

# Ediacaran fossils from the Innerelv Member (late Proterozoic) of the Tanafjorden area, northeastern Finnmark

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(Received 5 March 1991; accepted 29 August 1991)

**Abstract** – An Ediacaran assemblage dominated by an unidentified species of *Cyclomedusa* Sprigg 1947, along with species of *Ediacaria*? Sprigg 1947, *Beltanella* Sprigg 1947, *Hiemalora* Fedonkin 1982, and *Nimbia*? Fedonkin 1980, is described for the first time from the Innerelv Member of the Stappogiedde Formation exposed in coastal outcrops west of Tanafjorden on Digermul Peninsula, in northeastern Finnmark, northern Norway. The fossil assemblage is dominated by discoidal forms which share certain affinities with the cosmopolitan genera *Cyclomedusa* and *Ediacaria*. However, our specimens differ from these and other discoidal Ediacaran fossils in the absence of radial sculpture. This, along with a basically concentric organization, are characteristics shared with *Kullingia* from the Dividal Group of northern Scandinavia, the White Sea, Podolia, and northwestern Canada, along with undescribed discoidal remains from the Charnian Supergroup, Charnwood Forest, Leicestershire, England, and the Conception Group, Avalon Peninsula, Newfoundland.

Our discovery of an Ediacaran-type assemblage within the Middle Innerelv Member provides support for previous suggestions of a late Vendian age for this sequence. This general conclusion is consistent with the occurrence of early Cambrian taxa, including the trace fossil *Phycodes*, and the problematical forms *Vendotaenia* and *Sabellidites*, in basal portions of the Lower Breivik Formation, within the same stratigraphic section. The lowest formally-proposed faunal zone in northern Scandinavia is the *Kullingia* Zone, based on the occurrence of the fossil medusoid *Kullingia concentrica* in Member III (Middle Sandstone C) of the Dividal Group, northern Scandinavia. *Kullingia* is a distinctly chambered form that was probably pelagic. In contrast, *Cyclomedusa*, and related genera of the so-called *Cyclomedusa* plexus, comprise an informal grouping of intergrading, probably benthic, taxa that possess radial and/or concentric organization. In light of the intergradational nature of taxa, present difficulties in taxonomic interpretation and correlation, and the abundance of cyclomedusoids in many Ediacaran assemblages, we suggest that the concept of the *Kullingia* Zone, as originally defined for northern Scandinavia, be broadened to include the common form genera of the *Cyclomedusa* plexus, inclusive of the occurrences in the Innerelv Member described herein. It is our hope that additional fieldwork will provide a basis for more refined taxonomic evaluations and biozonation.

## 1. Introduction

Our knowledge of the pre-skeletal history of multicellular animal life rests exclusively on published descriptions of about one hundred species that comprise the Ediacaran fauna, an assemblage of soft-bodied fossil animals of complex organization that are presently known from about 25 localities on five continents (Glaessner, 1984; Sokolov & Ivanovskiy, 1985; Conway Morris, 1985a, b; Hofmann, 1988; Walter, 1989). Although the phylogenetic and evolutionary significance of this unique fossil assemblage remains controversial (e.g. Glaessner, 1984; Bergstrom, 1989; Seilacher, 1989; Valentine, 1989; Walter, 1989;

Runnegar & Fedonkin, in press), our understanding of its stratigraphic and spatial distribution is becoming increasingly refined (Glaessner, 1979; Hofmann, 1988; Hofmann & Bengtson, in press).

Elements of the Ediacaran assemblage were first described in Namibia by Gürich (1930) and later by Pflug (1970a, b, 1972, 1973). However, the stratigraphic and age significance of the assemblage was first brought to attention by Sprigg (1947, 1949), based on occurrences in the Ediacara Hills, Flinders Range, South Australia. The probable age of the assemblage was subsequently established as late Vendian (Germis, Knoll & Vidal, 1986). Since that time the list of species and localities has continued to grow, and the fauna is now considered to be global in distribution. Previous occurrences are summarized in

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detail elsewhere (Glaessner, 1979, 1984; Hofmann, 1988; Hofmann *et al.* in press).

With the exception of a recently reported occurrence of discoidal fossils from inter-tillite beds in the late Proterozoic Windermere Supergroup of northwestern Canada (Hofmann & Narbonne, 1990; Hofmann, Narbonne & Aitken, 1990), a consistent feature of the Ediacaran assemblage worldwide is that it postdates glacial deposits of the late Proterozoic (Glaessner, 1979). It also predates the first appearance of small shelly fossils of early Cambrian age. A mass extinction of most Ediacaran forms appears to have preceded the early Cambrian radiation (Fedonkin, 1985a). In the East European Platform, and in Baltoscandia, the first appearance of Ediacaran fossils is above tillites representing the late Proterozoic (Varangerian) glaciation, but below the first appearance of the putative foraminiferan, *Platysolenites antiquissimus* (Føyn & Glaessner, 1979).

The generally accepted age of the Ediacaran fauna, based on radiometric dates, brackets it within the range 575–640 Ma (Glaessner, 1979). However, unpublished U/Pb zircon dates suggest an earlier age of  $565 \pm 3$  Ma for the Ediacaran fauna of the Mistaken Point Formation, Newfoundland (Benus, 1989).

Although present knowledge does not support a detailed stratigraphic biozonation based on Ediacaran fossils, the widespread occurrence of this distinctive assemblage has led to proposals for the formal recognition of a sub-Cambrian geological period (see discussion by Mount, 1989) variously termed the Vendian (Sokolov, 1972; Sokolov & Fedonkin, 1984), Ediacaran (Jenkins, 1981), Ediacarian (Cloud & Glaessner, 1982) and the Sinian (Grabau, 1922; Sheng, 1984). The Varangian (Varangerian) and Ediacarian have also been proposed as stages of the Vendian Series (Sokolov, 1973). Guidelines of the Precambrian–Cambrian boundary working group suggest that the Ediacaran assemblage should be considered Precambrian in age (Cowie, 1989), but formal stratigraphic nomenclature and type localities are still under evaluation (Harland *et al.* 1982; Conway Morris, 1987; Narbonne *et al.* 1987).

The Ediacaran fauna as a whole has been described from a variety of lithofacies (Glaessner, 1979), including shallow subtidal clastic and carbonate lithotopes (Goldring & Curnow, 1967; Germs, 1972; Fedonkin, 1981; Gehling, 1983; Jenkins, Ford & Gehling, 1983, and this report), muddy, basin slope (Narbonne & Aitken, 1990), and deep-slope, submarine fan facies (Ford, 1980; Anderson & Conway Morris, 1982; Gibson, Tetter & Fedonkin, 1984; Benus, 1989; Landing *et al.* 1989). Most occurrences are preserved as soft-bodied impressions in finely-laminated siltstone/shale sequences as either low relief casts (hyporeliefs) on the bases of beds, or as moulds on the upper surfaces of beds (epireliefs) (Glaessner & Wade, 1966; Glaessner, 1984; Seilacher, 1989).

The Ediacaran fauna is dominated by discoidal forms that, until recently, were generally regarded as pelagic (Sprigg, 1947, 1949; Glaessner & Wade, 1966; see discussion by Narbonne & Aitken, 1990, p. 953). However, recent work suggests that many Ediacaran discoidal forms (including the cyclomedusoids) were actually benthic (Seilacher, 1984; Fedonkin, 1985a, 1987; Jenkins, 1988, 1989; Narbonne & Aitken, 1990).

The preservation of soft-bodied organisms usually requires special environmental conditions. However, Glaessner (1984) has emphasized that the Ediacaran fauna is not *lagerstätten*. Under conventional models, the preservation of soft-bodied organisms requires early diagenetic mineralization, controlled by burial rate, the abundance of organic matter, and salinity (Allison, 1989). But lithofacies associations, modes of preservation, and the diversity of inferred lifestyles represented argue against the importance of such processes in Ediacaran taphonomy.

