Dendroid graptolites in the Elnes Formation (Middle Ordovician), Oslo Region, Norway

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Maletz, J. & Egenhoff, S.O.: Dendroid graptolites in the Elnes Formation (Middle Ordovician), Oslo Region, Norway. *Norwegian Journal of Geology*, Vol. 85, pp. 217 - 221. Trondheim 2004. ISSN 029-196X.

Well preserved relief specimens of the dendroid graptolites *Dendrograptus rigidus* Bulman, 1936 and *Acanthograptus* sp. have been discovered in a siltstone within the basal Engervik Member of the Elnes Formation. The specimens are the first dendroid graptolites found in the Middle Ordovician of the Oslo Region, although planktic graptolites are common in the shales of the Elnes Formation.

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Introduction

Graptolites are the most common fossil group in the late Middle Ordovician Elnes Formation of the Oslo Region, Norway (Bulman 1953; Berry 1964; Maletz 1997a). The faunas include numerous, often well-preserved specimens of dichograptid and diplograptid - planktic- graptolites, but benthic faunal elements have not been found before. The graptolites are common in many levels of the dark grey to black shales of the Elnes Formation, but are less common in the more coarse-grained units. The preservation of the material ranges from full relief specimens to flattened and poorly preserved specimens.

The graptolite fauna has been used to establish a detailed biostratigraphy for the late Middle Ordovician of Scandinavia (Maletz 1995; 1997a). Comparable faunas are distributed widely in southern Scandinavia. One of the most striking characteristics of the graptolite faunas of the Elnes Formation, as well as those of the underlying Tøyen Shale Formation (Monsen 1937), is the fact that benthic graptolites are completely absent. In this respect the faunas differ considerably from faunas of comparable age in eastern North America. The Lower Ordovician graptolite faunas of the Quebec Appalachians, for example (Hall 1965; Clark 1924; Maletz 1997b), contain a high percentage of dendroid elements. The same is true for the Middle Ordovician faunas of the Table Head (Albani et al. 2001), and the Lower to Middle Ordovician Cow Head Groups of western Newfoundland (Williams & Stevens 1988). This lack of dendroid graptolites in the Scandinavian successions has not been explained so far and requires our attention. A few poorly preserved dendroids have been discovered recently in the higher parts of the Elnes Formation (Maletz et al. 2004, unpublished).

The dendroid fragments were found in the upper part of a siltstone layer at 31.5-32.0 m in the "abandoned factory section" at Slemmestad (Maletz 1997a). The section was identified as the Bjørkåsholmen old quarry, Oslo-Asker district (map reference NM 839 289) by Tongiorgi et al. (2003). Siltstones form the basal part of the Engervik Member of the Elnes Formation. The specimens are preserved in full relief as silvery shining periderm infilled with sediment.

Lithostratigraphy

The succession at the Slemmestad factory (Maletz 1997a) consists mainly of black siliciclastic mudstones with some intercalated quartzose to carbonaceous siltstones (Fig. 1). The siltstone beds are typically between 1 and 5 cm thick, but may exceptionally reach 20 cm. The thickness of individual siltstone layers does not significantly vary at outcrop scale, but a larger scale correlation of beds between outcrops appears to be difficult. The individual beds are generally characterized by sharp bases and tops. Internally, they may show a lower horizontally stratified part overlain by cm-thick current ripples or are composed entirely of ripples. When heavily weathered, no structures are preserved. The siltstones sometimes contain mm-sized calcareous

Fig. 1. Siltstone with current ripples from the Elnes Formation at the Slemmestad factory (see Maletz 1997a for location map).

biogenic fragments and rounded siliciclastic mudstone pebbles. Bedding-parallel bioturbation is observed in quite a number of beds. Septarian concretions occur at some levels.

Origin of siltstones

The siltstone beds in the Elnes Formation show transport of the graptolites, in contrast to most of the intervening shales in which indications of transport are rare, but may be represented by current aligned graptolites (Williams & Rickards 1984). In general the depositional environment of the Elnes Formation appears to be low energy and is dominated by suspension deposition of mudstones. The intercalated siltstone beds, however, reflect episodic high-energy events. The sedimentary process that brought in the carbonate and quartz grains is still a matter of debate. Whereas Bjørlykke (1974) favours storm-induced currents and a shallow-water origin of the siltstones from the vicinity of the depositional site, Seilacher & Meischner (1964) argue for turbidites as the depositing flows. The fine grain sizes within the siltstone beds indicate a distal setting and a relatively long transport path, or a source area, which supplied only fine-grained material. There is still a considerable deficit in reconstructing the provenance of the siltstones that could be used to detect the original habitat of the benthic graptolites decribed in this paper. However, the first results deduced from ripple set orientations within the siltstone beds reflect transport directions towards northern, western as well as eastern directions. Based on this, several sources for the origin of the siltstones and also of the enclosed benthic faunas have to be considered:

