

# Trace fossils from the Dividalen Group, northern Sweden: implications for Early Cambrian biostratigraphy of Baltica

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Trace fossils from the Torneträsk Formation, Dividalen Group, in northern Sweden indicate that most or all of the succession is Early Cambrian in age. This contrasts with previous work which placed the lower part of the formation in the Vendian, a conclusion based on the occurrence of the 'medusoid' body fossil *Kullingia concentrica*. We report here an assemblage of Early Cambrian traces below *Kullingia*-bearing horizons. In addition, we report the body fossil *Sabellidites* sp. from the upper Lower siltstone member at the same level as *Kullingia*. Together these fossils indicate correlation with sections in Ukraine attributed to the upper part of the Rovno 'stage'. Late Early Cambrian trilobites in the uppermost part of the Torneträsk Formation occur above a dolomitic horizon with phosphatic pebbles. Below this horizon, no fossils indicative of Talsy or younger age were found, suggesting that the phosphatic level may represent a significant unconformity. The age of the oldest deposits of the Torneträsk Formation, including the Lower sandstone member and the basal Lower siltstone member, remains uncertain, as no age-diagnostic fossils were observed. Many of the trace fossils observed in this study, including cf. *Curvolithus*, *Treptichnus*, *Phycodes*, and *Teichichnus*, exhibit a three-lobed lower surface on some of the specimens. This feature is common in Early Cambrian traces, but extremely rare in younger deposits, suggesting that it represents a significant but unknown group of Early Cambrian burrowing animals.

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## Introduction

The Torneträsk Formation of the Dividalen Group is exposed beneath the Caledonian nappes as the autochthonous cover of Archaean and Proterozoic crystalline basement. It forms a thin margin along the eastern Caledonian front in northern Sweden (see e.g. Kulling 1964, 1972, 1982; Thelander 1982) (Fig. 1). It is dominantly a siliciclastic succession (Fig. 2) formed in a shallow-water fluvial, tidal and storm-influenced setting (Thelander 1982). In its upper part, trilobites indicative of a late Early Cambrian age have been found (see e.g. Ahlberg 1985). Following finds of the supposed Ediacaran-type non-skeletonized metazoan *Kullingia concentrica* Glaessner, in Føyn & Glaessner (1979), the lower part of the Torneträsk Formation has been considered Vendian in age (Kulling 1968, 1972; Føyn & Glaessner 1979). No other body fossils have been reported from, or below, the horizon yielding *K. concentrica*, except for reports of large filamentous organic films attributed to *Vendotaenia* cf. *antiqua* (Vidal 1981, p. 39).

Trace fossils in the Torneträsk Formation have been reported but, although some were illustrated by Kulling (1950, Fig. 2; 1964, Figs. 17–19) and Thelander (1982, Fig. 7), they were not fully documented. A more detailed study of trace fossils from the Torneträsk Formation, based on a collection made by Oskar Kulling, can be found in a thesis (Stodt 1987). Stodt (1987) suggested that beds with *Kullingia* correlate with the Rovno 'stage' of the East European Platform.

In recent years, trace fossils have emerged as key elements in stratigraphy at the Precambrian–Cambrian boundary owing to an increase in trace fossil diversity in the Early Cambrian, and the recognition of a similar sequence of first appearances in different successions world-wide (see e.g. Crimes 1987, 1992; Narbonne et al. 1987; Walter et al. 1989). Here we describe the distribution of trace fossils in the Torneträsk Formation, and discuss the implications for regional correlation and correlation with the East European Platform. This study demonstrates that the entire Torneträsk Formation may be Early Cambrian, and that the body fossil *Kullingia concentrica* occurs above trace fossils indicative of Early Cambrian or younger strata.

This study is based on material collected during fieldwork in the Torneträsk area in 1992. We also examined material in the Swedish Geological Survey, Uppsala, largely consisting of a collection made by Oskar Kulling. Figured material is housed with the Swedish Museum of Natural History, Stockholm (RM) and the Swedish Geological Survey, Uppsala (SGU).

## The Torneträsk Formation

### *Geological setting and previous studies*

The dominantly siliciclastic strata of the Dividalen Group rest unconformably upon Proterozoic crystalline basement ( $1565 \pm 25$  Ma; Welin et al. 1971) in the northwest-

ern part (current orientation) of Baltica (Fig. 1). Deposition occurred following episodic rifting of Baltica from Laurentia that spanned most of the Neoproterozoic (Kumpulainen & Nystuen 1985; Vidal & Moczyłowska 1995). These autochthonous (or para-autochthonous) sediments below the Caledonian overthrust in the Torneträsk area were first described in detail by Moberg (1908) from a brook-section on the north side of the mountain Luovárri (in the literature given as Luopahta and Luopakke; Fig. 1). Subsequently, several schemes of lithological subdivisions have been used (Kulling 1960, 1964, 1972; Thelander 1982; Stodt 1987). Here we follow the scheme of Thelander (1982), who recognized the Torneträsk Formation as the clastic rocks between the Proterozoic basement and the overlying black Alum shale (Fig. 2). The Torneträsk Formation and the Alum Shale Formation together form the Dividalen Group (Føyn 1967). Thelander (1982) recognized five informal members that in part correspond to Kulling's (1964) formations (Fig. 2). Thickness of the members varies considerably between sections; the following description refers mainly to the Luovárri section, which is the best studied and most complete (Fig. 2). We also refer to the Davip Duobdejohka section (given as Tjäurajåkka in the literature) from the northern side of Lake Torneträsk, which preserves a somewhat different succession (Fig. 2).

The Lower sandstone member consists of cross-bedded feldspathic sandstones and quartzose sandstones, interpreted as mostly fluvial (Thelander 1982). The basal part is conglomeratic and locally a regolith is developed on the crystalline basement (Thelander 1982; Stodt 1987). Kulling (1964, p. 26) stated that in two localities north of Lake Torneträsk, there are abundant trace fossils on bedding planes of shaly sandstone near the top of the Lower sandstone formation. Unfortunately, no details were given of the morphology of these trace fossils. The Lower siltstone member consists of siltstones, fine sandstones and rare layers of coarse sand, with the input of sand increasing towards the top. It is the upper part of this member (corresponding to the Middle sandstone of Kulling), that contains *Kullingia concentrica* (Kulling 1960, 1972; Føyn & Glaessner 1979) (Fig. 3).

At Luovárri, *K. concentrica* occurs in a 1.2 m-thick pack of shaly to silty beds just below dolomitic sandstones (Figs. 2, 4c). On the northern side of Lake Torneträsk, *K. concentrica* is found in silty to sandy storm beds of the upper part of the Lower siltstone member at Davip Duobdejohka (Figs. 2, 4a). On the northern side of Lake Torneträsk, the Lower siltstone member is truncated by the Vakkejokk Breccia (Fig. 4a). This breccia is not found at Luovárri, but dolomitic sandstone with a basal conglomerate occupies a correlative position (Fig. 4c). This conglomerate has been taken to indicate a stratigraphic gap and has been used to divide Proterozoic rocks below and Lower Cambrian rocks above (Kulling 1972; Vidal 1985). Thelander (1982) placed the conglomerate at the base of the Red and green siltstone member which consists largely of siltstone, with increasing

amounts of sandstone in the upper part. *Platysolenites antiquissimus*, *P. lontova*, *Hyolithus* sp. and *Volborthella tenuis* have been reported from this member in the Torneträsk area (Moberg 1908; Kulling 1964). With the exception of *Platysolenites antiquissimus* (Moberg 1908), the reported body fossils are poorly documented. The report of *Volborthella* is doubtful according to Bergström (Bergström & Gee 1985, p. 251), and the one figured specimen of *Hyolithus* sp. (Moberg 1908) is difficult to evaluate.

