-Jensen Land. These species show no similarity to the *Cruziana* sp. previously described from East Greenland. The occurrence of *C.* cf. *C. dispar* could indicate some similarity in Cambrian trace fossil 'ichnofaunas' between Greenland and Europe but available material is insufficient to clarify this relationship.

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Cruzianaeform and rusophyciform arthropod burrows are infrequent trace fossils in the Cambrian of Greenland. Cowie & Spencer (1970) have assigned a few specimens from the Lower Cambrian Ella Island Formation of Strindberg Land, East Greenland (fig. 1) to *Cruziana* sp. but they show no similarity to the burrows described here. Despite the widespread occurrence of Lower Cambrian siliciclastic shelf sediments from Inglefield Land in North-West Greenland to Danmark Fjord in eastern North Greenland (figs 1, 2), arthropod trace fossils of this type have proved elusive. This paper describes the few available specimens from northern Greenland and assigns them to *Cruziana* cf. *C. dispar* Linnarsson, 1869 and *Rusophycus marginatus* n. ichnosp.

Lower Cambrian siliciclastic shelf sediments in northern Greenland are assigned to the Buen Formation of Jepsen (1971) in the region east of Wulff Land and to the equivalent Humboldt Formation in Daugaard-Jensen Land (Jepsen & Dueholm, 1978; see Palmer & Peel, 1981 and Peel, 1982) and Dallas Bugt Formation in Inglefield Land (Peel *et al.*, 1982). The siliclastic sediments form part of the southern shelf sequence of the Franklinian Basin of Arctic Canada and northern Greenland and pass northward into a deep-water trough sequence assigned to the Polkorridoren Group in northern Peary Land (Higgins *et al.*, in press). The Buen Formation varies in thickness between about 250 m and 500 m, being thinner in outcrops in more northern parts of the shelf sequence (northern Wulff Land, fig. 1). A lower sandstone-dominated unit was deposited in inshore tidal and high-energy

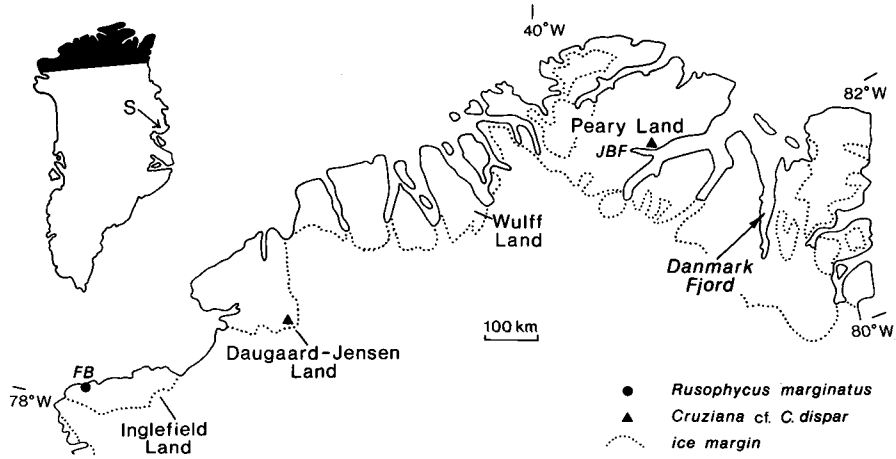

Fig. 1. Localities for Lower Cambrian *Rusophycus* and *Cruziana* in northern Greenland. JBF, Jørgen Brønlund Fjord; FB, Force Bugt. The inset map indicates Strindberg Land (S), the locality for *Cruziana* sp. described by Cowie & Spencer (1970).

storm-dominated environments, while an upper recessive unit is mainly composed of mudstones reflecting lower energy, outer shelf, environments. Peary Land specimens of *Rusophycus marginatus* were collected a few metres from the top of the formation, near the transition to starved ramp carbonate facies present at the base of the overlying Brønlund Fjord Group (Higgins *et al.*, in press).