The late Proterozoic was a unique time in metazoan evolution, with an absence of macrophagous predators, limited bioturbation of sediment by burrowing organisms, and low levels of atmospheric oxygen (Glaessner, 1979; Walter, 1989). Extrinsic factors may account, in part, for many of the unusual biological (Runnegar, 1982) and preservational features (Fedonkin, 1985c) of the Ediacaran fauna. However: recent taphonomic and functional studies suggest that the Ediacaran organisms may have also possessed intrinsic properties which favoured their preservation, including having been composed of stiffer materials than comparable living species (Norris, 1989), or having possessed a fundamentally different body architecture (Seilacher, 1989). In addition, microbial mats were more widespread during the Vendian and may have enhanced the preservation of soft-bodied forms by promoting early mineralization (Gehling, 1986; Gall, 1990).

## 2 Stratigraphy and palaeoenvironments

The late Proterozoic to early Cambrian sequences of northeastern Finnmark, northern Norway, consist of > 5000 m of terrigenous, fluvial, and shallow-water marine strata (Reading, 1965; Siedlecka & Siedlecki, 1967, 1971; Siedlecka, 1985). In the Tanafjorden–Varangerfjorden region (Fig. 1), the stratigraphic interval is subdivided, from oldest to youngest, as follows: the Vadsø (late Riphean–early Vendian; Vidal, 1981; Vidal & Siedlecka, 1983), Tanafjord (Vendian), Vestertana (late Vendian–early Cambrian), and Digermul Groups (Cambrian–early Ordovician). General stratigraphic and age relationships have been established by the correlation of tillites within the Smalfjord and Mortensnes formations (Fig. 2) of the Lower Vestertana Group (Edwards, 1975, 1984). These tillites are correlated to the late Proterozoic

Varangerian (= Varangian, or 'Laplandian') glaciation, recognized throughout Scandinavia (Føyn, 1985).

In addition to the lithostratigraphic framework described above, a generalized biostratigraphic framework has also begun to emerge (Føyn, 1985; Siedleka, 1985), based primarily on acritarchs (Vidal, 1979, 1981), stromatolites (Bertrand-Sarfati & Siedleka, 1980), trace fossils (Banks, 1970, 1973a; Crimes, 1989), and the first appearance of *Platysolenites antiquissimus*, and other shelly fossils (Føyn, 1967; Hamar, 1967; Føyn & Glaessner, 1979).

The youngest division of the Proterozoic is the Vendian Period (Sokolov & Fedonkin, 1984), erected for sequences underlying the East European Platform. Stratigraphic criteria for defining the base of the Vendian remain controversial. As originally defined, the beginning of the Vendian Period was placed at the base of the lowest Varanger tillite (Sokolov & Fedonkin, 1984). Jenkins (1981) later proposed an Ediacaran Period, based on the earliest appearance of metazoans. Cloud & Glaessner (1982) independently proposed an Ediacarian Period, with the base being defined by the top of the youngest glaciogenic strata. The latter proposal has apparently been the most broadly applied in practice, although not without some difficulty in the type area within the East European Platform (Vidal & Siedleka, 1983).

Geochronological criteria for recognition of the base of the Vendian are also poorly constrained, with estimates falling generally between 650 and 670 Ma (Fsyn, 1985; but see Vidal & Siedleka, 1983 for an alternative viewpoint). For example, the interglacial Nyborg Formation which lies between the two tillites in the Tanafjorden-Varangerfjorden region has yielded a Rb/Sr whole rock date of  $654 \pm 7$  Ma (Sturt, Pringle & Roberts, 1975; see also Pringle, 1973) that is consistent with an estimate of 670 Ma for shales just above the late Proterozoic tillites of northwestern Australia (Coats & Preiss, 1980).

In our study area, the oldest outcrops belong to the Mortensnes Formation exposed on the island: Areholmen, east of the Digermul Peninsula (Fig. 1). On Areholmen, the Mortensnes Formation is a tillite comprised of chiefly dolomite clasts (some with stromatolites), presumably derived locally from the underlying Grasdal Formation (Edwards, 1915, 1984). The upper part of the sequence is a dark grey shale containing dropstones.

The post-glacial depositional history of northeastern Finnmark commences with the Lillevatn Member of the Stappogiedde Formation. The contact with the Mortensnes tillite is not exposed, and lies within the fjord between the island of Areholmen and the Digermul Peninsula (Fig. 1). However, on the Varanger Peninsula to the northeast, the Lillevatn Member consists of a basal quartz conglomerate overlain by grey, medium-grained sandstones in a

transgressive, fining-upward sequence believed to represent a transition from fluvial to shallow subtidal conditions (Reading & Walker, 1966; Banks, 1970, 1973b).

The Lillevatn Member is overlain by the Innerelv Member with a transitional contact marked by the presence of several dark, pyritic mudstones and fine-grained, lenticular sandstones. On Digermul Peninsula, the Innerelv Member is about 275 m thick and consists of two shallowing-upward sequences, each representing a transition from offshore marine (quiet basin, below wave-base), to wave-influenced, shallow subtidal and intertidal deposition (Banks, 1973b). The basal part of the Innerelv Member consists of green and red shales containing occasional lenticular interbeds of fine-grained, red sandstone. Near Manndraperelva (Fig. 1), the Middle Innerelv Member consists of interbedded greenish-grey shales and fine-grained, ripple cross-laminated sandstones. Near the top of the first shallowing-upward cycle, exposed just north of the mouth of the creek, Manndraperelv (Map sheet Langefjorden 223611, UTM coordinates 428 310), the sequence also includes thick interbeds of medium to coarse, parallel-laminated sandstone, in some cases displaying rippled tops and extensive deformation due to sediment loading and slumping (Facies 14 of Banks, 1973b). Individual beds wedge out over a distance of 100 m or so along strike. Orientations of asymmetrical ripple marks suggest a southwesterly palaeocurrent directions. These sandstones are interpreted to represent deposition in a current swept (upper flow regime), wave-influenced environment. Sedimentary structures suggest rapid sedimentation, perhaps in shallow tidal channels, followed by slumping and load deformation of water-saturated sands. This interval is overlain by 14 m of greenish-grey, parallel-laminated siltstone, interbedded with centimetre or less thick beds of fine-grained, ripple-marked sandstone (Facies 12 of Banks, 1973b), believed to represent sedimentation in quiet water, below wave-base.

In the study area, strata of the Innerelv Member strike between N45E and N55E, with dips between 19 and 28° W. A prominent cleavage, striking between N20E and N85E, dipping 35–75° W, intersects bedding, and in finer-grained lithologies obscures sedimentary structures, and tends to limit bedding plane exposures. However, the cleavage is less pronounced in the coarser and thicker sandstones, and primary structures and bedding plane features are often visible.

The Innerelv Member is overlain by the Manndraperelv Member, interpreted to be a shallowing-upward, turbidite sequence (Reading & Walker, 1966). Locally the Manndraperelv Member consists of 190 m of red, coarse-grained, quartzitic sandstone and conglomerate, with interbedded greywacke and mudstone. The contact with the underlying Innerelv

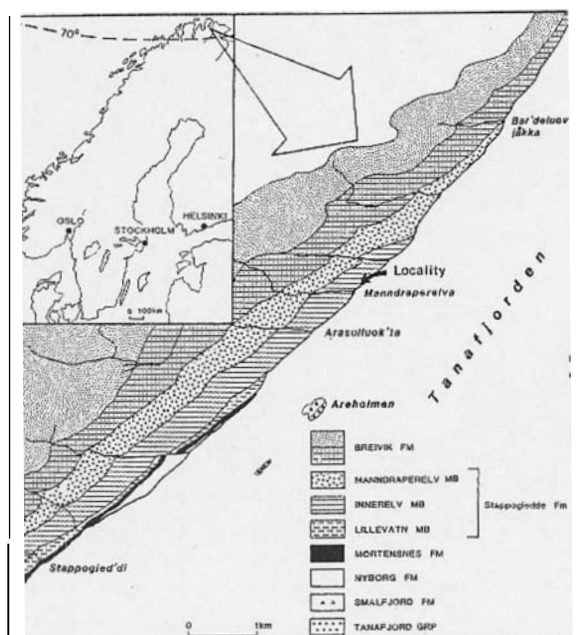


Figure 1. Map of the Tanafjorden region of northeastern Norway, showing the location of coastal outcrops of late Proterozoic to lower Cambrian sequences along Digermul Peninsula.