In addition to the above body fossils, Moberg (1908, p. 16) reported conical bodies comparable with *Monocraterion*. We were unable to find any such structure during this study. Reports of an erratic boulder with the trace fossil *Monocraterion tentaculatum*, attributed to the 'Middle sandstone formation' by Kulling (1960, p. 41; 1964, p. 29), were later said to originate from the Upper sandstone member (Kulling, personal communication in Føyn & Glaessner, 1979). The overlying Upper sandstone member (35 m) consists of thin- to medium-bedded sandstones with thin shale interbeds (Fig. 4b). In its lower part, mud-clasts are common (Fig. 2). No body fossils are known, but trace fossils have been reported (Kulling 1960; Thelander 1982) and Mens et al. (1987, 1990) listed *Scolicia*, *Spirodesmos* and *Gyrolithes*?. The Upper sandstone member at Luovárri is topped by conglomeratic sandstone, followed by thin dolomitic limestone containing phosphorite pebbles and stromatolites (Kulling 1960; Thelander 1982; Stodt 1987). This dolomitic horizon constitutes the basal part of the Upper siltstone member. North of Torneträsk, at the Vaivantjåkka locality in Norway, this level contains the trilobite *Ellipsocephalus* cf. *grippi*, and inarticulate brachiopods (Ahlberg 1980). The Upper siltstone member (18 m) consists largely of massive siltstone with some horizons containing significant amounts of carbonate. Trilobites have been found in calcareous units at the top of the Upper siltstone member at Luovárri (Moberg 1908; Ahlberg 1980, 1984, 1985; Ahlberg & Bergström 1978): a recent listing includes *Strenuaeva inflata*, *Comluella? lapponica* and *Proampyx triangularis*. These trilobites indicate a stratigraphic level high in the Early Cambrian (see e.g. Ahlberg 1991), corresponding to the *Holmia kjerulfi* or *Proampyx limmarssoni* Zones (see e.g. Mens et al. 1987, 1990).

#### Trace fossils

The following discussion concentrates on trace fossils that are considered stratigraphically important, but does not constitute a complete listing. In this study, trace fossils were first encountered in the Lower siltstone member at Luovárri (Fig. 2). Ichnofossils in this member are abundant in thin- to medium-bedded sandstones with thin shale partings, and include *Treptichnus* isp., *Gyrolithes* isp., *Bergaueria perata*, *Palaeophycus* isp., and cf. *Curvolithus* isp. (Fig. 5). The *Treptichnus* range from

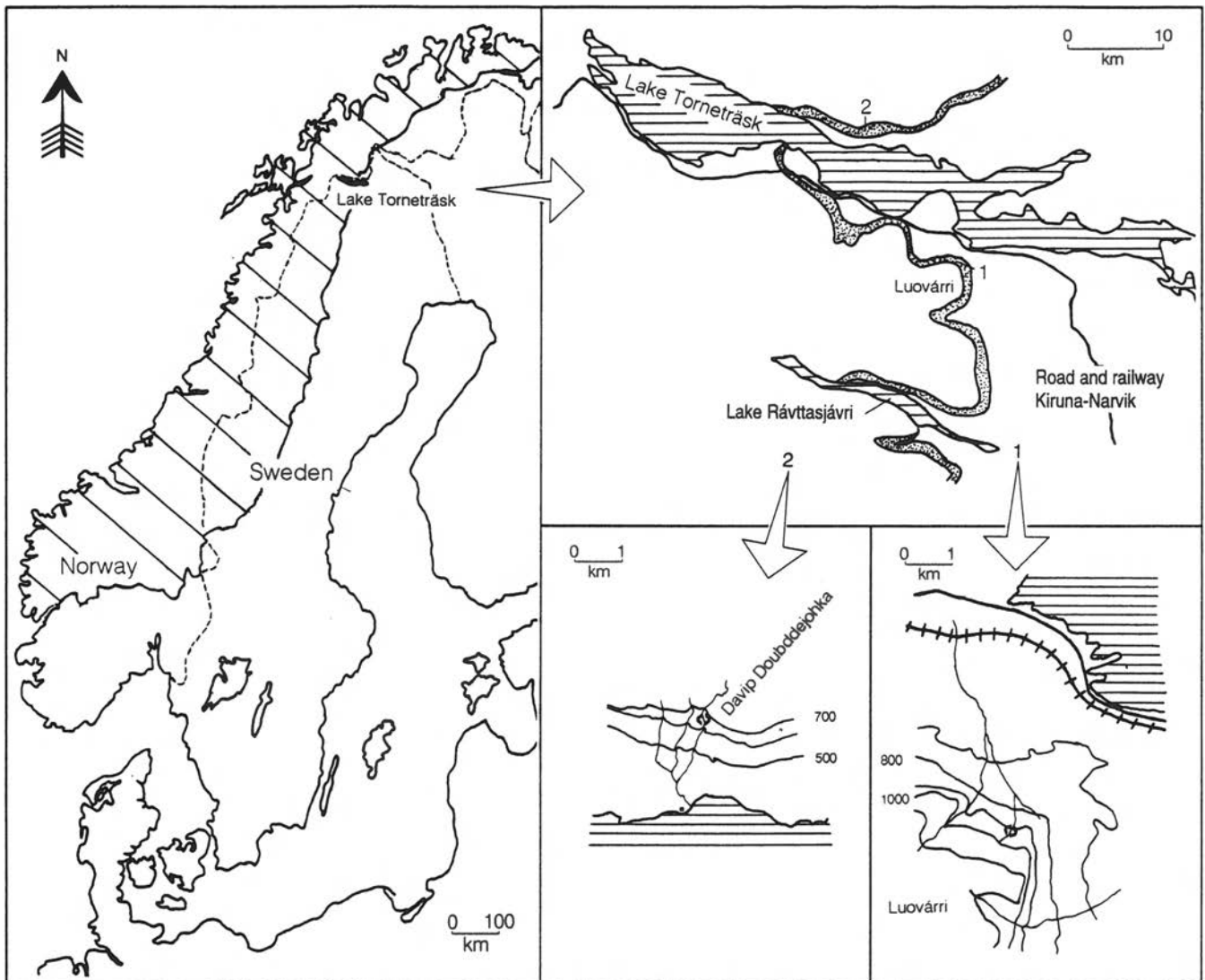


Fig. 1. Generalized maps showing site of localities of the Tornetråsk Formation examined in this paper. Area covered by slanting lines marks Caledonide nappes. Stippled area shows distribution of Dividalen Group at Tornetråsk. Based on Kulling (1964) and Thelander (1982).

specimens with segments of strongly alternating direction, including zigzag development, to forms generally attributed to *Phycodes pedum* (Figs. 5d, 5f; see below for discussion on the relation of *Treptichnus* and *Phycodes pedum*). Only one specimen of *Gyrolithes* was found, with a partly preserved vertical spiral (Fig. 5b).

A type of trace fossil, occasionally occurring in great numbers, consists of straight to curved burrows which often form loops (Fig. 5a). Similar burrows have been described by Hanken & Bromley (1984, Fig. p. 6) from the Dividalen Group at Nordreisa, Norway. *Bergaueria* in the Lower siltstone member consist of plug-shaped burrows up to 25 mm long, some possessing a poorly-developed central depression (Fig. 5c). These appear to conform with *Bergaueria perata* Prantl, 1946 (see Pemberton et al. 1988). cf. *Curvolithus* isp. exhibit burrows with a wide central lobe and two narrow marginal lobes (Fig. 5e). Specimens of cf. *Curvolithus* isp. were found in float, but in close proximity to identical rocks in the

upper part of the Lower siltstone member. Higher up in the Lower siltstone member at Luovárre, in beds yielding *Kullingia*, the most common trace fossils are horizontal straight to contorted burrows 1–2 mm wide, occasionally with a beaded appearance. These burrows range in appearance from *Palaeophycus* to *Helminthoidichnites* and possibly *Torrowangea*. In addition, *Bergaueria perata* are found in the *Kullingia*-bearing horizons, but these specimens are notably smaller than those observed downsection.

Several forms of ichnofossils were found in the top layers of the Red and green siltstone member and the Upper sandstone member, including *Phycodes palmatus*, *Teichichnus* isp., and large trace fossils of the *Psammichnites* group (Fig. 6). Interestingly, several of these also show a three-lobed lower surface, suggesting that these different trace fossils may have been produced by the same type of animal. One specimen combines features of *Teichichnus*, cf. *Curvolithus* and *Treptichnus* (Fig. 6b).

