Ordovician graptolite biostratigraphy in North Greenland

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Up to 500 m of black-bedded cherts and mudstones with thin turbidites and thick local beds of redeposited limestone and chert conglomerates were deposited during the Ordovician in North Greenland, along the southern margin of an east–west trending deep-water trough forming a continuation of the Franklinian Basin of Arctic Canada. A large collection of Ordovician graptolites has recently been obtained from this clastic sequence. The graptolite fauna, not collected in continuous sections, compares particularly well with the fauna from the Canadian Cordillera and for the most part is interpreted in terms of the established biozones from that area. The faunas are also correlated with the Australian zonal sequences.

In North Greenland neither the Cambrian–Ordovician boundary nor the Ordovician–Silurian boundary can be precisely demarcated by graptolites. The following graptolite biozones are represented: *Anisograptus*, *Adelograptus* & *Clonograptus*, *T. approximatus*, *P. fruticosus*, *D. bifidus*, *I. victoriae lunatus*, ? *I. victoriae victoriae*, ? *I. victoriae maximus*, *Oncograptus*, *P. tentaculatus*, ? '*D.*' *decoratus*, ? *H. teretiusculus*, *N. gracilis*, *C. bicornis*, ? *O. amplexicaulis*, *O. quadrimucronatus*, *D. ornatus* and ? *P. pacificus*.

The relationship of the North Greenland graptolites to the Ordovician 'Pacific faunal realm' and oceanic graptolite biofacies is briefly discussed.

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In early Palaeozoic time the Franklinian Basin of the Canadian Arctic Islands extended from northern Ellesmere Island across North Greenland. In Greenland the exposed segment of the basin is approximately 800 km long and has a maximum preserved north–south width of 200 km. Two major depositional environments are represented. A deep-water trough was situated along the northern coast of Greenland and fringed to the south by a shallow shelf dominated by carbonate sediments. The deep-water sequence attains an exposed thickness of at least 8 km and comprises siliciclastic and calcareous turbidites with subordinate mudstones, whereas on the platform an approximately 3 km thick sequence of mainly carbonates accumulated (e.g. Higgins *et al.*, in press).

During the Ordovician up to 500 m of deep-water clastic sediments, mainly black-bedded cherts and mudstones with thin turbidites, and with thick local beds of redeposited limestone and chert conglomerates, were deposited along the southern margin of the trough. On the platform to the south an up to 1 km thick sequence of carbonates was deposited. The stratigraphy and geological development of the Ordovician have recently been described by Trettin & Balkwill (1979), Peel (1982), Friderichsen *et al.* (1982), Surlyk & Hurst (1984), Higgins & Soper (1985) and Higgins *et al.* (in press).

The tectonic and sedimentological development of the Ordovician sequence was included in basin evolution stages 4 and 5 by Higgins *et al.* (in press). From the Late Cambrian to the Middle Ordovician (stage 4) the sedimentation was dominated by progradational platform and starved basin deposits. There was a differential subsidence and southwards expansion of the east–west deep-water trough and uplift of eastern North Greenland. To the west outermost shelf and slope rocks outcrop between Nyeboe Land and J. P. Koch Fjord (fig. 1). Here the uppermost unit from the upper Middle Cambrian to lowermost Ordovician sequence is between 150 and 300 m thick and composed of dark lime mudstone, with lime turbidites to the east and thin-bedded grey limestones and yellow dolomites to the west. Towards the north the sequence passes into chert and cherty shales less than 100 m thick, indicating slope environments. To the east, in southern Johannes V. Jensen Land, Amundsen Land and the region around