Member is gradational, and on Digermul Peninsula is marked by the presence of a dark grey, pyritic shale, containing stringers and lenticles of fine-grained

sandstone in the upper part. This sequence is overlain by red and green shales, and capped by a red, coarse-grained sandstone which marks the basal Manndraperelv Member.

### 3. Fossil assemblages and localities

In this study, we describe an assemblage of discoidal megafossils from shoreline outcrops of the Innerelv Member of the Stappogiedde Formation (Vestertana Group) exposed along the east side of Digermul Peninsula near Manndraperelva (Fig. 1). We also include a description of pseudofossils and small burrows, from shallow water facies of the Middle Innerelv Member exposed along the eastern side of the Varanger Peninsula near Kvalneset (locality Komagenes 36WVC45912; Vidal, 1981). Finally, trace fossils and problematica, including *Vendotaenia* and *Sabellidites*, are described from levels 9 and 16 m above the base of the Lower Breivik Formation, exposed immediately south of Bar'deluoventjåkka or Digermul Peninsula (Fig. 1; coordinates: 449, 334, topographical map sheet 223511, Langefjorden).

#### 3.a. Innerelv Ediacaran assemblage

An Ediacaran assemblage, comprised primarily of *Cyclomedusa* sp. Sprigg 1947, but including un-

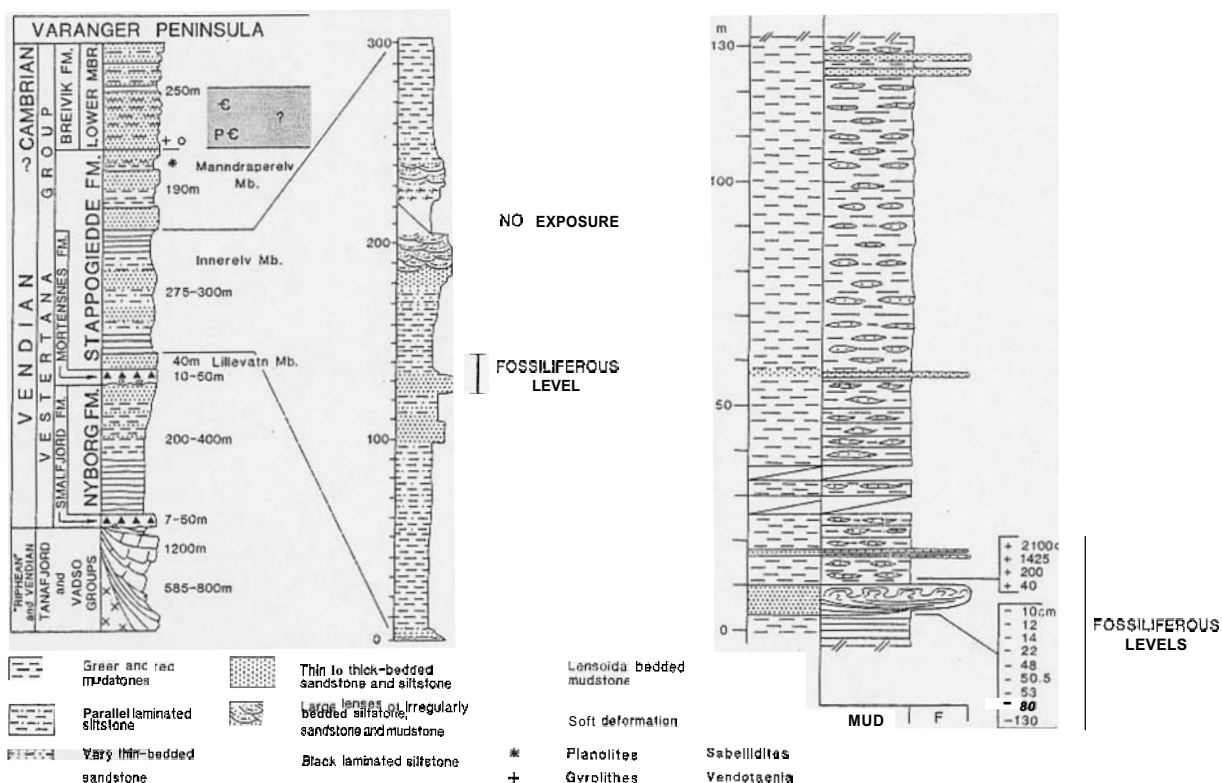


Figure 2. Composite stratigraphic section (left) for the late Proterozoic to early Cambrian sequences on Varanger Peninsula. Expanded section (centre) indicates position of fossiliferous interval within the Middle Innerelv Member of the Stappogiedde Formation exposed north of Manndraperelva. Section to the right indicates the stratigraphic levels sampled. Position of fossiliferous zones is indicated by elevations in centimetres above (+) the top or below (-) the base of a reference sandstone bed at the top of the first coarsening upward cycle in the Middle Innerelv Member.