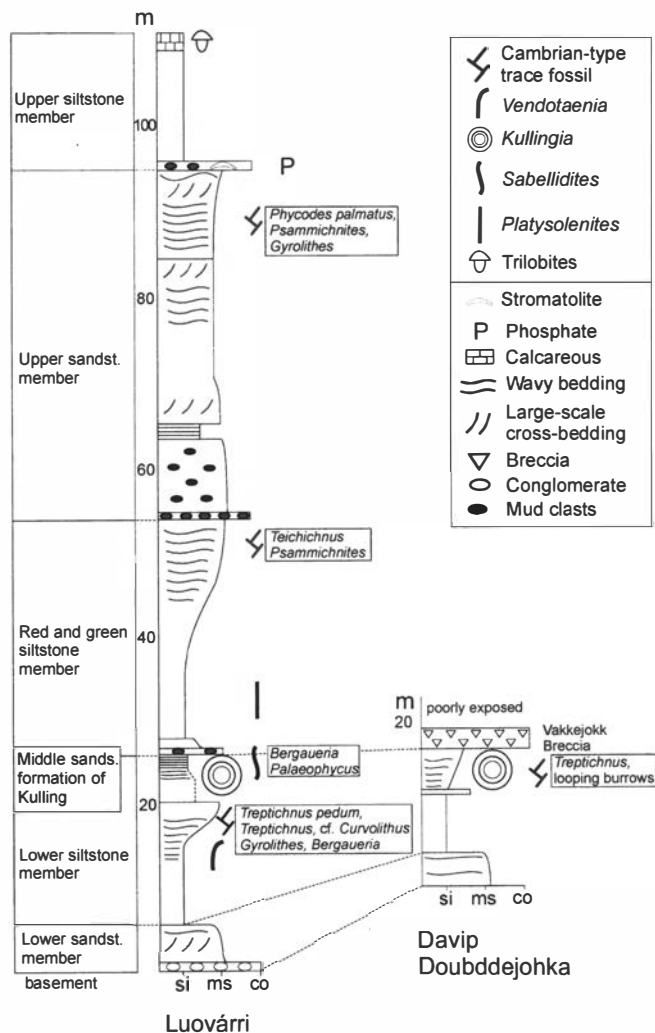


Fig. 2. Geological sections of the Torneträsk Formation from brook-section on the north-east slope of Luovárri (1) and along the rivulet Davip Doubdejojka (2). Lithostratigraphical units are those of Thelander (1982) with inset of Kulling's (1964) Middle sandstone formation. The interval between 20–25 meter is very poorly exposed, but according to Moberg (1908) consists of beds of fine-grained sandstone with fine muddy partings.

**Ichnotaxonomy.** – Several trace fossils from the Torneträsk Formation provide nomenclatural problems since there are abundant transitions and intermediate forms. Furthermore, we think that some common Cambrian

ichnotaxa, including forms present in the Torneträsk Formation, are doubtfully assigned.

As pointed out by Osgood (1970, p. 342), *Phycodes pedum* differs from most species of *Phycodes*, including the type species, *P. circinatum* Richter, 1853. In this species, branches tend to emanate from a common area, whereas in *P. pedum* branches are added distally. However, *P. pedum* does share some important common features with the ichnogenus *Treptichnus*, to which ichnogenus we propose *P. pedum* should be transferred (Jensen & Grant 1992, 1993). The type material of *Treptichnus bifurcus*, from the Namurian of Indiana, consists of an irregularly-running zigzag trail with short projections at each angle (Miller 1889; Maples & Archer 1987). Where the course of the burrow is straight, segments usually alternate in direction; where the course is curved, the projections are directed outward. The current usage of *Treptichnus* is restricted to burrows with a straight course with segments regularly alternating in direction (see e.g. Häntzschel 1975). However, the type material for *Treptichnus bifurcus* contains curved portions with segments directed outwards that are similar to what has been called *Phycodes pedum*. Moreover, it is not rare to find burrows which combine *P. pedum*-type curved sections with portions with zigzag pattern (e.g. Fig. 5f; Bryant & Pickerill 1990). Owing to this, and the fact that *P. pedum* does not exhibit features typical of *Phycodes*, we believe that most reports of *Phycodes pedum* are of burrows with a morphology more consistent with an assignment to *Treptichnus*. Geyer & Uchman (1995) did not accept this, since they saw *Treptichnus* as being more regular, symmetrical, permanently open burrow systems lacking sediment reworking.

The original material of *Treptichnus* we think answers the first point. We find that deciding whether a burrow was permanently open or back-filled is in most cases not possible, and therefore not a good distinguishing criterion. Trace fossils, by their very nature, do not lend themselves to pegging into distinct morphological headings, and this may be particularly true in the Cambrian (as exemplified in this study), but we maintain that most *Phycodes pedum* can be assigned to *Treptichnus*.

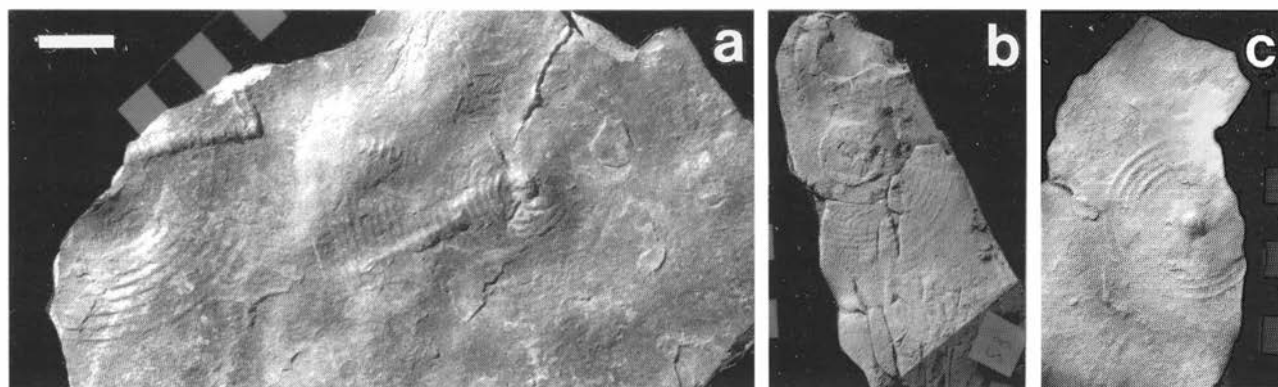


Fig. 3. Specimens of the problematicum *Kullingia concentrica*, upper part of the Lower siltstone member. Hyporeliefs. (a) SGU 8622, from the Davip Duobdejojka section. (b) SGU 8623 from the Luovárri section. (c) SGU 8624 from the Luovárri section. Scale bar in (a) is 2 cm for all.