Two units can also be recognised in the Humboldt Formation (*c.* 150 m) in south-east Daugaard-Jensen Land where a lower cross-bedded sandstone unit with reactivation sur-

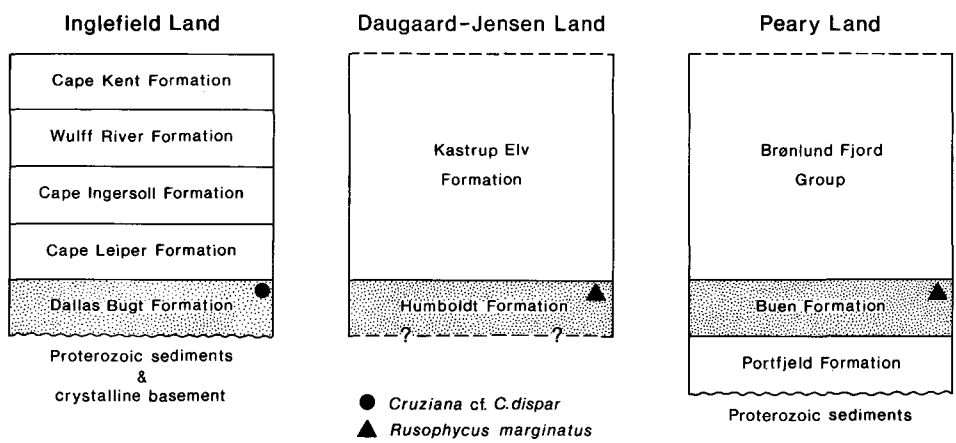

Fig. 2. Lower Cambrian sequences in northern Greenland yielding *Rusophycus* and *Cruziana*. The trace fossils occur in a siliciclastic shelf sequence (shaded) variously assigned to the Dallas Bugt, Humboldt and Buen Formations.

faces and massive beds packed with *Skolithos* is overlain by about 35 m of glauconitic siltstones and sandstones containing *Rusophycus marginatus*.

Sediments of the Dallas Bugt Formation (25–145 m) of Inglefield Land clearly record a Lower Cambrian transgression across eroded Proterozoic siliciclastic sediments and crystalline basement. Older Cambrian strata of the Portfjeld Formation (see Peel, 1988) and Skagen Group, present in more northern and north-eastern areas of Greenland, are not present in Inglefield Land (fig. 2). Feldspathic, conglomeratic red sandstones forming the lower part of the Dallas Bugt Formation (Kap Scott Member) are succeeded by well-sorted, large-scale cross-bedded, white sandstones with reactivation surfaces and massive beds with *Skolithos* (similar to the lower unit in Daugaard-Jensen Land) assigned to the Qáqaitsut Member. These sandstones become interbedded with greenish bioturbated siltstones with *Cruziana* cf. *C. dispar* of the Marshall Bugt Member prior to grading up into dolomites of the overlying Cape Leiper Formation.

The specimens described here are well preserved but their small number hampers appreciation of variation. In consequence, the determination of *Cruziana* cf. *C. dispar* is regarded as only provisional.

Systematic descriptions

Rusophycus marginatus n. ichnosp.

Figs 3–7

Holotype. MGUH 17.591 from GGU sample 270610, upper 3 m of the Buen Formation, Early Cambrian, west side of valley of Børglum Elv, north of Jørgen Brønlund Fjord, Peary Land, central North Greenland (fig. 1). Collected by Stig Schack Pedersen, 15th June 1978.

Additional figured material. MGUH 17.592–17.593 from GGU sample 206302, MGUH 17.594–17.595 from GGU sample 206306. Humboldt Formation, Early Cambrian, extreme south-eastern Daugaard-Jensen Land, western North Greenland. Collected by John S. Peel and Peter Frykman, 13th–15th June 1976.

Diagnosis. An arthropod burrow having scratches made by a comb-shaped limb; occasionally also transverse scratches more irregularly arranged; impression of head-shield with anterior arch; commonly rusophyciform, but also cruzianaeform.