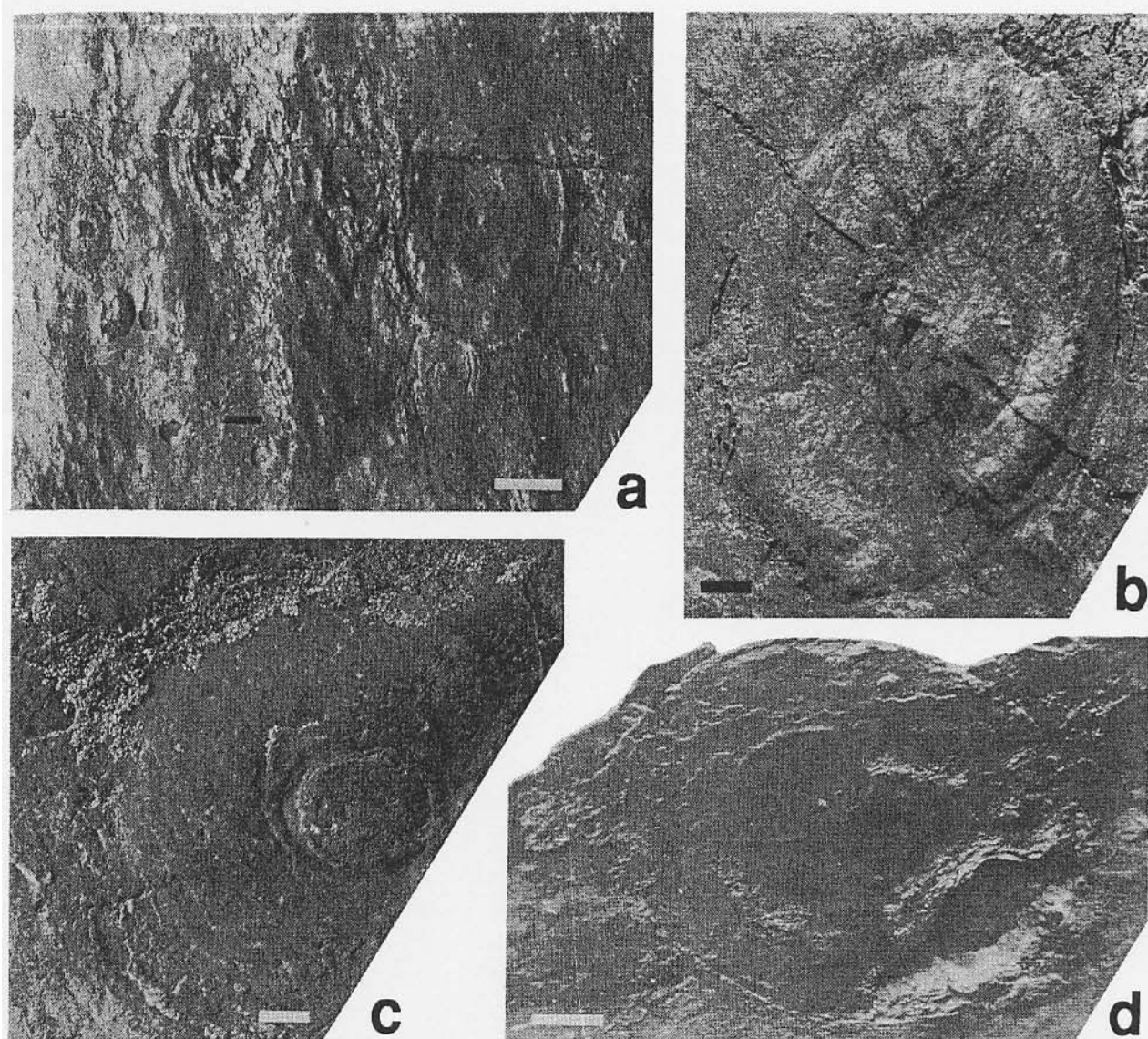


Figure 3. (a) 'Cyclomedusoid' assemblage from upper bedding plane surface of sandstone in Middle Innerelv Member, north of Manndraperelva. Level: +40 cm. Scale bar = 2.0 cm. (b) 'Cyclomedusoid' from float in Middle Innerelv showing faint radial sculpture. Same location as above, Scale bar = 0.5 cm. LO #6394. (c) *Ediacaria?* sp. Collected as a loose block from Middle Innerelv Member exposed along shoreline just north of the creek, Manndraperelva on Digermul Peninsula, Tanafjorden region, northeastern Norway, Scale bar = 1.0 cm. LO #6399. (d) 'Cyclomedusoid' from lower bedding plane surface (overhang) of medium-grained sandstone within uppermost Middle Innerelv Member, north of Manndraperelva. Level: +200. Scale bar = 2.0 cm.

identified species of *Ediacaria?* Sprigg 1947, *Beltanella* Sprigg 1947, *Hiemalora* Fedonkin 1982 and *Nimbria?* Fedonkin 1980, was discovered in fine-grained sandstones and siltstones of the Middle Innerelv Member exposed immediately north of Manndraperelva (Fig. 1).

As noted previously, sedimentary structures and facies relationships suggest deposition in a shallow, subtidal marine environment. The fossiliferous interval (Fig. 2) lies within the upper portion of the lower of two successive coarsening-upward cycles that characterize the Innerelv Member in this region (Banks, 1973b). Illustrated specimens, identified by the prefix LO, have been deposited in the type

collections of the Department of Historical Geology and Palaeontology, University of Lund, Sweden.

Taphonomic studies of living groups provide important constraints for evaluating fossil taxa. Artificially-produced fossils of living Cnidaria show a broad range of taphonomically-induced variation comparable to that observed among many Ediacaran forms (Norris, 1989). In fossilization experiments, the details of medusoid musculature are not preserved, suggesting that the observed morphological differences between living and fossil forms may be largely preservational, and not necessarily indicative of phylogenetic relatedness. The demonstrated importance of taphonomically induced morphological varia-



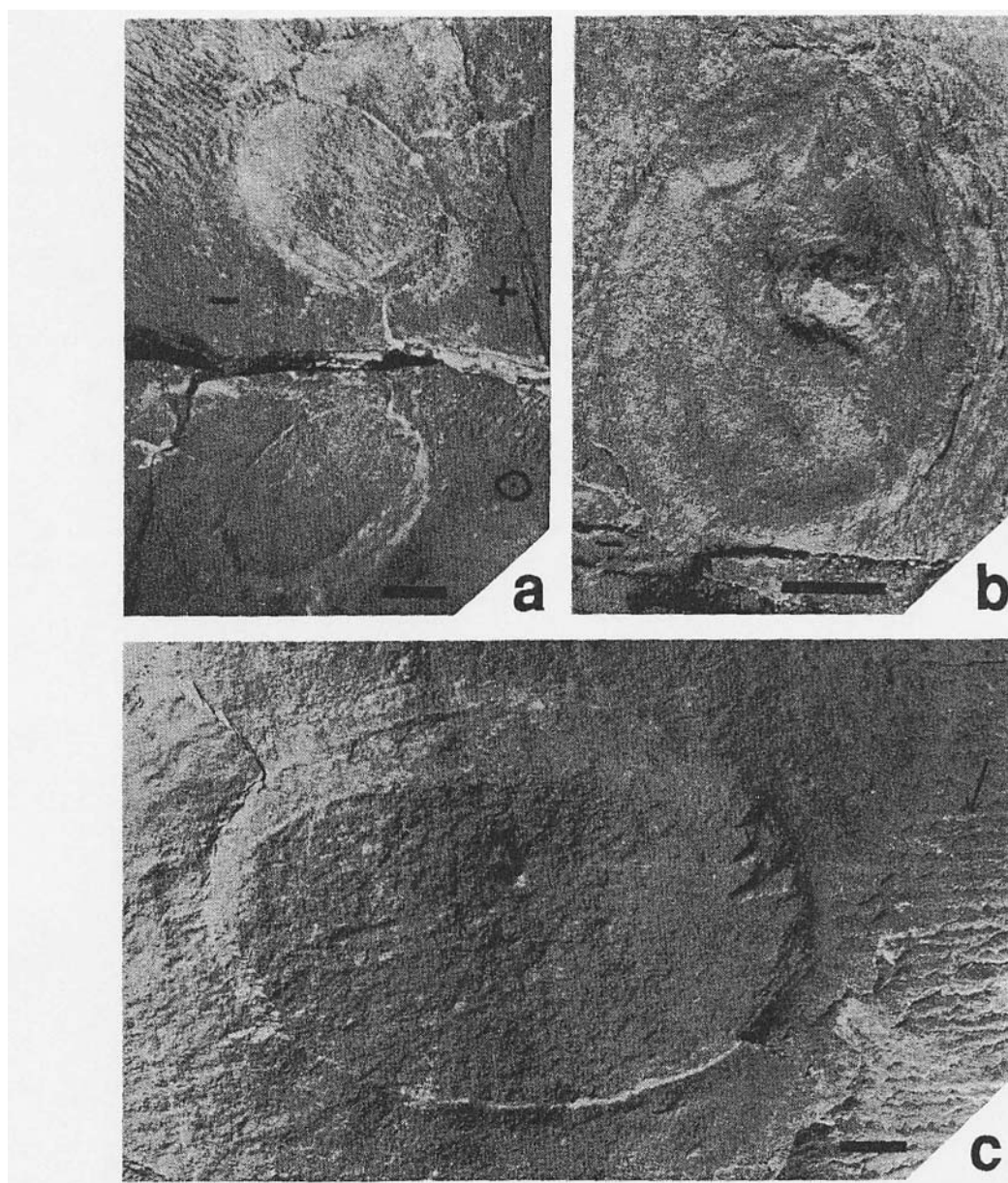
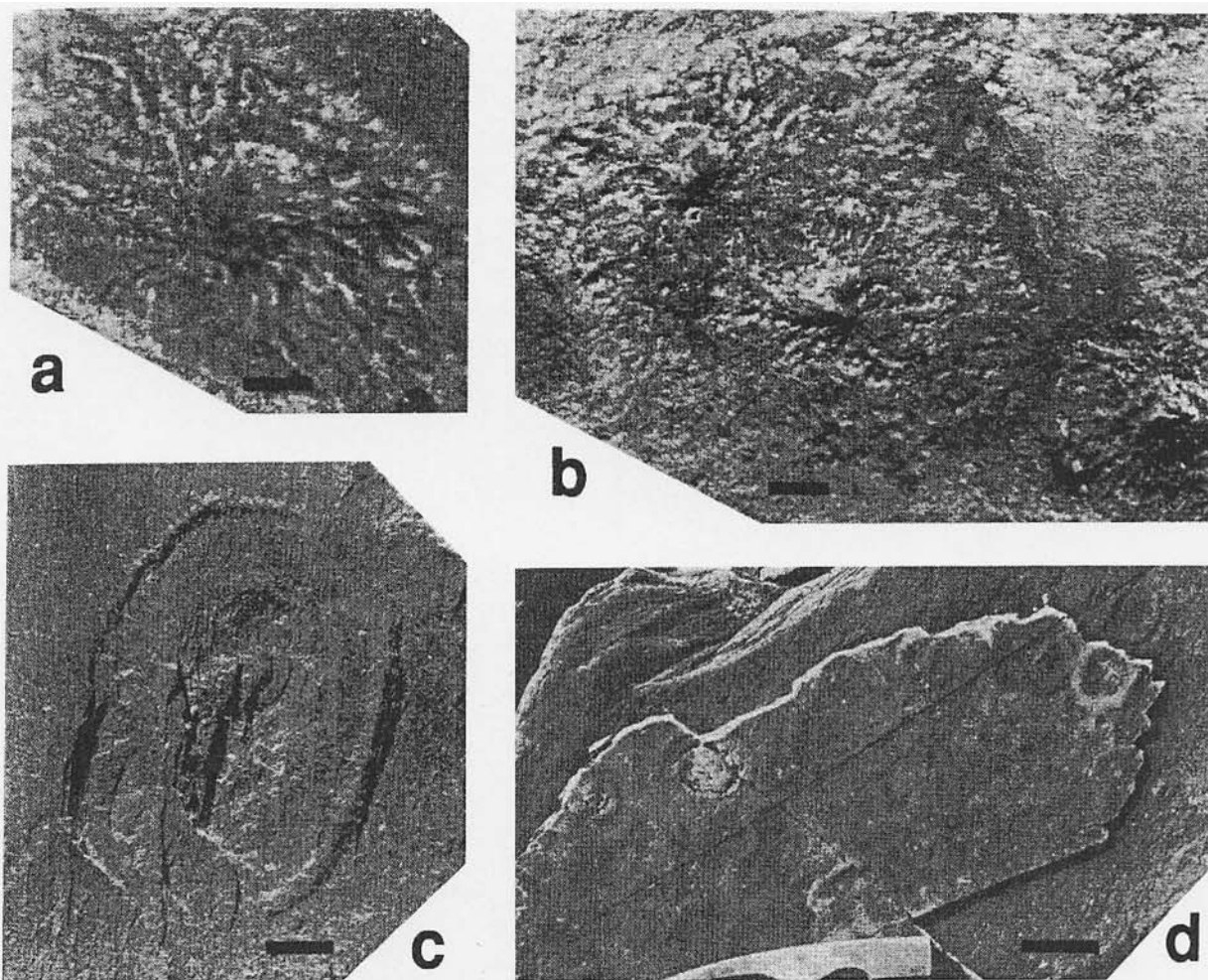