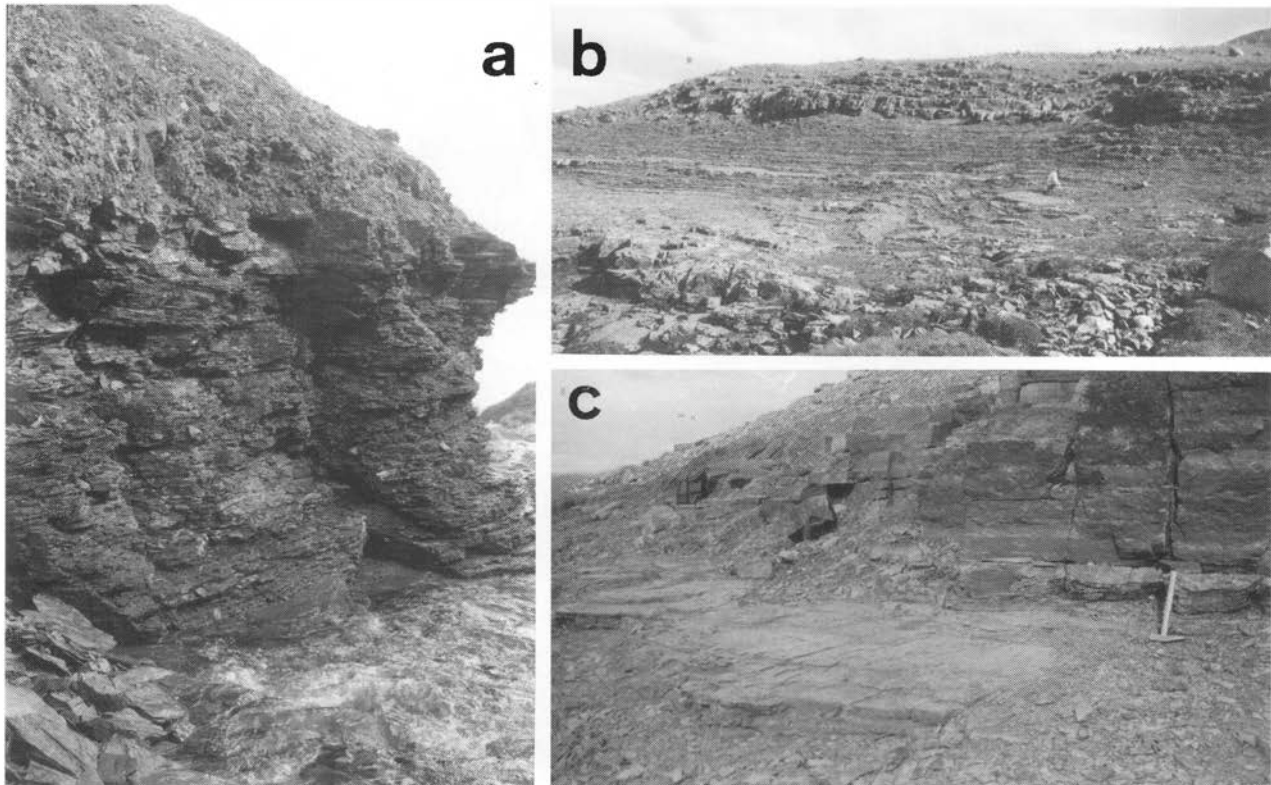


Fig. 4. Exposures of the Torneträsk Formation. (a) Upper part of the Lower siltstone member from section along Davipp Doubdejojka with thin-bedded sandstone truncated by the Vakkejokk Breccia. Distance between waterline and base of breccia is 2.6 m. (b) Upper part of Upper sandstone member at Luovárri, about 80–100 m above basement with trace fossil rich thin-bedded sandstone. Crouching geologist right of centre for scale. (c) Boundary between the Lower siltstone member and Red and green siltstone member at Luovárri. Hammer shaft rest on conglomeratic level that in previous studies have been taken to mark the Precambrian–Cambrian boundary in the section. The problematicum *Kullingia concentrica* occurs in the siltstone and fine sandstone below the level of the hammer head.

Most reports of post-Cambrian *Curvolithus* are of burrows with a three-lobed upper surface (e.g. Heinberg 1973), whereas Early Cambrian reports of *Curvolithus* have a three-lobed lower surface. The type species of *Curvolithus* is *C. multiplex*, which Fritsch (1908) described from the Ordovician of Bohemia (Czech Republic) as having several longitudinal ridges, with an illustrated specimen (Fritsch 1908, Pl. 12:5; Mikuláš 1992) described as four-lobed. In a recent review of *Curvolithus*, Buatois et al. (in press) retained *Curvolithus multiplex* for specimens with a trilobate upper and quadralobate lower surface. They erect a new species for forms with a trilobate upper and unilobate to trilobate lower surface. Sections have failed to reveal the morphology of the upper surface in the specimens from Torneträsk, and this information appears to be missing also for other Cambrian occurrences. Because of this uncertainty, we refer to burrows with a three-lobed lower surface described here as cf. *Curvolithus* isp.

#### Body fossils

Well-documented body fossils from the Torneträsk Formation include late Early Cambrian trilobites from the Upper siltstone member (*Strenuaeva inflata*, *Comluella? lapponica*, *Proampyx triangularis*, *Ellipsocephalus* cf. *grippi*) (Ahlberg 1980, 1984; Ahlberg & Bergström 1978),

*Platysolenites antiquissimus* from the Red and green siltstone member (Moberg 1908; Kulling 1964), and *Kullingia concentrica* from the upper part of the Lower siltstone member (Kulling 1964; Føyn & Glaessner 1979; Stodt 1987). The affinity of *Kullingia concentrica* is problematic. We argue that it was a benthic organism rather than a free-swimming chondrophoran (Jensen & Grant 1992, 1993).

Here we add to the list of body fossils the first documentation of the tubular fossil *Sabellidites* from the Lower siltstone member, Torneträsk Formation. According to the field notes of Oskar Kulling (kept in the archives of the Swedish Geological Survey, Uppsala), this slab originates from Luovárri, in the same beds that yield *Kullingia*. The fossil consists of a shiny black, flat, parallel-sided band with a greatest width of 1 mm (Fig. 7). Fine transverse grooves divide the specimen into 0.08–0.12 mm-long segments. The fossil is straight or gently curved except for one marked twist. The preserved length is about 40 mm. This specimen is closely similar to *Sabellidites cambriensis* Yanishevskij, 1926, from the East European Platform (see e.g. Sokolov 1967; Korkutis 1966), differing in that the width of the segments appears to be somewhat larger. Vidal (1981) identified *Vendotaenia* cf. *antiqua* from the upper part of the Lower siltstone member, and it seems that *Sabellidites* and *Vendotaenia* occur in close stratigraphic proximity, as they do in the