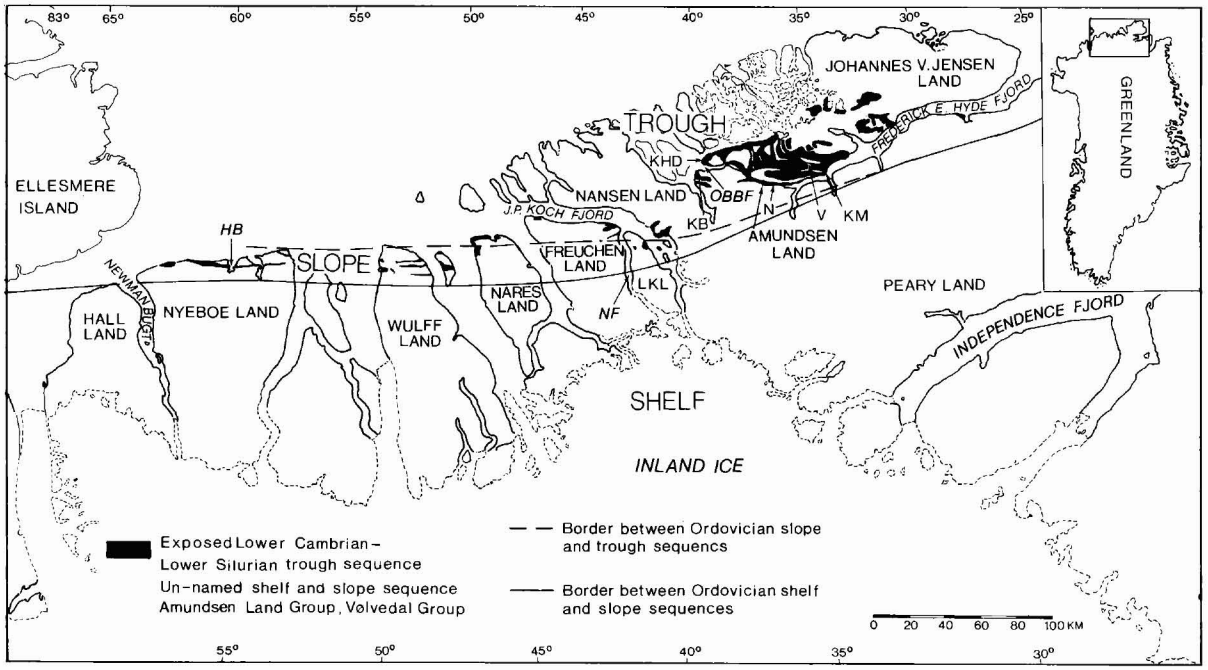

Fig. 1. Map of North Greenland showing the position of Ordovician slope and trough sequences and important graptolite localities. From Geological Map of North Greenland (Bengaard & Henriksen, 1986; Higgins *et al.*, in press). HB Hand Bugt; KB Kap Bopa; KHD Kap Holger Danske; KM Kap Mjølner; LKL Lauge Koch Land; N Nordpasset; NF Navarana Fjord; OBBF O.B. Bøggild Fjord; V Vølvedal.

Frederick E. Hyde Fjord, an outer slope and trough-floor sequence (600–700 m thick) with dark mudstones, cherts, turbidites including thick sandstone sequences and base-of-slope conglomerates was deposited.

From the Middle Ordovician to Early Silurian (stage 5) the basin can be divided into a stable platform and a starved slope and trough. In this period carbonate deposition continued to build up on the platform. North of the scarp-like platform margin, in the area from Nyeboe Land to J. P. Koch Fjord, very restricted amounts of sediment were deposited on a broad slope (starved slope). Here Cambrian – Lower Ordovician strata are overlain by a sequence of chert and cherty shales, with partly chertified siltstones, black limestones and dolomitic mudstones. The starved slope sediments are generally between 50 and 150 m thick. Further north in the deep-water trough, deposition was still slow but greater than in the slope areas. The Ordovician trough sediments outcrop in southern Johannes V. Jensen Land, including Amundsen Land and along the south side of Frederick E. Hyde Fjord. The sedimentary facies are mainly radiolarian cherts and black and green mudstones, including thin turbidites. In the Middle Ordovician an up to 200 m thick sequence of carbonate conglomerates was deposited over wide areas of Amundsen Land. During the late Middle Ordovician the conglomerate and turbidite deposition faded out and, in the Late Ordovician, the slow sedimentation of fine-grained deposits continued. Starved basin deposition was terminated by basin expansion, and sandy turbidite deposition started in the Late Llandovery.