Figure 4. (a) *Beltanella* sp. Epirelief (lower specimen) and corresponding hyporelief (upper specimen) from the Middle Innerelv Member, just north of Manndraperelva. Scale bar = 2.0 cm. Level: -14 cm. LO # 6395. (b) *Beltanella* sp. Hyporelief showing concentric features around central tubercle, perhaps due to compaction. Middle Innerelv Member, just north of Manndraperelva. Scale bar = 1.0 cm. LO # 6396. (c) *Beltanella* sp. Enlargement of upper specimen, Figure 4b. Hyporelief in fine-grained sandstone. Middle Innerelv Member, just north of Manndraperelva, on Digermul Peninsula. Note that intersections of rock cleavages (arrow) are oriented parallel to long axis of specimen, suggesting that the elliptical form is secondary. Scale bar = 1.0 cm. Level: -14 cm. LO # 6395.

bility in living Cnidaria suggests the need for caution in assessing the taxonomic classification of Ediacaran fossils. Given the generally poor state of preservation of the fauna described in this report, species level assignments are considered problematic.

*Cyclomedusa* is the most cosmopolitan of the Ediacaran discoidal fossils (Wade, 1972; Narbonne & Hofmann, 1987). Although taxonomic assignment of the most abundant Innerelv form (Fig. 2a, b) is considered problematic, it appears to be most closely related to *Cyclomedusa* Sprigg 1947. The fossils are

preserved as both epireliefs and hyporeliefs (upper and lower bedding plane surfaces, respectively) in fine-grained, greenish-grey sandstones and siltstones. About 100 individuals were measured and photographed in the field from thirteen separate stratigraphic levels. Of these, 85 were *in situ* occurrences, while the remainder were found on loose blocks. Bedding plane assemblages at levels +40 cm and +1425 cm (Fig. 2) account for more than half of the measured specimens (24 and 28 individuals, respectively). The fossils have an elliptical outline, and are

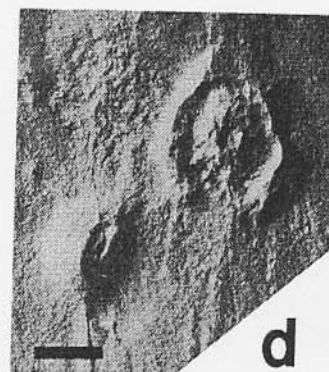
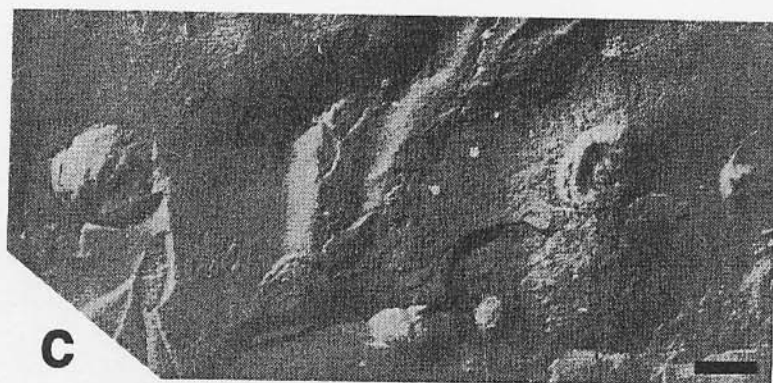
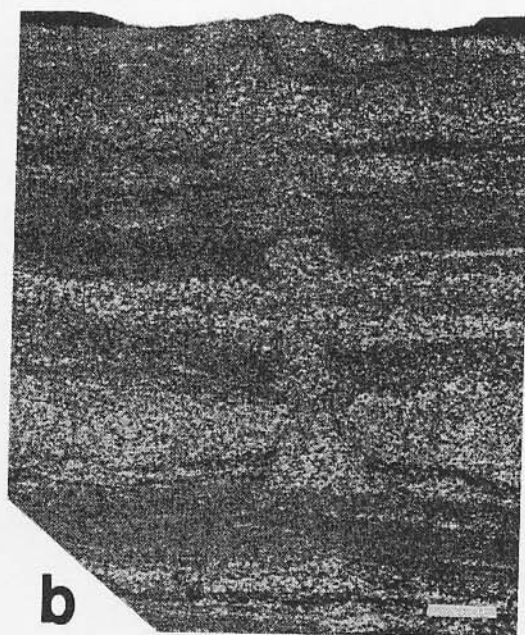
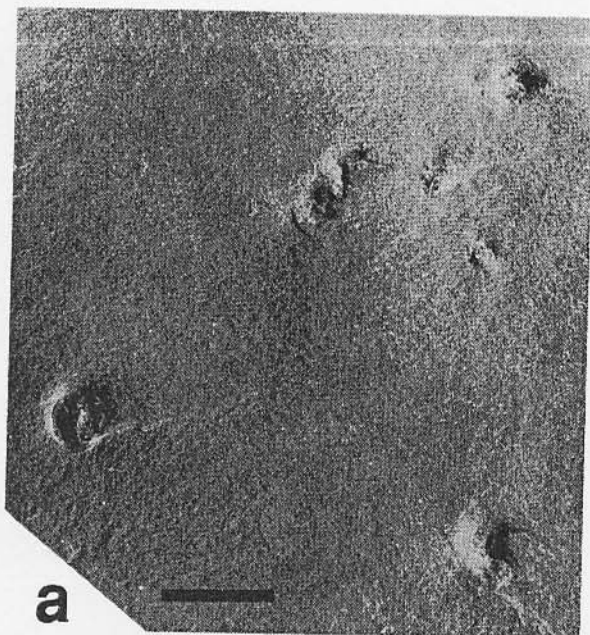