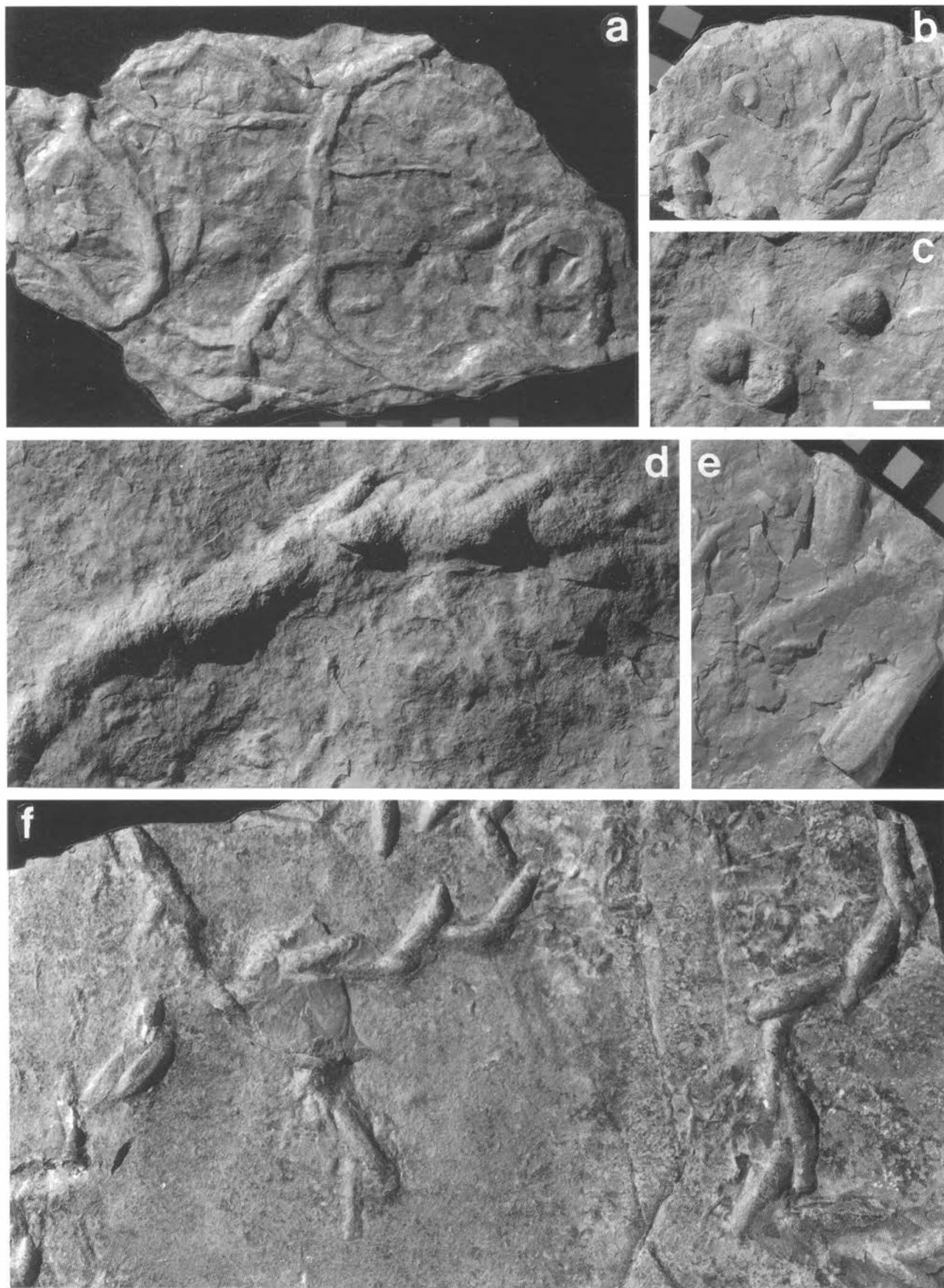


Fig. 5. Trace fossils from the upper part of the Lower siltstone member. All preserved as positive features on base of beds. (a) Winding horizontal burrows from sections along Davip Doubddejohka in places displaying a three-lobed lower surface, RM X3353. (b) *Gyrolithes* isp. from float at Luovárri, RM X3354. (c) *Bergaueria perata* from Luovárri, about 18 m above the basement, RM X3355. (d) *Treptichnus pedum* from Luovárri, about 18 m above basement, RM X3356. (e) Cf. *Curvolithus* isp. from float at Luovárri, RM X3357. (f) *Treptichnus* isp., from Davip Doubddejohka, SGU 8625. Scale bar in (c) is 2 cm in all.

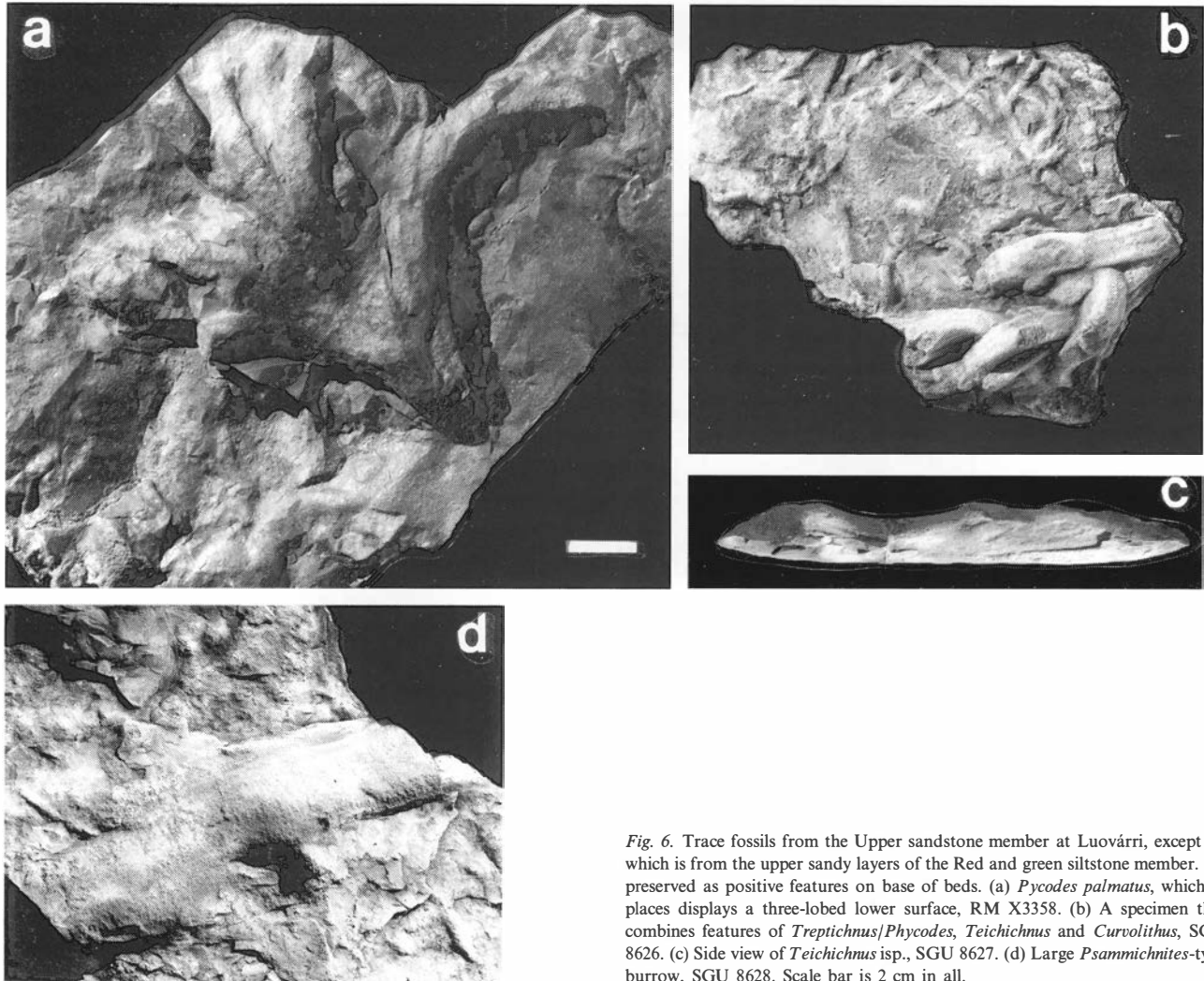


Fig. 6. Trace fossils from the Upper sandstone member at Luovárri, except (c) which is from the upper sandy layers of the Red and green siltstone member. All preserved as positive features on base of beds. (a) *Pycodes palmatus*, which in places displays a three-lobed lower surface, RM X3358. (b) A specimen that combines features of *Treptichnus/Phycodes*, *Teichichnus* and *Curvolithus*, SGU 8626. (c) Side view of *Teichichnus* isp., SGU 8627. (d) Large *Psammichnites*-type burrow, SGU 8628. Scale bar is 2 cm in all.

lower member of the Breivik Formation in northern Norway (Farmer et al. 1992).

### Regional correlation in northern Scandinavia

The Dividalen Group has been considered to span the Proterozoic–Cambrian boundary (e.g. Føyen & Glaessner 1979; Vidal 1985; Nystuen & Siedlecka 1988). The presence of burrows that are unknown in Vendian strata (e.g. *Treptichnus*) (Crimes 1987) in the upper part of the Lower siltstone member demonstrates that the interval with *Kullingia* is post-Neoproterozoic. This rules out earlier suggestions that a putative hiatus at the top of the Lower siltstone member (=top of Kulling's Middle sandstone member) encompasses the Precambrian–Cambrian boundary.

The Lower sandstone member is unfossiliferous, and the lower part of the Lower siltstone member contains only undiagnostic, thin, straight to gently meandering

burrows. Hence, the age of the lowermost part of the Torneträsk Formation may be Vendian or Cambrian. It must be stressed that the occurrence of trace fossils in the Torneträsk Formation is facies-controlled (Fig. 2). Most traces are found in the upper parts of upward-coarsening sequences with the appearance of sharp-based sandstone beds. The absence of Cambrian-type trace fossils in the Lower sandstone member and lower part of the Lower siltstone member may therefore be facies-controlled.