Description. This is a quite variable trace fossil. Most specimens (9) are rusophyciform but there are also at least 3 band-shaped, cruzianaeform traces. The border of the head shield can be clearly impressed in both kinds of traces. The impression appears rounded in the rusophyciform specimens (figs 3, 7) but V-shaped in the cruzianaeform ones (fig. 4), probably owing to different postures of the head during the different kinds of burrowing. Whereas the rusophyciform traces usually have one or a few impressions of the head shield only at the front end, the cruzianaeform traces show a long series of imprints, indicating that the head was repeatedly dipped into the sediment, perhaps once per limb stroke (fig. 4). The impressions indicate a cephalic margin that was elevated in front and supplied with a median fold, a so-called anterior arch. The genal corners appear to have been rounded, lacking a spine.

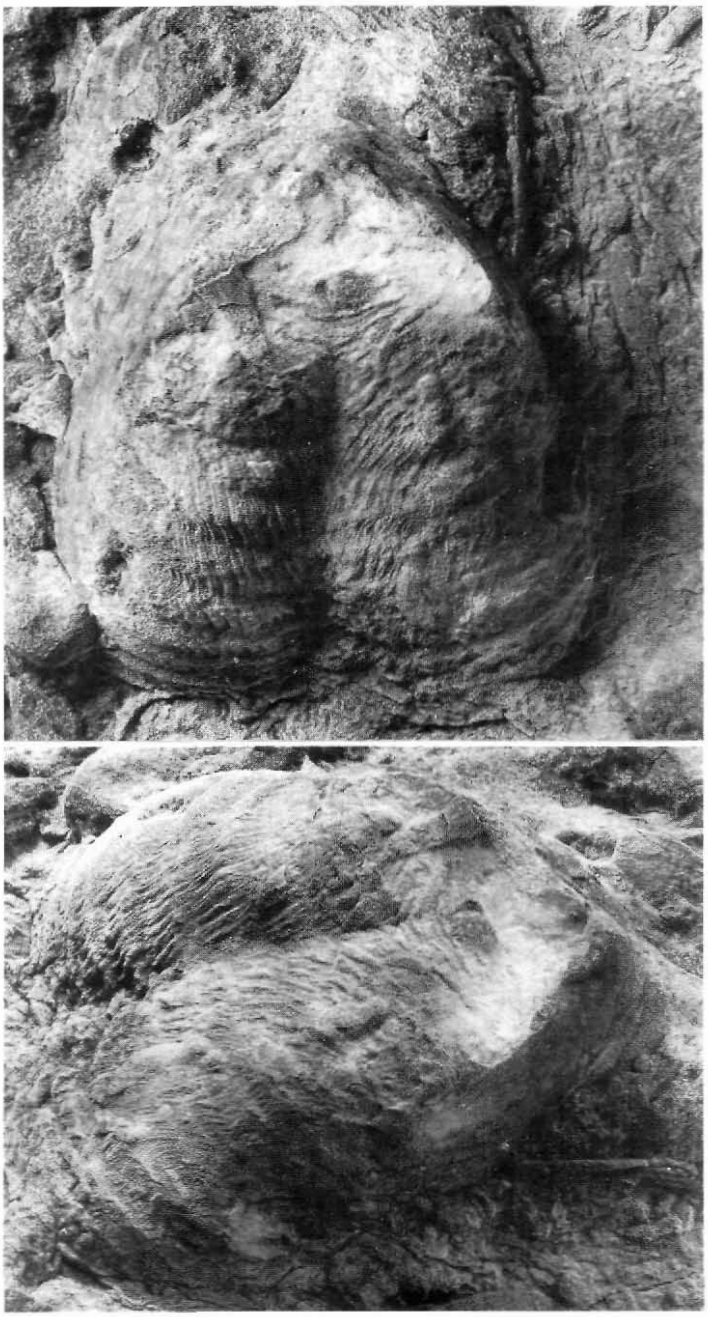

Fig. 3. *Rusophycus marginatus* n. ichnosp. Holotype MGUH 17.591 from GGU sample 270610, Buen Formation, Peary Land. Two views of the deep, rusophyciform burrow with impression of the cephalic shield border and regularly arranged scratches, × 0.8.