(a–b) *Hiemalora* sp. Upper bedding plane surface (epirelief), Middle Innerelv Member, just north of Manndraperelva. Note well-preserved tentacle impressions in (a). Scale bar for (a) = 0.5 cm; scale bar for (b) = 1.0 cm. Level: –50.5 cm. LO # 6398. (c) *Nimbia*? sp. in float block of fine-grained sandstone, collected from Middle Innerelv Member just north of Manndraperelva. Scale bar = 0.5 cm. (d) *Nimbia*? sp. Collected from float derived from the lower Innerelv Member, about 0.5 km south of Manndraperelva. Scale bar = 2.0 cm. LO # 6397.

typically subdivided into two zones by a single prominent concentric furrow (epirelief) or ridge (hyporelief) which surrounds a centrally-located pit or tubercle, averaging 2.1 mm (range 1–6 mm) in diameter. A faint radial ornamentation is observed in a few specimens (e.g. Fig. 3b), but most specimens show only concentric features. The long axis of the discs averages 5.05 cm ( $\sigma = 2.56$ ; range: 2.2–17.8 cm), while the short axis averages 3.50 cm ( $\sigma = 1.77$ ; range: 1.4–12.5 cm). The orientation of long axes for the bedding plane assemblages (average N22E; range N15E to N30E) is roughly parallel to the strike of the cleavage (average N55E; range N20E to N85E), suggesting that the elliptical shape is a secondary feature.

Preservational variations are conspicuous within many Ediacaran discoidal fossils, and some taxa, notably *Cyclomedusa*, have been applied very broadly (Glaessner, 1984). For example, the type species, *Cyclomedusa davidii* (Sprigg, 1947), to which most

species have been referred, is a circular to slightly elliptical form that has a sub-umbrellar surface characterized by numerous fine radial grooves, along with a variable number of irregularly-spaced concentric furrows which subdivide the surface into distinct regions (Sun, 1986a). However, radial structures are not present in all specimens. For example, paratypes of this species lack radial grooves and have concentric ridges only near the periphery (Glaessner, 1984; Sun, 1986a). Specimens of *C. davidii* Sprigg illustrated by Wade (1972, pl. 41, fig. 1) lack radial striations, as do specimens of *Cyclomedusa* sp. described by Narbonne & Aitken (1990, pl. 1, figs 1, 2; pl. 2, figs 3, 5). The presence of such features may depend on preservation (Sun, 1986a), and pending revision of this genus, it seems unrealistic to base the identification of genera on the presence or absence of radial features (Narbonne & Aitken, 1990, p. 959). Occurrences of *Cyclomedusa* in the Windermere Supergroup of the Wernecke and Mackenzie Moun-





tains Of Canada (Narbonne & Hofmann, 1987; Narbonne & Aitken, 1990) contain a mixture of forms, that show both radial and concentric elements.

The common 'cyclomedusoid' from the Innerelv Member is characterized by a general absence of radial sculpture, and the presence of one or more prominent furrows that subdivide the disc into distinct regions. Typically, regionation is by a single deep furrow which divides the disc into two subequal parts, surrounding a central papilla. However, our specimens show neither the fine radial sculpture typical of *Cyclomedusa*, nor the fine concentric sculpture typical of *Kullingia*. As noted above, whether the absence of these features is due to preservation, or reflective of actual taxonomic differences, remains uncertain. However, based on the above diagnosis, our specimens appear to be allied most closely with the *Cyclomedusa* complex (Sun, 1986a), and are provisionally placed with that genus, pending further study.

Narbonne & Aitken (1990, p. 959) interpret *Cyclomedusa* as a firm-bodied, conical form that lived with the aboral surface permanently attached to the substrate at the position of the central tubercle. Interestingly, where large aggregations of individuals are preserved on bedding planes in the Innerelv, in no case were the discs observed to cut across one another. This is suggestive that individuals may have been living attached to the bottom, rather than accumulating there passively before burial.

*Ediacaria flindersi* Sprigg 1947 is the largest discoidal fossil known from the Ediacaran assemblage (Glaessner & Wade, 1966; Narbonne & Hofmann, 1987). It is characterized by a basic tripartite organization in which the smooth ex-umbrellar surface is subdivided into equal portions by two prominent furrows. In the type specimens, radial furrows are present, but only on the sub-umbrellar surface. In addition, their distribution is confined largely to the outer zone (Glaessner & Wade, 1966; Sun, 1986a). The central region of the disc is smooth, slightly elevated, and lacks the central papilla typically observed in *Cyclomedusa*. We recovered a single, partial specimen (Fig. 3c) from float derived from the fossiliferous interval just north of Manndrapereiva.

The specimen exhibits the smooth, central disc and middle zone typical of *Ediacaria*, but the outer zone, if present at all, is only faintly preserved. Our partial specimen resembles hyporeliefs of *Ediacaria* reported previously from Australia (Glaessner & Wade, 1966), the Wernecke Mountains, Canada (Narbonne & Hofmann, 1987) and the White Sea region, U.S.S.R. (Fedonkin, 1981), and is questionably assigned to this genus pending further study.

Two of our specimens (Fig. 4a, b) are comparable to *Beltanella* Sprigg 1947 (Narbonne & Hofmann, 1987; Narbonne & Aitken, 1990), but differ in having elliptical rather than circular outlines. The long axis of the specimens parallels exactly the strike of the cleavage (Fig. 4c), suggesting that the elliptical form is a secondary feature. Both surfaces are characterized by a smooth, flat disc with a slightly elevated margin, surrounding a central papilla. The lack of any regular concentric or radial ornamentation is notable, although some of our specimens do exhibit irregular concentric features which may be due to compaction and flattening of the central papilla (e.g. Fig. 4b). Narbonne & Hofmann (1987, p. 666) suggest that *Beltanelliformis*-type discoidal fossils were originally globular forms that lived 'attached to the seafloor'.

Four specimens resembling *Hiemalora* Fedonkin 1982 were discovered on a single bedding surface in fine-grained siltstones at fossiliferous level -50.5 cm (Fig. 2). The specimens are preserved as low epireliefs, and consist of a smooth central disc averaging 1.0 cm in diameter (range 0.85–1.2 cm), surrounded by an irregular fringe of overlapping tentacle impressions (Fig. 5a, b). This genus was reported previously from the Vendian of the White Sea region (Fedonkin, 1982, 1985b), and Siberia (Vodyanuk, 1989).

Discoidal fossils were also discovered south of Manndrapereiva, in float derived from the Lower Innerelv Member. The discoidal, ring-shaped forms are elliptical in outline and occur on the bases of fine-grained, red sandstones (Fig. 5d). They range in size from 1.3 to 2.7 cm (long axis), and possess a well-defined outer ridge (range 2.5–3.0 mm wide) surrounding a slightly depressed central area. Comparable fossils were also found in fine-grained sand-

Figure 6. (a) Pseudofossils. Small pillar structures preserved in epirelief on upper surface of fine-grained, ripple cross-laminated sandstone from the Middle Innerelv Member, Kvalneset, west Varangerfjorden. (Note that similar structures from this locality (Banks, 1970) were previously interpreted as vertical burrows). Scale bar = 0.5 cm. LO # 6403. (b) Transverse thin section view of small pillar structures shown in Figure 6a. Section reveals that the features penetrate several centimetres into underlying bed. Orientation of clay stringers suggests fluidization and upward movement of sand into overlying shale layer. Middle Innerelv Member, Kvalneset. Scale bar = 0.5 cm. LO # 6407. (c) Pseudofossils. Pillar structures preserved on surface of fine-grained, ripple cross-laminated sandstone of Middle Innerelv Member, Kvalneset. Scale bar = 1.0 cm. LO # 6404. (d) Pseudofossils. Casts of pillar structures similar to those in Figure 6c, preserved in hyporelief on base of fine-grained sandstone. Middle Innerelv Member, Kvalneset. Scale bar = 0.5 cm. LO # 6405. (e) Pseudofossils resembling *Medusinites* (left) and *Bergueria* (right). Enlargement of pillar structure in Figure 6c (right) preserved on surface of fine-grained, ripple cross-laminated sandstone of Middle Innerelv Member at Kvalneset, west Varangerfjorden. Scale bar = 0.5 cm. LO # 6404. (f) Thin section of large specimen shown to left in Figure 6e. Ripple cross-laminations in fine-grained sandstone show disrupted laminae in upper part and sand penetrating upward into overlying shale layer. Interpreted to be a pillar structure formed by fluidization. Middle Innerelv Member, Kvalneset. Scale bar = 1.0 cm. LO # 6406.

stones of the Middle Innerelv Member, north of Manndraperelva (Fig. 5c). The fossils from these localities resemble *Nimbia* Fedonkin 1980, originally described from the Valday 'Series' of the White Sea region, and more recently from inter-tillite beds in the Windermere Supergroup of Northwestern Canada (Hofmann, Narbonne & Aitken, 1990). Pending further study, we questionably assign our Lower Innerelv specimens to this genus.