No distinctive arthropod trace fossils in the Torneträsk Formation have been reported. This is of special interest, as the Upper sandstone member certainly contains sedimentary facies suitable for the preservation of such trace fossils. This lack of arthropod traces contrasts with finds of *Holmia kjerulfi* Zone trilobites in the Upper siltstone member. The earliest arthropod trace fossil in southern Scandinavia is *Rusophycus parallelum* Bergström, 1970, known from the Hardeberga sandstone, Scania, Sweden (Bergström 1970). Acritarchs

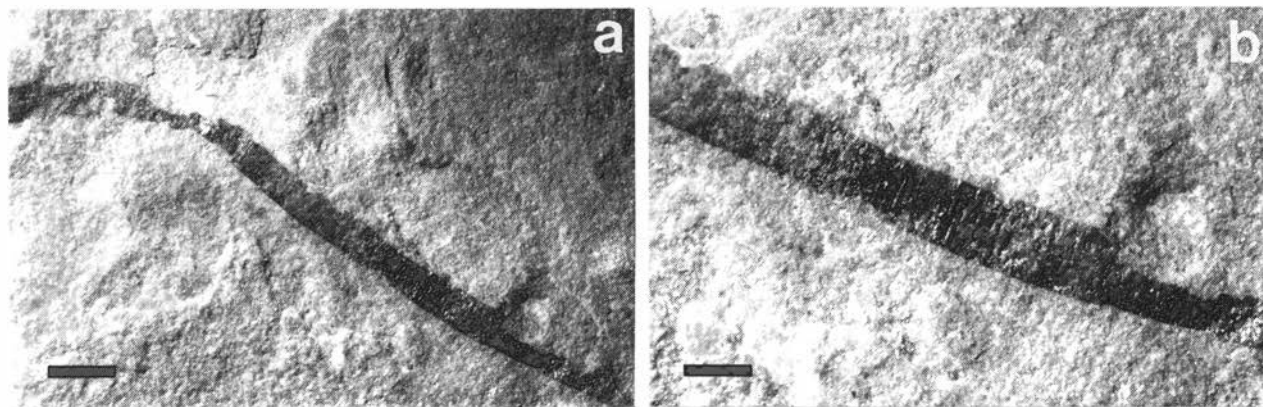


Fig. 7. *Sabellidites* sp., from the Lower siltstone member (*Kullingia* beds) Luovárri, SGU 8629. (a) Scale bar is 2 mm. (b) Close up of (a), scale bar is 1 mm.

indicate that this unit corresponds to the *Skiagia ornata-Fimbrioglomerella membranacea* Zone (Moczyłowska 1991). *Rusophycus* isp. is known from the Mazowsze Formation from the Lublin slope (Fedonkin 1977), at a level assigned to the *Asteridium tornatum-Comasphaeridium velvetum* Zone. Shallow *Rusophycus* have been documented from member IV of the Dividalen Group at Halkkavarre, Finnmark, Norway (Banks 1973). This level has been correlated with the Red and green siltstone member (Føyn & Glaessner 1979), making the absence of *Rusophycus*-type burrows at Luovárri somewhat unexpected. It could be that *Rusophycus*-type trace fossils will eventually be found in the Torneträsk Formation at other localities. However, no deep *Rusophycus* or *Cruziana*, which in Baltica first appear in deposits of Talsy (Dominopol') age (Norretorp Formation Scania, and Lükati Formation, Estonia), are known from the Dividalen Group. This may have hitherto unappreciated biostratigraphic significance. We suggest that the lack of deep arthropod traces in the Upper sandstone member and the presence of late Early Cambrian trilobites in the Upper siltstone member indicate a stratigraphic gap encompassing at least part of the Talsy 'stage'. The conglomeratic sandstone capping the Upper sandstone member, followed by the thin dolomitic and stromatolitic horizon with phosphatic pebbles of the basal Upper siltstone member, may represent a flooding surface following a depositional hiatus (Fig. 2).

The revised stratigraphy of the Torneträsk Formation also brings into doubt the position of the Precambrian–Cambrian boundary for the Dividalen Group in other areas where the position of the boundary has been extrapolated from the Torneträsk area. The Dividalen Group can be followed along a narrow stretch from northern Sweden into Norway (Føyn 1967; Vogt 1967) and Finland (Lehtovaara 1982, 1988). Vogt (1967) compared a number of sections along this stretch and found that the main lithologic units could be recognized with local variations in thickness and development. He used 'niveau' A–F (units A–F of Føyn & Glaessner 1979)

corresponding to Kulling's formations. Føyn (1967) divided the type section at Halkkavarre into the informal units I–IV, corresponding to the four lower units of Kulling's scheme at Torneträsk (Føyn & Glaessner 1979). Trace fossils were briefly described by Banks (1973) from sections at Halkkavarre, Finnmark. Member II contains small burrows, including a form with Y-shaped branching, and a trace described as a loosely-coiled horizontal spiral (Banks 1973, p. 4). Banks (1973) reported sinuous epichnial grooves in member III. Trace fossils were found throughout member IV, including arthropod scratch marks that were compared with *Rusophycus* (Banks 1973). Bromley & Hanken (1991) reported *Diplocraterion parallellum*, *Arenicolites* isp., *Buthotrephis palmatum* (= *Phycodes palmatus*), *Altichnus foeyni* (Bromley & Hanken 1991), and *Teichichnus* isp., from the upper part of the Dividalen Group in sections at Imobekken and Voullenjoaski. Lithostratigraphic correlation indicates that this is in Unit E, corresponding to the Upper sandstone member in the Torneträsk area. The Red and green shale member has been recognized as a key unit in correlation. This unit is sparsely but regularly fossiliferous. From Norway, Føyn & Glaessner (1979) listed *Aldanella kunda*, *Platysolenites antiquissimus*, *P. spiralis*, *Sabellidites cambriensis*, *Torella laevigata* and '*Hyolithes*' sp.

The lithostratigraphic units recognized in Sweden and Norway cannot be identified in Finland. Tynni (1980) reported possible *Platysolenites antiquissimus* from northern Finland in beds that were correlated with Unit D in Norway (corresponding to the Red and green siltstone). *Sabellidites cambriensis* was reported from a lower, not specified level (Tynni 1980). There is thus no positive biostratigraphical evidence for Vendian-age sediments in the Dividalen Group. This affects correlation with the Vestertana Group in Finnmark, which is considered a lateral equivalent of the Dividalen Group and which encompasses Vendian sediments (see e.g. Vidal & Moczyłowska 1996).