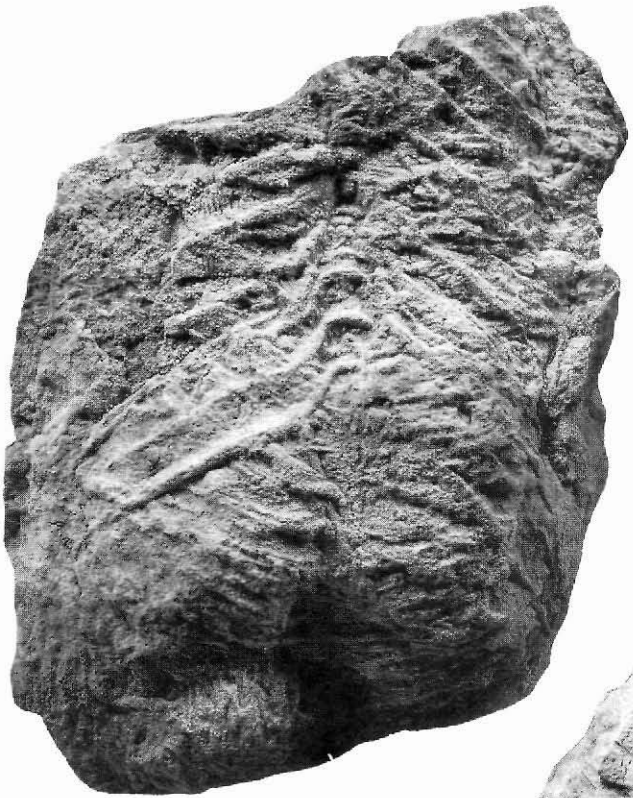

Fig. 4. *Rusophycus marginatus* n. ichnosp., MGUH 17.592 from GGU sample 206302, Humboldt Formation, Daugaard-Jensen Land. Cruzianaeform expression with multiple imprints of cephalic shield border, × 1.

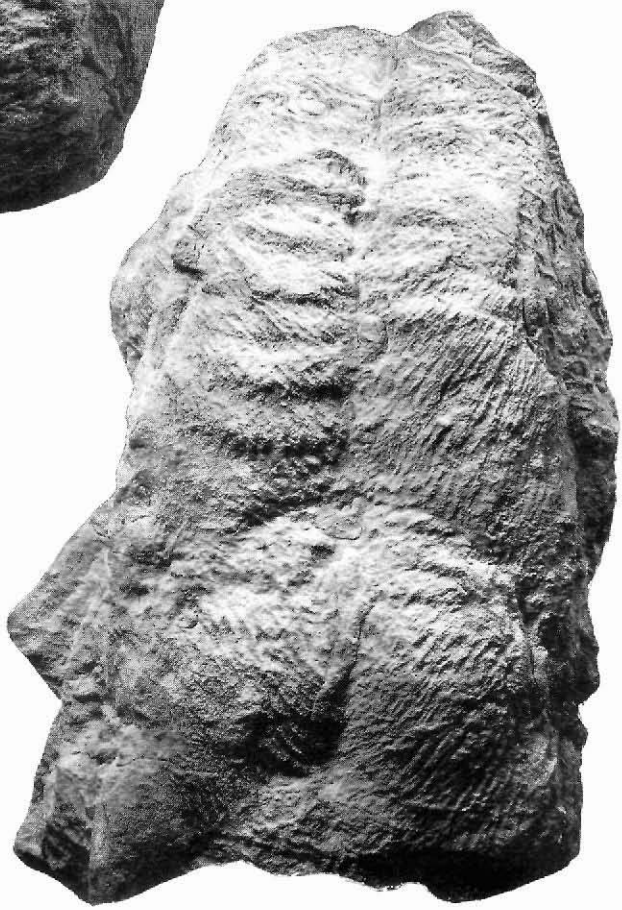

Fig. 5. *Rusophycus marginatus* n. ichnosp., MGUH 17.593 from GGU sample 206302, Humboldt Formation, Daugaard-Jensen Land. Cruzianaeform specimen with regularly arranged scratches made by comb-like organ, × 0.6.