During the Ordovician the graptolites are the only age-diagnostic fossils in the deep-water sediments along the southern margin of the trough. Here other fossils are represented by rare ceratiocarid fragments.

Until recently, information on Ordovician graptolites in North Greenland has been sparse. Poulsen (1927) reported '*Didymograptus bifidus*' and '*Phyllograptus angustifolius*' from the Nunatami Formation within the platform sequence in Washington Land, western North Greenland. Cowie (1961) reported the presence of *Didymograptus* from eastern North Greenland. In a preliminary report by Dawes & Soper (1970) an Ordovician age was suggested for graptolites found in Peary Land, central North Greenland. The fauna was listed by Bjerreskov *in* Bjerreskov & Poulsen (1973) and reported to be of Tremadoc and Arenig ages and was referred to the 'Pacific' graptolite fauna.

Between 1978 and 1985, during the systematic regional investigation and mapping of North Greenland

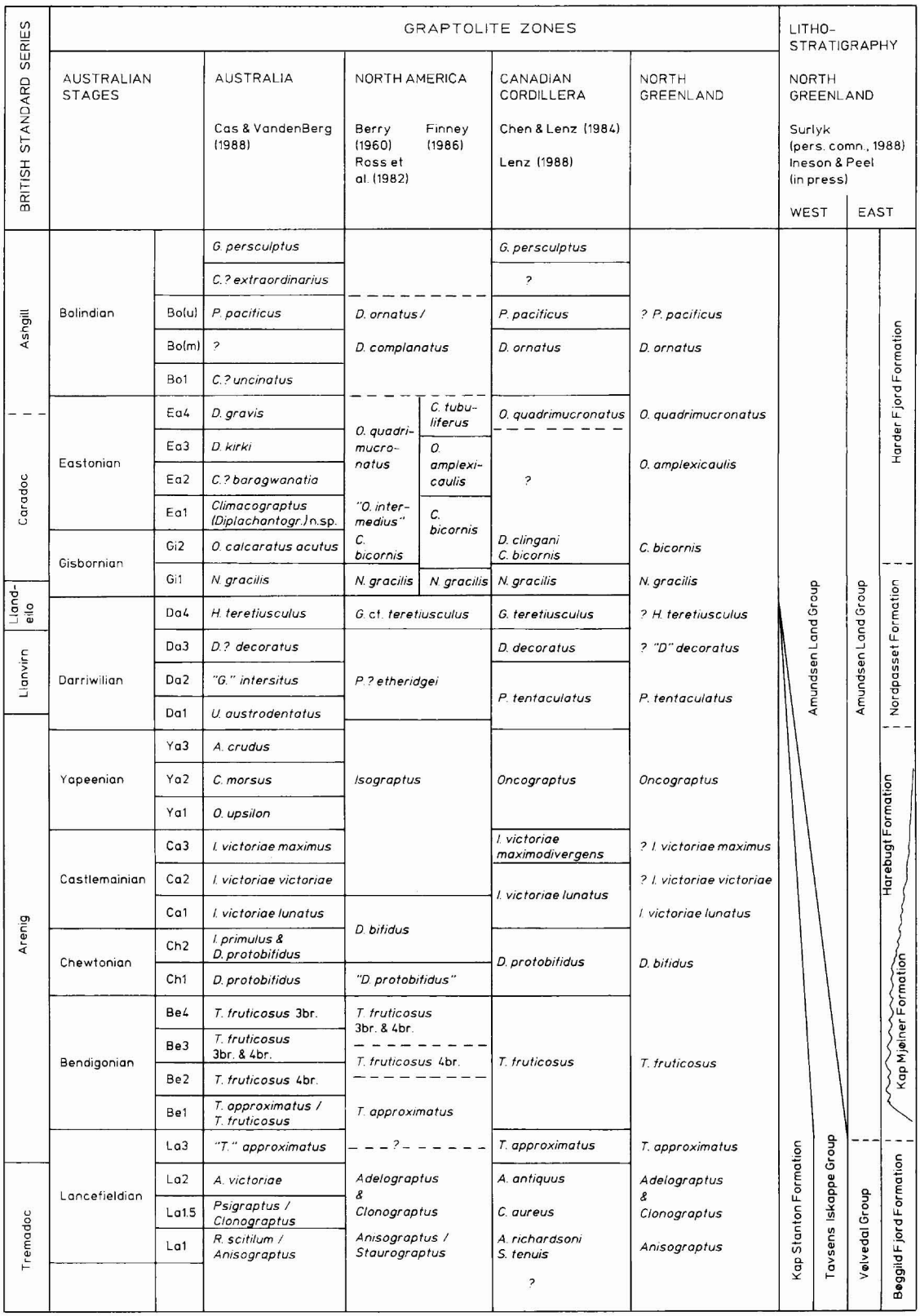

Fig. 2. Ordovician lithostratigraphy and graptolite zones in North Greenland correlated with the graptolite zonations of Australia, Canadian Cordillera and the United States. WEST = west of 40°W, EAST = east of 40°W.

by the Geological Survey of Greenland, about 85 samples with Ordovician graptolites were collected. Ordovician graptolite facies in North Greenland are principally confined to the deep-water basin margin and outer slope sediments in the Franklinian Basin sequence; only two graptolite samples have been found in the equivalent platform rocks. Some preliminary age determinations based on these graptolites were reported in Surlyk *et al.* (1981), Friderichsen *et al.* (1982), Higgins & Soper (1985), Sønderholm *et al.* (1987) and Bjerreskov (1988).

Lithostratigraphy