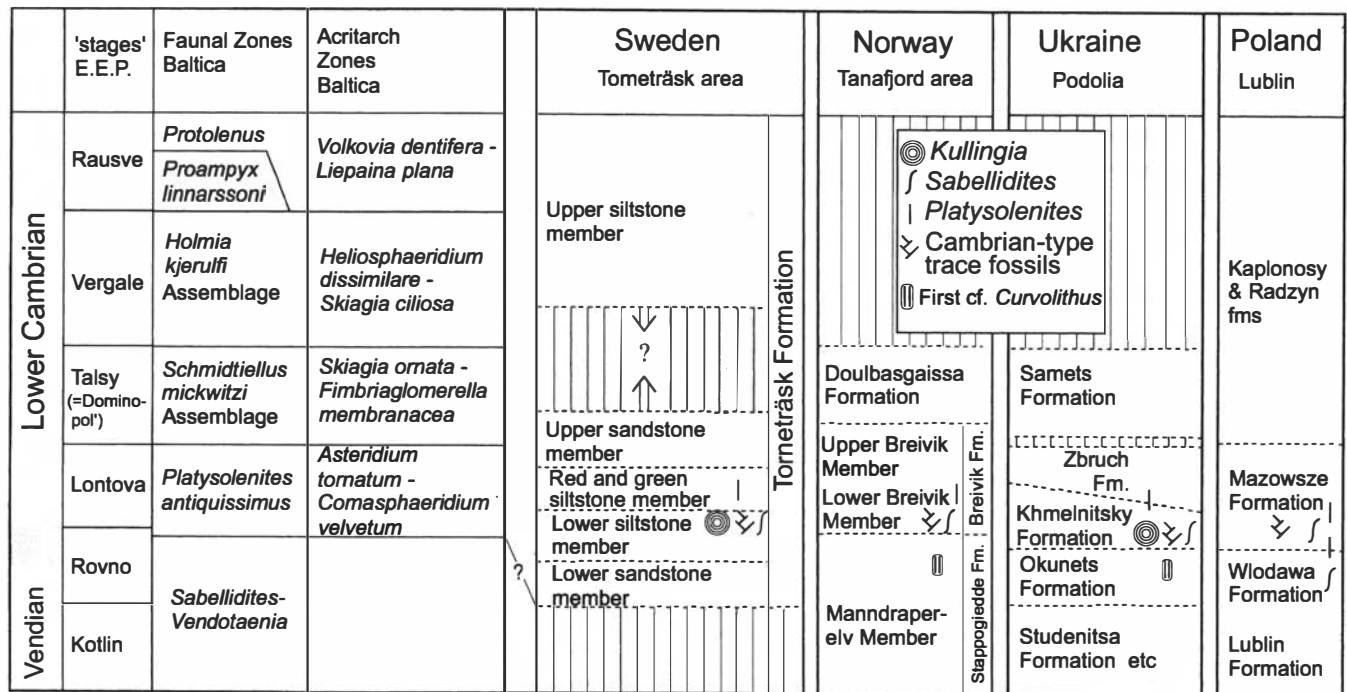


Fig. 8. Tentative correlation of the Torneträsk Formation with selected late Vendian–Early Cambrian successions on Baltica. Based on Moczyłowska (1991), Ahlberg & Bergström (1993) and various other sources.

Correlation with the Vestertana Group, Finnmark

With the new information from trace fossils from the Dividalen Group in Sweden, correlation with the Vestertana Group in Finnmark must be modified. The Vestertana Group of East Finnmark consists of clastic rocks mainly deposited in a shallow-water setting. Above the glacially-influenced Varangerian deposits, the succession includes the Stappogiedde Formation (with the Lillevatn, Innerelv and Manndraperelv Members), followed by the Breivik Formation (with a Lower and Upper Member) (Reading 1965; Banks et al. 1971; Vidal 1981). The Innerelv Member of the Stappogiedde Formation contains fossils attributed to the Ediacara fauna (Farmer et al. 1992). The upper part of the Manndraperelv Member contains

horizontal burrows with lateral grooves that can be assigned to cf. *Curvolithus* isp. (Banks 1970, Pl. 2d). Within the lowermost part of the Lower Breivik Member appear burrows of *Treptichnus*-type, including *Phycodes* (= *Treptichnus*) *pedum* (Banks 1970) and the vertical spiral burrow *Gyrolithes* (Farmer et al. 1992). Higher up in the same member, *Rusophycus* was reported and described as shallowly-dug paired sets of scratch marks, as well as more deeply excavated bilobate pits (Banks 1970, pp. 28–29). The Precambrian–Cambrian boundary interval has been considered to include the Manndraperelv Member and the lower part of the Lower Breivik Member. The occurrence of *Treptichnus pedum* already at the base of the latter member signifies post-Proterozoic age, strengthened by the presence of *Gyrolithes*. Farmer et al. (1992) reported *Vendotaenia* and

carbonaceous annular tubes, tentatively assigned to *Sabellidites*, 10 m above the base of the Lower Breivik Member. Based on this and *Phycodes* (= *Treptichnus*) *pedum*, they opted for placing the boundary ‘just above the basal sandstones of the Lower Breivik Formation’ (Farmer et al. 1992, p. 192).

Føyn (1967) advocated a lithostratigraphic correlation of the three lower members of the Dividalen Group with the three members of the Stappogiedde Formation in Finnmark. The *Kullingia*-bearing horizons in the upper part of the Lower siltstone member at Torneträsk have previously been correlated with either the Innerelv Member (Vidal 1981) or the lower part of the Manndraperelv Member (Føyn & Glaessner 1979). The presence of *Treptichnus pedum* and *Gyrolithes* in the upper Lower siltstone member, however, suggests a correlation with the Lower Breivik Member (Fig. 8). This supports the time-transgressive nature of the lithostratigraphic correlation, as suspected by Føyn (1967).

A loosely-based *Kullingia* Zone has been put forward as the lowermost formal biostratigraphic zone in Scandinavia (Føyn & Glaessner 1979; Farmer et al. 1992). This zone was based on the presence of *Kullingia* and a position below the first *Platysolenites*, and has been considered to predate the Cambrian. Farmer et al. (1992, p. 192) tentatively suggested that the zone should be extended to include finds of ‘the *Cyclomedusa* plexus’ from the Innerelv Member of the Tanafjord area. In view of the trace fossils reported here from the Torneträsk Formation, it is clear that the *Kullingia* Zone would partly overlap with the *Sabellidites*–*Vendotaenia* Zone. We suggest that the *Kullingia* Zone be abandoned (Fig. 8).

## Correlation with the East European Platform

Over large areas of the East European Platform, basal Cambrian is attributed to the Baltic (regional) 'Series', which consists largely of siliciclastics. The Baltic 'Series' consists of a lower Rovno 'stage' and upper Lontova 'stage'. These have been mainly characterized by acritarch assemblages and a sparse record of body fossils (Kiryanov 1979; Volkova et al. 1979; Mens et al. 1987, 1990). However, Moczyłowska (1991) and Moczyłowska & Vidal (1993) argued that acritarchs used as indicative of the Rovno 'stage' are either of doubtful taxonomic status, lack diagnostic features or have a range exceeding the Rovno 'stage'. We recognize that these Russian-style 'gorisont', which have been variously translated as horizon, regional-stage or stage, although largely based on acritarchs are combined geological units, and that their chronostratigraphic status is debatable (cf. Vidal & Moczyłowska 1995). However, since they form the framework under which rocks over large areas of the East European Platform are discussed, we find it impractical not to refer to them.

Probably the most extensively studied sequence of rocks on the East European platform spanning the Vendian–Cambrian boundary is known from cores of the Lublin area, eastern Poland (Lendzion 1972; Aren & Lendzion 1979; Paczeńska 1985, 1986; Moczyłowska 1991). Moczyłowska (1991) has erected regional acritarch assemblage Zones that have been found to be widely recognizable (Moczyłowska 1991; Vidal & Moczyłowska 1996). Acritarchs have been reported from the Torneträsk Formation, but are either undiagnostic (Lower siltstone member), or long-ranging, Early–Middle Cambrian (Upper sandstone member) (Vidal & Moczyłowska 1996, p. 151). Further south, in the central and southern Swedish Caledonides, Vidal & Moczyłowska (1996) recognized acritarchs belonging to the *Heliosphaeridium dissimulare*–*Skiagia ciliosa* and *Asteridium tornatum*–*Comasphaeridium velvetum* Zones. Correlation between the lower part of the Torneträsk Formation and these sections further to the south is, however, unclear. Body fossils in the Red and green siltstone member and correlative beds in Norway suggest correlation with the Lontova 'stage' on the East European Platform.

Here we want to draw attention to a striking similarity in fossils between the lower part of the Torneträsk Formation and the Khmelnsky Formation in Ukraine, and suggest that there is a possibility of correlation. An assemblage of fossils very similar to that in the Lower siltstone member occurs in the Khmelnsky Formation in Ukraine. *Kullingia concentrica* from the Khmelnsky Formation at Kitaigorod (Gureev 1985, 1987, 1988) is very similar to *K. concentrica* from the Lower siltstone member, Torneträsk Formation. Gureev (1985) reports the occurrence of *Kullingia concentrica* 1 m below the erosional contact with the Ordovician in sections at Kitaigorod. This level corresponds to the occurrence of

an assemblage of trace fossils including *Treptichnus*, *Gyrolithes polonicus*, *Didymaulichnus*, *Curvolithus*, and *Bergaueria* (Palij 1976; Palij et al. 1979; Gureev 1986; Velikanov et al. 1990).