Fig. 6. *Rusophycus marginatus* n. ichnosp., MGUH 17.594 from GGU sample 206306, Humboldt Formation, Daugaard-Jensen Land. Specimen somewhat intermediate between rusophyciform and cruzianaeform expressions, with repeated cephalic border imprints and regularly arranged scratches made by comb-like organ, but also with transverse scratches made by the tips of the walking legs, × 1.5.

Behind the impression of the head margin, the trace widens to a maximum of some 90 mm in the holotype, a specimen having a head shield some 80 mm wide (fig. 3). Regularly arranged scratches made by a comb-shaped limb often make up the rest of the trace (figs 3, 5, 7). The comb imprints are transversely arranged, and cover the whole distance from the mid-line of the trace to the lateral margin. Each individual scratch-trace makes an angle of some 20 to 30 degrees with the length axis of the trace and appears to have been made by a backward–inward directed movement. Particularly in the cruzianaeform specimens, there are scratches forming an angle of 50 to 95 degrees to the length axis. These scratches are more irregular and could have been made by the tips of the walking legs. One specimen instructively shows both kinds of scratches, the transverse ones being more deeply impressed (fig. 6). Most traces are fairly shallow, but two rusophyciform burrows dip considerably toward the head end (fig. 3).

Discussion. In its typical appearence, this trace has similarities with *Cruziana rugosa* d'Orbigny, 1842, which is a cruzianaeform burrow usually without imprints of the head shield. It should be noted, however, that the greatest similarity is with the rusophyciform aspect of the Greenland trace. *C. rugosa* is considered to be restricted to the Arenig–Llandeilo (Ordovician) whereas the similar *C. furcifera* d'Orbigny, 1842 and *C. goldfussi* (Rouault, 1850) have been reported from the Tremadoc (basal Ordovician) as well (Crimes, 1970, 1975; Seilacher, 1970; Bergström, 1976). None of them is reported from the Cambrian, nor is any other form with comb-set scratches.

The Buen Formation yields *Olenellus? hyperboreus* (V. Poulsen, 1974), *O.* cf. *O. svalbar-*

Fig. 7. *Rusophycus marginatus* n. ichnosp., MGUH 17.595 from GGU sample 206306, Humboldt Formation, Daugaard-Jensen Land. Rusophyciform burrow with regular scratches and impression of cephalic border, × 2.

densis Kielan, 1960 (V. Poulsen, 1974) and a new nevadiid described as *Buenellus* by Blaker (1988). Other as yet undescribed olenellid and nevadiid trilobites are also present (Palmer & Peel, 1979). The shape of the cephalic border, however, precludes these from being the trace makers. The anterior arch indicates that the trace-maker may have been able to roll up into a spiral. The arch then would have accommodated the pygidial or posterior thoracic axis, just as it does, for example, in the calymenids. A similar adaptation is found in various solenopleuraceans, a group extending into the Lower Cambrian. Solenopleuraceans such as ellipsocephalids are often devoid of genal spines, a feature also apparently characterising the trace-maker. Solenopleuraceans have been reported from slightly higher levels in the Lower Cambrian of Inglefield Land (C. Poulsen, 1927), but they seem to be too small to be potential trace-makers.

Large arthropods other than olenellid trilobites do occur, however, in Lower Cambrian strata from North Greenland. Blaker (1986) has reported diverse assemblages of Lower Cambrian trilobites from the Brønlund Fjord Group of central North Greenland which stratigraphically overlies the Buen Formation (fig. 2). Species of *Ogygopsis* Walcott, 1889 are common and individuals may reach 100 mm in length.

Conway Morris *et al.* (1987) described the occurrence of a poorly mineralised fauna from the Buen Formation of western Peary Land. The fauna is as yet poorly known but a conspicuous element is an arthropod resembling the arthropod *Tegopelte* Simonetta & Delle Cave, 1975, differing from the type species in possessing at least 10 segments. Greenland specimens of this form may attain a length of 250 mm.