The Ordovician deep-water clastic sediments in North Greenland are lithostratigraphically subdivided into two groups, the Vølvedal and Amundsen Land Groups, with the type areas situated in the eastern part of central North Greenland (fig. 2; Friderichsen *et al.*, 1982). The Vølvedal Group extends down into the Cambrian but graptolites of Late Tremadoc age have been collected from near the top. It is subdivided into three formations, of which only the uppermost O. B. Bøggild Fjord Formation is relevant to the present investigation; it is mainly of Tremadoc age. The formation consists of quartzitic turbidites alternating with thin units of black mudstones (F. Surlyk, personal communication).

The overlying Amundsen Land Group, deposited during a period of basin starvation, extends from the end of the Tremadoc to the Early Silurian (Friderichsen *et al.*, 1982). The group is subdivided into four formations (Higgins *et al.*, in press; F. Surlyk, personal communication). The lowermost formation is the Tremadoc – Late Arenig Harebugt Formation, which consists of black mudstones and cherts interbedded with sandstone turbidites, in all 100–200 m thick. This formation locally interfingers with the Kap Mjølner Formation, composed mainly of resedimented limestone conglomerates, with a maximum formation thickness of 150 m and without any graptolites. The Nordpasset Formation corresponds in age to the latest Arenig and earliest Caradoc and consists mainly of green-grey ribbon cherts, chertified mudstones and siltstone. The formation is 170 m thick in the type section. The Early Caradoc to Early Silurian Harder Fjord Formation consists of black chert and mudstone and is estimated to be 150–200 m thick. All four formations have type sections in eastern areas of central North Greenland, and their ages are indicated by the graptolites.