The occurrence of *Treptichnus*, *Gyrolithes polonicus*, *Didymaulichnus*, *Curvolithus* and *Bergaueria* marks a significant increase in trace fossil diversity in the basal Khmelnsky Formation of Podolia (Palij 1976; Palij et al. 1979; Gureev 1986; Velikanov et al. 1990). Palij (1976) reported *Treptichnus triplex* from a depth of 168 m in a core at the Kamienec Podolski. From descriptions and schematic graphs in Kiryanov & Krasheninnikova (1972, Fig. 8; see also Kiryanov 1979, Fig. 29), it occurs near the top of the preserved Khmelnsky Formation in the core, close to a level that also yields *Sabellidites*.

An almost identical assemblage of traces was encountered in this study in beds just below the *Kullingia*-bearing horizons in the Lake Torneträsk area. In both the Torneträsk and Khmelnsky Formations, *Kullingia concentrica* and an assemblage of Cambrian-type trace fossils occur with *Sabellidites*, below the first *Platysolenites*. We argue that taken together, these circumstances provide the best available means of correlation between sections in northern Sweden and Podolia (Fig. 8).

Correlation between the sections in Podolia and other regions on the East European Platform is not straightforward. In the Lublin area, the appearance of Cambrian-type trace fossils including *Treptichnus lublinensis*, *Gyrolithes polonicus*, *Phycodes pedum* and *Bergaueria major* (Paczeńska 1986) approximately coincides with the appearance of acritarchs of the *Asteridium tornatum*–*Comasphaeridium velvetum* Zone, and the body fossils *Platysolenites* and *Onuphionella* near the base of the Mazowsze Formation. Correlation between the Lublin Slope and Podolia using traditional schemes, in which the Khmelnsky Formation is regarded as older than the Mazowsze Formation, results in a discrepancy in the first appearance of Cambrian-type trace fossils, as noted by Paczeńska (1985, 1986). In addition, these schemes would put the base of the *Asteridium tornatum*–*Comasphaeridium velvetum* Zone in the Lublin sections well above the base of the Cambrian, as defined by the Cambrian index fossil *Phycodes* (= *Treptichnus*) *pedum*. Paczeńska (1986) suggested that facies is the controlling factor in the discrepancy in appearance of Cambrian-type trace fossils that results from traditional correlation schemes of sections in Podolia and Lublin (Mens et al. 1987, 1990). However, it appears that Cambrian-type trace fossils in the Rovno 'stage' are known only from the Khmelnsky Formation in the Dnestr Valley area. Furthermore, if the Okunets Formation is assigned to the Rovno 'stage' (Velikanov et al. 1985), the Khmelnsky Formation would correspond only to the upper part of the Rovno 'stage' (Fig. 8). Correlation of the Okunets and Khmelnsky Formations with the Rovno Formation of the Volhyn area has been based on similarity in acritarchs, common abundance of *Sabellidites* and trace fossil composition. However, we have not been able to find any

reports of Cambrian-type trace fossils from the Rovno Formation in the Volhyn area. As a matter of fact, we have not found any reports of Cambrian-type trace fossils from strata assigned to the Rovno 'stage' from Russia, Moldavia, Byelorussia, Estonia, Latvia or Lithuania.

## Discussion

The base of the Cambrian system is defined by the lowest occurrence of *Phycodes pedum* (Narbonne et al. 1987; Narbonne & Myrow 1988) in the stratotype on Fortune Head, Newfoundland. The *Phycodes pedum* Zone in Newfoundland records a dramatic increase in diversity and vertical exploitation of the sediment. Besides the nominal taxon, there occur, for example, *Curvolithus* isp., *Gyrolithes* isp., *Skolithos annulatus*, *Arenicolites* isp. and *Monomorphichnus* isp. (Narbonne & Myrow 1988). In the *P. pedum* Zone in Avalonia also occur *Sabellidites cambrienses* and *Kullingia delicata* (Fedonkin, 1981) (Landing et al. 1989; Narbonne et al. 1991). This provides a basis for correlating the upper part of the Lower siltstone member with the *Sabellidites cambriensis* Zone on Avalonia. We would like to point out, however, that the relation between these *Kullingia* is uncertain. Narbonne et al. (1991) interpreted *Kullingia delicata* in Newfoundland as a free-swimming chondrophoran, whereas *Kullingia concentrica* in northern Sweden is clearly a sedentary benthic organism (Stodt 1987; Jensen & Grant 1992). *Kullingia* has also been reported from Vendian deposits (Narbonne & Aitken 1990; Gureev 1987; Bekker & Kishka 1989), but their relation to *Kullingia concentrica* needs to be critically evaluated. By far the greatest similarity exists between the Cambrian specimens from northern Sweden and those of Ukraine.

Facies control on the occurrence of trace fossils is evident on the East European Platform. Over large areas of the East European Platform, the basal Cambrian consists of homogenous silt or claystones in which conditions for preservation of discrete trace fossils is generally poor. For example, Piskun & Abramenko (1986) report only simple horizontal trace fossils, identified as *Planolites*, from Rovno and Lontova equivalents in Byelorussia. The sections examined in this study near Lake Torneträsk also exhibit facies control over trace fossil distribution. At Luovárri, Cambrian-type trace fossils are absent or, in the case of *Bergaueria*, of smaller size in beds with *Kullingia concentrica*. As described earlier, there is a fairly diverse assemblage of Early Cambrian traces from beds below the finer-grained *Kullingia* horizons at Luovárri, indicating that physical conditions related to sedimentary environment influenced the type and diversity of trace fossils preserved in the *Kullingia* beds. Furthermore, as discussed above, trace fossil finds throughout the Torneträsk Formation are strongly controlled by lithology, such that the first appearances are coupled with preservational conditions of episodic sedimentation occurring in the upper parts of upward-coarsening sequences (cf. Goldring & Jensen 1996; Lindsay et al. 1996).

Little is known about what animals produced the trace fossils at the Precambrian–Cambrian boundary interval. Most trace fossils reflect behaviour; only rarely are there details of the producers' morphology. Besides the distinctive traces left by burrowing arthropods, there is some evidence of Cambrian burrowing priapulids (Jensen 1990). Some trace fossils having a distinctive morphology, such as *Plagiogmus*, appear to be restricted to the Cambrian, but their producer is unknown. Here we would like to emphasize that trace fossils having a three-lobed lower surface are widely reported from the Early Cambrian, but are rare in younger sediments, and may therefore only be related to one or few organisms in the Early Cambrian seas. On Baltica, trace fossils having a three-lobed lower surface first appear below the first assemblage of Cambrian-type trace fossils in Norway (Stappogiedde Formation, Banks 1970) and Ukraine (Okunets Formation, Gureev 1986). Such trace fossils have been reported from Early Cambrian beds in South Australia (Lintiss Vale Beds, Webby 1970; Uratanna Formation, Daily 1973), central Australia (Donkey Creek beds, Walter 1980; Arumbera Sandstone, Walter et al. 1989), India (Tal Formation, Singh & Rai 1983), Mongolia (Bayan Gol Formation, Goldring & Jensen 1996), Namibia (Nomtsas, Nababis and Gross Aub Formations, Germs 1972; Geyer & Uchman 1995; Grotzinger et al. 1995), Russia (Zireklinskaya beds, Bekker & Kishka 1991) and Newfoundland (Chapel Island Formation, Crimes & Anderson 1985).

The three-lobed lower surface found in trace fossils located in so many sections around the world is therefore of interest as a possible distinguishing trait for an unknown group of latest Vendian–Early Cambrian burrowing organisms. In the Torneträsk Formation, cf. *Curvolithus*, *Phycodes palmatus*, *Treptichnus* and *Teichichnus* preserve a three-lobed lower surface. It is not clear if this three-lobed pattern reflects a ventral three-lobed morphology of the producer or is the result of sediment manipulation.

Reports from the latest Proterozoic–Earliest Cambrian on Baltica show simple three-lobed, straight burrows below the first Cambrian-type trace fossils in sections in Northern Scandinavia and Ukraine; they appear to be evident also in Namibia. Higher in the stratigraphy, there appear several different behavioural morphologies sharing a three-lobed lower surface. This may represent behavioural expansion within a group of animals. While the Early Cambrian radiation in trace fossils certainly indicates that burrowing activity increased during the Neoproterozoic to Early Cambrian transition, its relationship to the diversity of burrowing animals is less clear.

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