1) Origin from the south. A Middle Ordovician foreland basin developed along the southern rim of Baltica due to the closure of the Tornquist Ocean, when eastern Avalonia collided with Baltica (Maletz et al. 1997a, 1998; Beier et al. 2000). In its initial phase, a thick succession of siliciclastic sediments was deposited at the northern rim of the approaching eastern Avalonia and is now represented by tectonically stacked strata in the subsurface of north-eastern Germany and northern Poland, with comparable graptolite faunas (Maletz 1998, 2001; Podhalanska 1980). The siltstone beds in the Elnes Formation may represent the deposition of sediments from the approaching orogen.

This interpretation is favoured by the fine grain sizes of the silt beds that is in agreement with a distal position relative to the active orogen. It is also supported by the composition of the Elnes mudstones that have a different geochemical signature in comparison to slightly older Baltica-derived sands (Bjørlykke 1965, 1974) thereby favouring an external source also for the siltstones. The shallow-water benthic graptolites then would not have been strongly affected by the long transport.

2) Origin from the west, where the Iapetus Ocean closed relatively slowly and the Caledonian orogeny was stacking up, starting in the Middle Ordovician. Faunas of the region show a loss of distinctiveness from the Middle Ordovician onwards, indicating the closure of the Iapetus Ocean (Shaw & Fortey 1977; Jaanusson 1979; Bruton & Owen 1979).

Bruton & Harper (1985) postulated an Arenig to Llanvirn magmatic arc in the Iapetus Ocean, that formed local palaeotopographic highs west of the study area. The siltstones could originate from these. As the margins of arcs in a tropical to warm temperate realm are often rimmed by carbonate-producing organisms this setting would well explain the mixture of siliciclastic and carbonate particles in the siltstone beds. The good preservation of benthic graptolites could be well explained by a relatively short distance between the arc and the mainland of Scandinavia due to ongoing Caledonian collision during the Ordovician. The distance must anyhow have been considerable, as is reflected in the fine grain size of the siltstone beds.

3) Origin from the interior of the large Baltica platform to the north and east. According to Nielsen & Harper (2003), the facies belt nearest to the shore in the Oslo Region was composed of silt- to sand-sized siliciclastics during the latest Ordovician, and the distribution of facies belts was probably similar during the deposition of the Elnes Formation. To transport silt grains from the shoreline to the Elnes Formation deep shelf environment, the siliciclastic sediments would have had to cross an entire carbonate platform. On the island of Öland, rich dendroid graptolite faunas are well known (Wiman 1895; Bulman 1936; Skevington 1963, 1965a,b) and have been isolated chemically from glauconitic limestones of Middle Ordovician age.