Cruziana cf. *C. dispar* Linnarsson, 1869

Fig. 8

Figured material. MGUH 17.596–17.597 from GGU sample 243404, Dallas Bugt Formation, Marshall Bugt Member, Early Cambrian. Force Bugt, Inglefield Land, North-West Greenland. Collected by Peter R. Dawes, 11th July 1978.

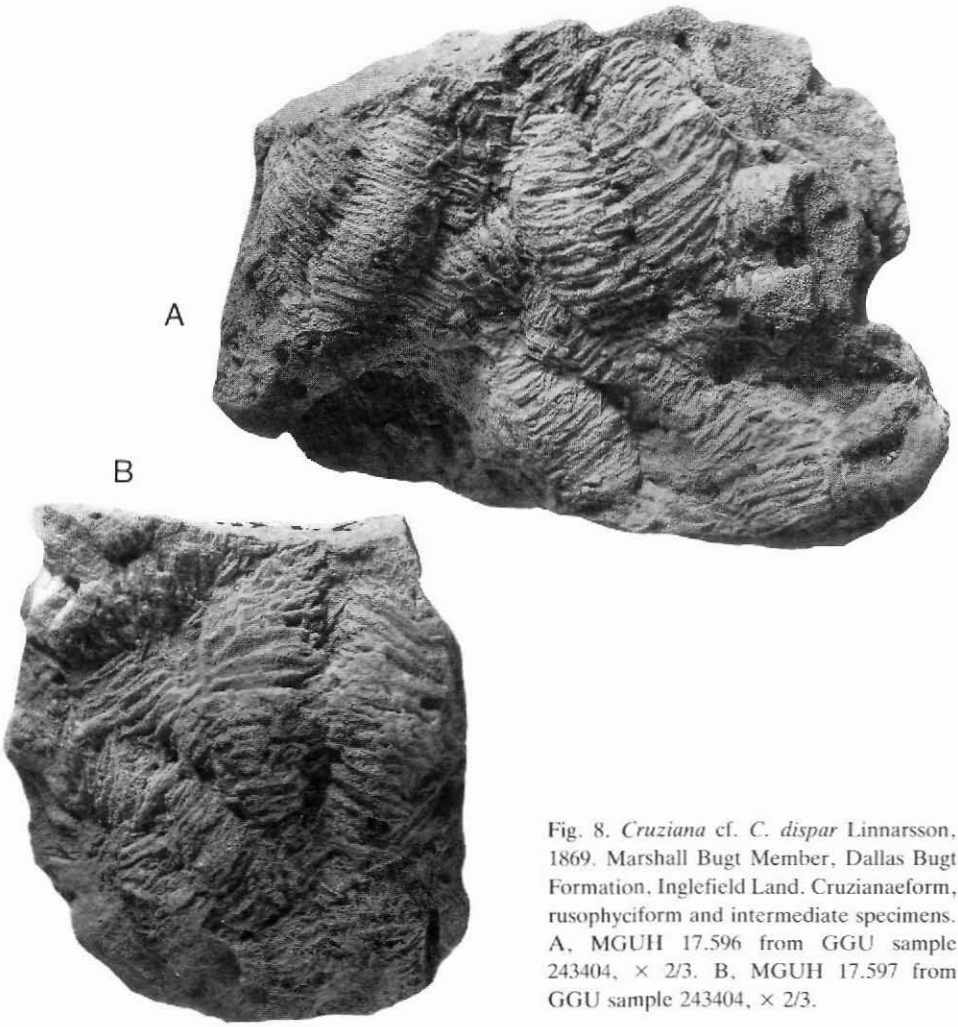

Fig. 8. *Cruziana* cf. *C. dispar* Linnarsson, 1869. Marshall Bugt Member, Dallas Bugt Formation, Inglefield Land. Cruzianaeform, rusophyciform and intermediate specimens. A, MGUH 17.596 from GGU sample 243404, × 2/3. B, MGUH 17.597 from GGU sample 243404, × 2/3.