### 3.b. Pseudofossils

The superficial similarities that exist between certain classes of inorganic sedimentary structures and body fossils of simple form are among the earliest lessons learned in palaeontology. The proper assessment of origin is especially important in late Precambrian rocks where the record is non-skeletal. The resemblance of some Ediacaran discoidal fossils (e.g. *Cyclomedusa*, *Medusinites*), to inorganically-produced sedimentary features (e.g. structures produced by dewatering or sediment loading) has been noted previously (Webby, 1970; Cloud, 1973; Plummer, 1980; Sun, 1986a). Within the field of ichnology, similar precautions should be noted, especially among Ediacaran trace fossils, which are typically simple, small, non-branching forms found on bedding planes.

Small, vertically oriented structures resembling burrows are common on some bedding plane exposures of the Middle Innerelv Member which crop out along the shoreline on the eastern side of the Varanger Peninsula, near Kvalneset (locality Komagenes 36WVC45912; Banks, 1973a; Vidal, 1981).

At Komagenes, the Innerelv Member consists of primarily fine sandstones (up to 20 cm thick) showing ripple cross-lamination, climbing ripples, and thin mudstone interbeds (Facies 4 of Banks, 1973b). Small cylindrical burrows, assigned to the ichnogenera *Skolithos* and *Arenicolites*, were described previously from the Middle Innerelv at Kvalneset (Banks, 1970, 1973a), and are reportedly the oldest trace fossils in northeastern Finnmark (Crimes, 1989). Vertical burrows are uncommon in stratigraphic sequences older than Lower Cambrian, and their presence in the Vendian is of special interest in evaluating models for the early evolution of the Metazoa (Valentine, 1989).

The burrow-like structures from Kvalneset are roughly circular in outline, 1–3 mm in diameter, and penetrate thin shale partings between fine-grained, ripple cross-laminated sandstone beds (Fig. 6a). The lithofacies association, and the complete absence of other evidence of biological activity (e.g. bioturbation, bedding plane trace fossils, etc.), suggests the need for caution in interpreting these structures. Oriented thin sections of several representative specimens were prepared in order to evaluate better the origin of the structures.

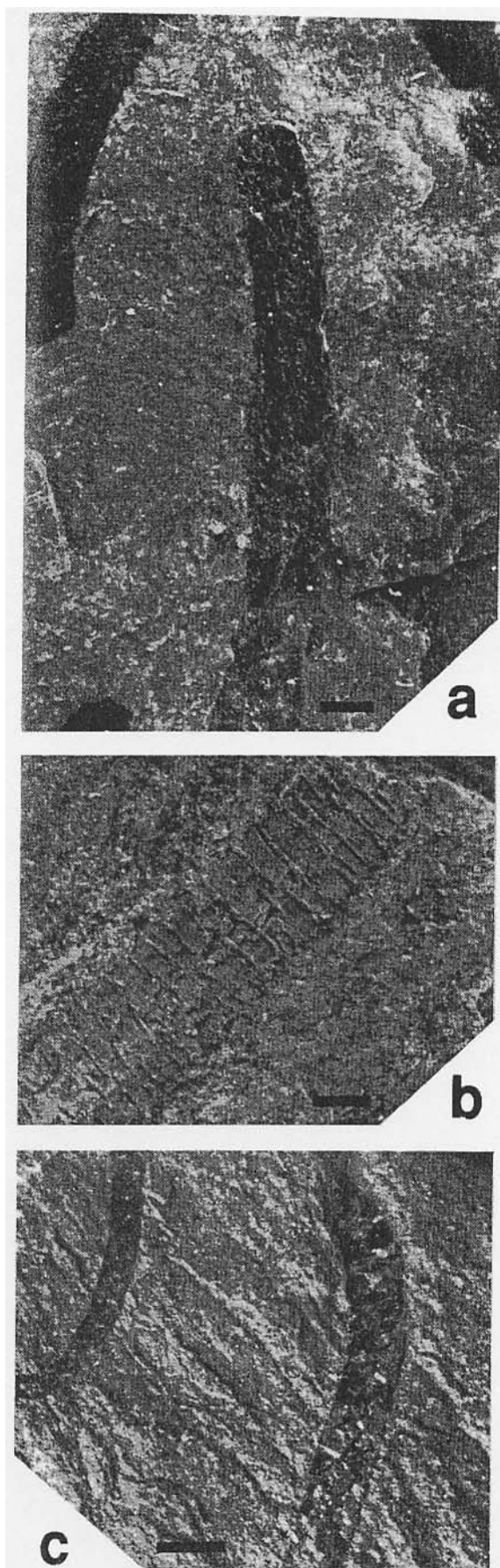
In thin section, the structures are filled with fine-grained sandstone derived from the underlying bed. They have shallow, cylindrical cross-sections which deform the overlying shale laminae in an upward direction (Fig. 6b). The cores of the structures typically have vertically oriented clay stringers which can be traced downward into the underlying sandstone bed a centimetre or more. The features are interpreted to be small-scale fluid-escape structures, or 'pillars' formed by the dewatering of water-saturated sands. This interpretation is consistent with the occurrence of climbing ripples with mud drapes, convolute bedding, and other features which suggest rapid sedimentation of water-saturated sediment (Lowe & Lopiccolo, 1974; Lowe, 1975).

Larger features, which resemble the discoidal fossil *Medusinites* (Glaessner & Wade, 1966), were also collected from both basal and upper surfaces of fine-grained sandstone beds at Komagenes (Fig. 6c–e). In thin section, the features are underlain by zones of disrupted lamination that penetrate several centimetres into the underlying bed (Fig. 6f). Within these zones, shale laminae have been deformed and bent upward, apparently by the fluidization and upward movement of the sand prior to lithification. The zones of deformation typically originate on ripple crests. The association of these features with climbing ripples and convolute lamination argues strongly for an inorganic origin by the dewatering of water-saturated sediment.

### 3.c. Trace fossils and problematica

The contact between the Manndraperelv Member and Lower Breivik Formation is exposed in coastal outcrops immediately south of Bar'deluoventjåkka (Fig. 1; coordinates: 449, 334, topographical map sheet 223511, Langefjorden). The Upper Manndraperelv Member is characterized by medium-grained red sandstones, some with ripple-marked tops, and thinner interbeds of wavy-bedded, ripple cross-laminated, fine sandstone and siltstone. The contact with the Lower Breivik Formation is identified by several thick, massively bedded, medium- to coarse-grained, greyish-green sandstones, some with ball and pillow structures, with thinner interbeds of medium-grained sandstone showing cross-bedding, graded bedding, and wavy-laminated, fine sandstone and siltstone.

Trace fossils are abundant on the bedding surfaces of thinly bedded, fine sandstones and siltstones of the Upper Manndraperelv Member at Bar'deluoventjåkka. Rock cleavage, developed at a low angle to laminations, makes observation of bedding surfaces difficult, particularly in the thinner units. However, small unbranched surface trails, and cylindrical burrows oriented parallel to bedding (*Planolites*-type), are abundant at selected horizons on the lower bedding surfaces of thin, fine-grained sand ripples in shale.