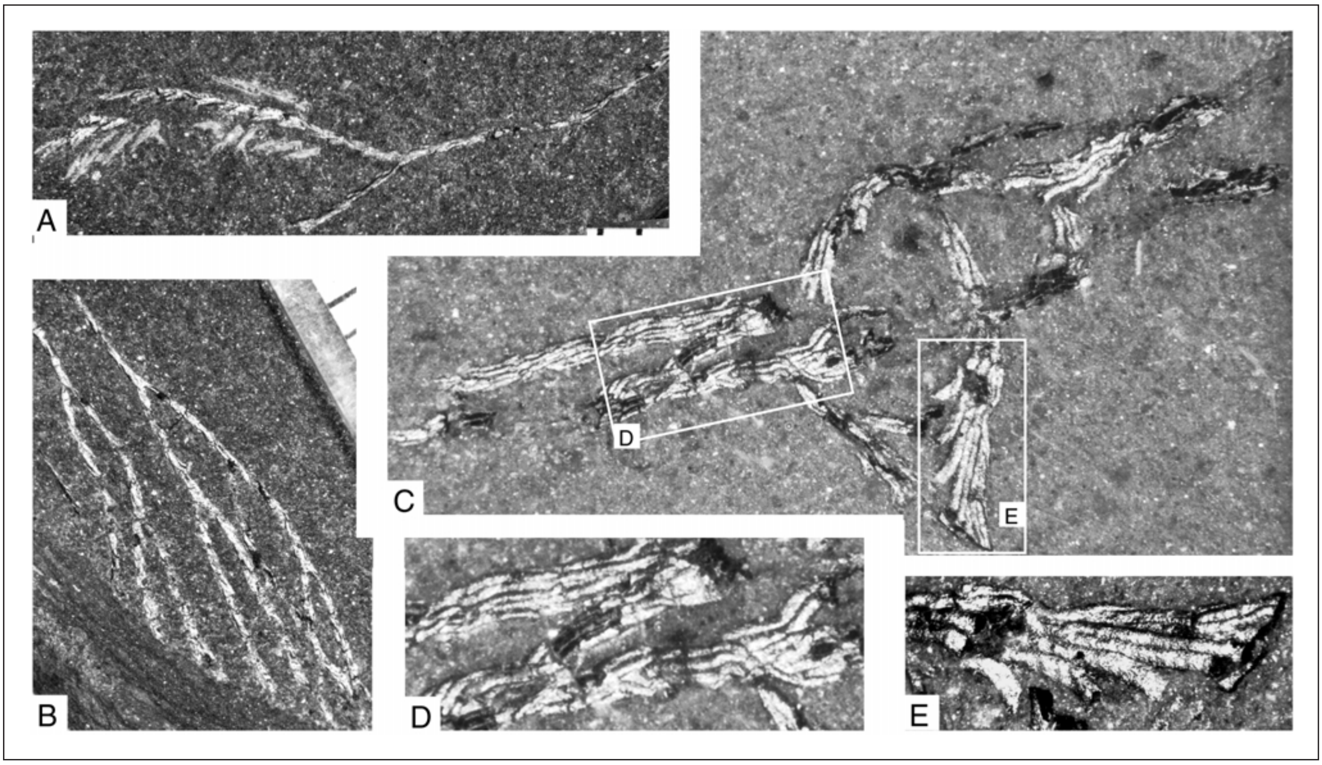

Fig. 2. A,B: Dendrograptus rigidus *Bulman. A: PMO 155.835. B: PMO 155.839. A,B: x5. C-E: Acanthograptus sp. PMO 155.836. B: complete specimen, white boxes show magnified parts of C, D. B: x10, C,D: x20.*

They are associated with a diverse graptoloid fauna (Jaanusson 1960; Skevington 1965a), are of a similar age as the Oslo Region specimens. If the Elnes Formation dendroids originate from a comparable environment, storms must have mixed shallow-water siliciclastics with carbonate particles, torn off the dendroid graptolites and transported them down to the lower portion of the shelf. During storms, sediment is generally shed downshelf (Swift & Thorne 1991), and an incorporation of attached benthic organisms is likely during these high-energy events. Until further data on the sedimentology and the source of the siltstone beds are available, it is therefore most likely that the benthic graptolites from the Elnes Formation are of Baltica origin and have been transported across the carbonate facies belts during storms.

Systematic palaeontology

Repository. All specimens are preserved in the Paleontologisk Museum, Oslo, Norway (prefix PMO).

Order Dendroidea Nicholson, 1872
Family Dendrograptidae Roemer in Frech, 1897
Genus *Dendrograptus* J. Hall, 1858

Dendrograptus rigidus Bulman, 1936. (Figs. 2A, B; 3B, C)
1936 *Dendrograptus rigidus* n. sp. – Bulman, p. 16, pl. 1, figs. 27-35; text-figs. 2-5
1963 *Dendrograptus rigidus* Bulman – Skevington, p. 8, figs. 4-9

Material. Several fragments from 31.5-32.0 m in the "abandoned factory section" (Maletz 1997a). The fauna belongs to the *Pterograptus elegans* Biozone.

Description. Dendroid fragment showing at least 3 branching divisions. The intervals between the strictly dichotomous branchings are from 5-8 mm. The stipes are 0.5-0.8 mm wide across the thecal apertures. The 2TRD is about 1.4-1.6, comparing well with the highly variable thecal density of 14-22 (Skevington 1963). Bithecae are visible at several points in the rhabdosome, but are difficult to interpret. They appear to be of the normal type with their apertures close to the autothecal apertures, but apertural characteristics are not available.

Remarks. The material is very similar to the isolated specimens described by Bulman (1936) and Skevington (1963) from the *Holmograptus lentus* Biozone of Öland, even though the Öland material is slightly older. The typical style of the bithecae opening into the autothecal apertures as described by Bulman (1936) and Skevington (1963) cannot be recognized in shale preservation, even when the specimens are preserved in full relief, but the outlines of bithecae alternating along the stipes are conspicuous (Fig. 3B).