Additional material. Poorly preserved *Cruziana* probably assigned to this ichnospecies may be locally common at several localities in the same stratigraphic unit in Inglefield Land.

Description. This is a distinctive arthropod trace fossil with coarse scratches made by walking legs. The scratches form an angle of 70 to 90 degrees to the mid-line of the trace. Close to the end of the short traces, the angles can be smaller, reaching some 60 degrees. Both cruzianaeform (repichnial) and rusophyciform (cubichnial) expressions occur. The width varies from about 40 mm to at least 50 mm.

Discussion. In the small collection available there seems to be roughly as many rusophyciform specimens (4) as there are cruzianaeform expressions of this trace fossil; the latter type of trace is usually disturbed by the former which makes a definite count difficult. This cross-cutting relationship may be taken to indicate that the rusophyciform traces were emplaced deeper in the sea floor than the cruzianaeform expressions.

The coarse transverse scratches are typical of traces produced by the walking leg branches of biramous arthropod limbs. The traces can not be distinguished from *Cruziana dispar,* originally described by Linnarsson (1869) from the Lower Cambrian *Mickwitzia* Sandstone of Västergötland, Sweden, but the identification is considered as provisional on account of the small number of specimens available. *C. dispar* has been identified subsequently from the Lower Cambrian Norretorp Formation (*Schmidtiellus mickwitzi* Zone) of Scania, Sweden (Bergström, 1973, p. 53) and from the Lower Cambrian of Mjøsa (1aβ) and Finnmark, Norway (Duolbasgaissa Formation). Orłowski *et al.* (1970) described *Cruziana rusoformis* from the Lower Cambrian *Holmia* beds and Middle Cambrian *Oelandicus* beds of Poland. It seems that Seilacher (1970) was justified in placing this species in synonymy with *C. dispar.* More or less similar traces are described as *C. barbata* Seilacher, 1970 from the Middle Cambrian of Spain, *C. grenvillensis* (Dawson, 1864) from the Middle Ordovician of Canada and *Rusophycus leifeirikssoni* Bergström, 1976 from the Tremadoc(?) of Newfoundland (Seilacher, 1970; Bergström, 1976). These are all made by walking leg branches but differ in general aspect from *C. dispar.* Traces probably produced in the same way are *C. cantabrica* Seilacher, 1970 and *C. fasciculata* Seilacher, 1970 from the Lower Cambrian of Spain (Seilacher, 1970; Crimes *et al.,* 1977), but the available illustrations do not permit a close comparison.

Seilacher (1970, p. 457 and figs 1, 5c and 7:6) indicated that there is an obvious divide between proverse and obverse scratches in *C. dispar* and similar traces, particularly in 'resting' (rusophyciform) burrows which were commonly made during hunting (cf. Bergström, 1973, p. 54). Such a divide is not seen in the Inglefield Land material. A clear divide, however, is rarely seen in specimens of this ichnospecies from Scandinavia and specimens having a divide so clearly indicated as in Seilacher's drawings must be rare. Usually, there is a more gradual change from the anterior to the posterior end.

Most walking-leg burrows are from the Lower Cambrian and, in Scandinavia, they may all be from the *Schmidtiellus mickwitzi* Zone (Bergström, 1981). The Lower Cambrian specimens from Scandinavia and Poland are thought to have been made by olenellid trilobites, as there are hardly any other potential trace-makers known as body fossils. This could also be the case with the Inglefield Land specimens, although this source area belongs to a different faunal province and the olenellids are forms other than those in Scandinavia and Poland. A large number of olenellids and other trilobites have actually been described from slightly

younger Lower Cambrian strata in Inglefield Land (C. Poulsen, 1927, 1958; V. Poulsen, 1964). On the other hand, in view of the known occurrence of poorly mineralised arthropods in the Buen Formation of Peary Land (Conway Morris *et al.*, 1987), the possibility that the trace-maker was not a trilobite must also be entertained.

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