About five metres above the contact with the Lower Breivik Formation, the trace fossil assemblage is more diverse, and ~~is~~ dominated by larger forms, including *Planolites*, *Cochlichnus*, *Gyrolithes*, and *Phycodes*. Our observations on the distribution of trace fossils in the Manndraperelv and the Lower Breivik **are** in general agreement with previous published **work** for this region (**Banks**, 1970, 1973*a*). However, new observations suggest the following refinements: (1) the vertical, spiral burrow, *Gyrolithes*, known previously from the Middle Breivik, also occurs in the Lower **Breivik**; and (2) the oldest undisputed trace fossils are small, *Planolites*-type burrows and simple surface trails that first appear in the Lower Manndraperelv Member. The latter conclusion **is** based on our evaluation of small vertical burrows reported previously from the Middle Innerelv Member, which **we** interpret to be inorganic.

In addition to the trace fossil assemblage described above, filamentous, carbonaceous films, identified as *Vendotaenia*, were discovered on the upper surfaces of ripple-marked, fine sandstones about 10m above the basal contact of the Lower Breivik at Bar'deluvotjåkka, along with carbonaceous annular tubes, tentatively assigned to *Sabellidites* (Fig. 7a–c).

#### 4. Stratigraphic significance

The lowest formally proposed faunal zone in northern Scandinavia is the *Kullingia* Zone (Føyn & Glaessner, 1979), defined on the occurrence of the fossil medusoid, *Kullingia concentrica* in Member III (Middle Sandstone C) of the Dividal Group, northern Scandinavia (Føyn & Glaessner, 1979). *Kullingia concentrica* Glaessner 1979 (Føyn & Glaessner, 1979) is a chambered form that **is** separated, on that basis, from superficially similar forms comprising the *Cyclo-medusa* plexus (Sun, 1986*a*). This species **is** comparable to fossils which occur near the top of the Arumbera Sandstone of central Australia and is probably late Vendian (Føyn & Glaessner, 1974; but see Jenkins, 1981). This is consistent with the first occurrences of the Lower Cambrian *Platysolenites antiquissimus* Eichwald in Member IV (Middle Shale Member) of the Dividal Group at Halkkavarre (Føyn, 1967; Hamar, 1967; Føyn & Glaessner, 1979), and at a level about 150 m **above** the base of the Lower Breivik Formation east of Tanafjord (Føyn, 1967) and on Digermul Peninsula (**Banks**, 1970). This

Figure 7. (a–c) *Sabellidites* sp. Carbonaceous tubes flattened by compaction, some showing annulations, and rounded terminations. Discovered in basal siltstones of the Lower Breivik Member at Bar'deluvotjåkka, Tanafjorden. Scales and specimen numbers: (a) scale bar = 10 mm, LO # 6402; (b) scale bar = 0.5 mm, LO # 6401; (c) scale bar = 10 mm, LO # 6400.

correlation is also consistent with the first appearance of the early Cambrian trace fossils, *Phycodes* and *Treptichnus*, in the Lower Breivik at Tanafjorden (Banks, 1970).

Our discovery of an Ediacaran assemblage in the Middle and Lower Innerelv Member on Digermul Peninsula provides support for previous suggestions of a late Vendian age for this sequence, based on acritarchs (Vidal, 1981). This general conclusion is also consistent with the occurrence of Lower Cambrian taxa, including the trace fossil *Phycodes*, and the problematical forms *Vendotaenia* and *Sabellidites*, in basal portions of the Lower Breivik Formation in the same stratigraphic section.

The fauna of the Innerelv Member is dominated by a discoidal form that shares certain features with the cosmopolitan genera, *Cyclomedusa* and *Ediacaria*, but which differs from these and related genera, in an absence of radial sculpture. These forms are included within the *Cyclomedusa* plexus (Sun, 1986a), an informal grouping of intergrading taxa that share a common concentric/radial organization. *Cyclomedusa* and other discoidal forms of the Ediacaran fauna have been variously regarded as pelagic medusae (Wade, 1968; Sun, 1986a), as benthic 'polyps' (Fedonkin, 1985a; Jenkins, 1988; Narbonne & Aitken, 1990), as the attachment structures of sea-pens (Jenkins, 1989), or as burrows of benthic cnidarians (Seilacher, 1984). In contrast, *Kullingia* (Føyn & Glaessner, 1979) is regarded as an unrelated pelagic form (for alternative view see Seilacher, 1984, 1989) which possessed an annular, chambered float similar to that of living chondrophorans, such as *Porpita* or *Velella* (Jenkins, 1984; Sun, 1986). These groups are generally regarded as more primitive in organization than modern bilateral chondrophorans, and probably evolved during the early Ediacaran, becoming common by the late Ediacaran (Jenkins, 1984).

In light of the present difficulties in taxonomic interpretation and present uncertainties in the correlation of the Ediacaran faunas of Baltoscandia, we suggest, as a working concept, that the *Kullingia* Zone, as originally defined (Føyn & Glaessner, 1979), be broadened to include related form genera of the *Cyclomedusa* plexus, inclusive of the common Innerelv form described herein. It is our hope that future work will provide the needed data for a refinement of the biozonation of late Proterozoic sequences of north-eastern Finnmark.

## 5. Summary and conclusions

An Ediacaran assemblage dominated by an unidentified discoidal form related to *Cyclomedusa* Sprigg 1947, and including species of *Ediacaria*? Sprigg 1947, *Beltanella* Sprigg 1947, and *Hiemalora* Fedonkin 1982 and *Nimbia*? Fedonkin 1980, is

described for the first time from the Innerelv Member of the Stappogiedde Formation exposed in coastal outcrops on Digermul Peninsula, west of Tanafjorden in northeastern Finnmark. The assemblage bears similarities to previously described occurrences of Ediacaran fossils from the Charnwood Forest, Leicestershire, England (Ford, 1958, 1963, 1968, 1980), the Conception Group, Avalon Peninsula, Newfoundland (Anderson & Mishra 1968; Anderson, 1978), the Windermere Supergroup of the Wernecke, Mackenzie and Rocky Mountains of Canada (Narbonne & Hofmann, 1987; Hofmann, Narbonne & Aitken, 1990; Narbonne & Aitken, 1990) and the Dividal Group, northern Scandinavia (Føyn & Glaessner, 1979), and provides support for previously described biozones and correlations that suggest a Vendian (late Ediacaran) age for the Innerelv Member (Siedlecka & Siedlecki, 1971; Vidal, 1981). Within the same sequence the earliest unequivocal trace fossils occur within the lower part of the Manndraperelv Member, consisting of small horizontal trails and *Planolites*-type burrows, preserved on the bases of thin sandstones.

This work is significant in providing a basis for more refined correlations of the stratigraphic interval between the Mortensnes Formation (youngest Varangerian tillite), and the first appearance of Lower Cambrian skeletal fossils (e.g. *Platysolenites antiquissimus*) in the Lower Breivik Formation (Banks, 1973a, Fayn & Glaessner, 1979). Based on the occurrence of the ichnofossil, *Phycodes pedum*, along with the problematic fossils, *Vendotaenia* and *Sabellidites*, the Precambrian–Cambrian boundary in our study area is placed just above the basal sandstones of the Lower Breivik Formation. In the East European Platform, *Vendotaenia* and *Sabellidites* precede the appearance of *Platysolenites antiquissimus* and accompanying biotic components marking the Precambrian–Cambrian boundary (Moczydlowska & Vidal, 1986; Moczydlowska, 1991). However, the stratigraphic ranges of *Vendotaenia* and *Sabellidites* extend well into the Lower Cambrian and overlap with the ranges of both *Platysolenites antiquissimus* and *Phycodes pedum*. In the Avalonian Platform, the earliest appearance of *Phycodes pedum* is taken to mark the base of the Cambrian (Narbonne *et al.* 1987). However, the combined evidence from shelly faunas and stable isotope chemostratigraphy (Strauss *et al.* 1990 and work in progress) suggests that a higher boundary, located near the base of the *Aldanella attleboroensis* Zone, may be preferable.

**Acknowledgements.** The authors are grateful for critical comments on the manuscript by Drs Simon Conway Morris, Guy M. Narbonne and Malcolm F. Walter. Field and laboratory work was supported by generous grants from the Natural Science Research Council (NFR) for on-going research by G. Vidal, M. Moczydlowska, and P. Ahlberg, and for fieldwork by J. Farmer during August 1989.



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