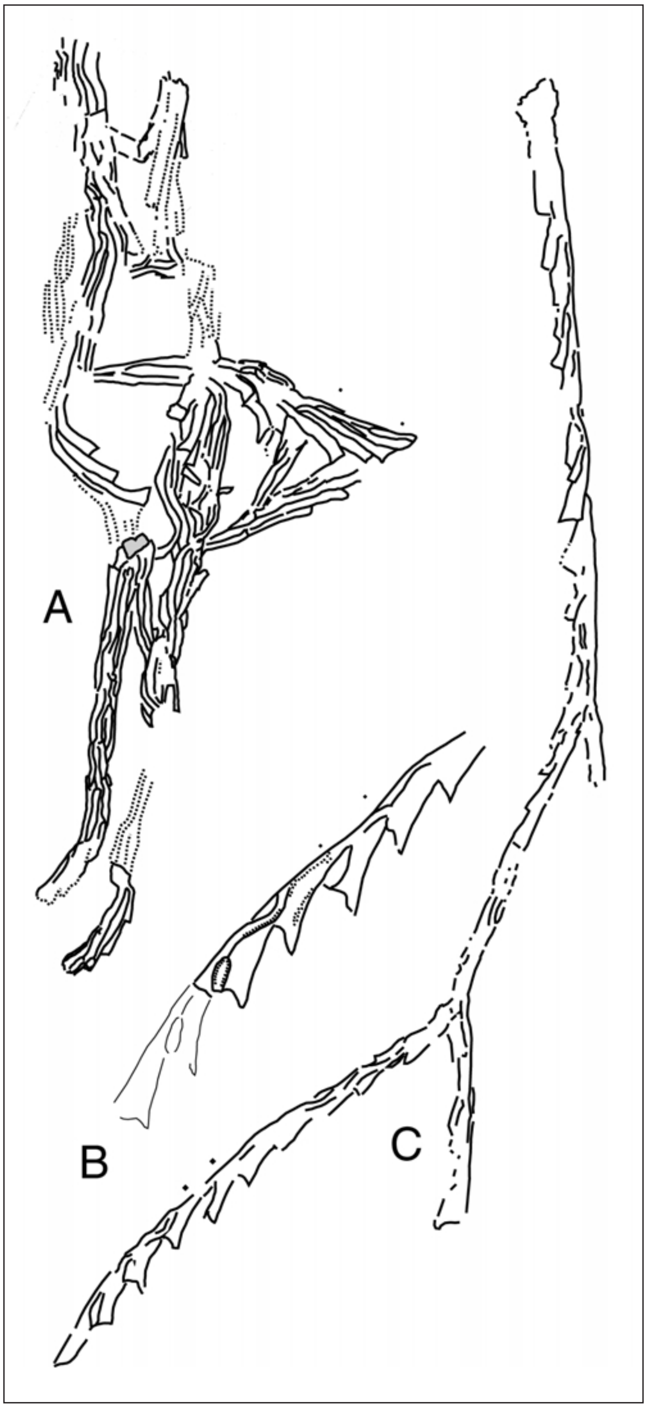

Fig. 3. A: Acanthograptus *sp., PMO 155.836, drawing of specimen. B,C: Dendrograptus rigidus Bulman, PMO 155.835. B is a magnification of the distal part of the stipe, showing bithecae and lateral budding of autothecae. A,B: x10, C: x5.*

Family Acanthograptidae Bulman, 1938
Genus *Acanthograptus* Spencer, 1878

Acanthograptus sp. (Figs. 2C-E; 3A)
Material. One specimen from 31.5-32.0 m at the Slemmestad factory section, preserved in full relief with the highly coalified periderm preserved as a silvery film, *Pterograptus elegans* Biozone.

Description. The material comprises a single, contorted specimen from a fragment of a larger colony. Several branching points are visible in the specimen, but the exact branching style is not visible. The material does not show enough detail to allow the branching intervals to be measured. The stipes consist of several, tube-like, parallel sided thecae, woven into a strand or stipe. They are about 0.3-0.5 mm wide. The distance between branching intervals is at least 6-7 mm in the small fragment. At least six thecae have been counted to be included in a single stipe. The thecae are long and slender, about 0.15-0.2 mm wide tubes, slightly narrower (0.1 mm) at their origins. The thecal apertures appear to be isolated in many cases (Text-fig. 2C-E), but apertural modifications are lacking. The thecal length is difficult to measure, but may be about 1.5 mm with a 2TRD of 1.0-1.3 mm. The presence of bithecae has not been proven as all thecae appear to be of the same size and distinctly smaller or more slender thecae are not visible.

Remarks. A few species of *Acanthograptus* are known from isolated or relief specimens showing the development of the genus. Bulman & Rickards (1966) revised the material described by Wiman (1901) and documented a typical graptoloid triad budding pattern. The thecal apertures are grouped into "twigs" formed by two autothecae and two bithecae, a pattern not visible in the specimen described here. Also, typical triad budding and the presence of bithecae was not recognised, even though budding of thecae can be observed in several places. Thus, the inclusion of the specimen in Acanthograptus remains tentative.

Acknowledgements: Fieldwork in Norway by JM was supported by DFG Grant Ma 1269/4-1. Many thanks go to Elisabeth Sunding and Jan Ove Ebbestad for their hospitality to JM during fieldwork in the Oslo Region. Verbundnetz Gas AG (Leipzig) kindly supported fieldwork of SOE and Mirko Werner (TU Bergakademie Freiberg).

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