In western North Greenland and western areas of central North Greenland, approximately between central J. P. Koch Fjord and northern Nyeboe Land, the Ordovician, starved, outer slope and basin sequences are referred to two formations of the Tavsens Iskappe Group and Amundsen Land Group. The Kap Stanton Formation of the Tavsens Iskappe Group has yielded graptolites from the Llanvirn Zone in the uppermost metres (Ineson & Peel, in press; Higgins *et al.*, in press). The overlying Amundsen Land Group sequence is referred entirely to a new formation of the group (Higgins *et al.*, in press) and ranges in age from the Tremadoc to the Late Llandovery. The starved basin sequence of this region consists largely of cherts and cherty shales, is from 50 to 150 m thick and has yielded the most complete successions of graptolites.

Biostratigraphy

The graptolites occur in dark shales, mainly as flattened carbon films; tectonic deformation is not uncommon. The flattening is so pronounced that detailed morphological structures cannot be observed. Graptoloid taxonomy is currently under revision, and the classifications of Fortey & Cooper (1986), Mitchell (1987) and Williams & Stevens (1988) have been followed here. Most of the graptolites are so badly preserved that they are unsuitable for photography; selected graptolites are illustrated by mainly camera lucida drawings (figs 4–7).

Only scattered graptolite samples were collected. Some samples are placed in profiles, but no section has been collected bed by bed. A few samples from scree material include graptolite species suggesting different ages. Consequently the present graptolite material does not allow evaluation of the vertical range of the taxa, and no full biozones and zonal boundaries can be defined. For each sample a faunal list has been made and compared with earlier reported assemblages from established graptolite zones in other areas. Thus the graptolite species listed in the stratigraphic scheme (fig. 2) indicate faunal assemblages which are correlated with formal biozones; they do not represent complete graptolite zones. Many of the samples contain only a few graptolites or graptolites which are badly preserved; the taxonomic position of many of these graptolites, and consequently their stratigraphical level, cannot be indicated.

Graptolite faunas representing most of the internationally recognised Ordovician graptolite zones have been found in North Greenland. The graptoliferous succession is most likely complete, although this cannot be proved by the present scattered samples. There is currently no evidence in the graptolite sequences for lowermost and uppermost Ordovician rocks, i.e. the transitions Cambrian–Ordovician and Ordovician–Silurian.

The most complete graptolite successions in North

Greenland have been found in the region west of 40°W, whereas east of 40°W mainly the lower part of the Ordovician comprising the *Anisograptus* to the *H. teretiusculus* zones has been recognised. Late Ordovician graptolite faunas have only been found in southern Johannes V. Jensen Land (Surlyk *et al.*, 1981) and at Kap Bopa, Peary Land. The apparent bias in graptolite distribution is most probably due to the scattered nature of the collections in the thick trough sequence of southern Johannes V. Jensen Land. In the more western areas the graptolite-bearing, 'starved', outer shelf and slope sequence is much thinner, more accessible and has been more systematically collected.

In terms of overall inter-regional graptolite correlation the North Greenland graptolite faunas appear to be most similar to those described from the Canadian Cordillera region, especially northern Yukon. Consequently the zones established in that area have been used as the basis of the zonal scheme from North Greenland. The Canadian Cordillera zonation is based on faunas listed in Jackson (1974, 1975), Lenz & McCracken (1982), Lenz & Chen (1985) and Lenz & Jackson (1986). The column in fig 2. is compiled from these papers, which were summarised in Chen & Lenz (1984) and Lenz (1988). However, there are some slight modifications based on the more recent descriptions of Finney (1986) and Williams & Stevens (1988) which apparently can be applied to the graptolites from North Greenland. These changes are mentioned in the appropriate descriptions of the graptolite zones below. Canadian Cordillera sequences have been compared with the Australasian graptolite sequences (Lenz, 1988). The Australasian stages and zones included in the scheme (fig. 2) are from Cas & VandenBerg (1988). The North Greenland graptolite fauna is also similar to Ordovician graptolite assemblages from other parts of North America (Berry, 1960; Ross & Berry, 1963; Carter & Tailleur, 1984; Finney, 1986; Williams & Stevens, 1988). The Ordovician graptolite zonation (fig. 2) in the United States is taken mainly from Ross *et al.* (1982), with some changes in accordance with the revision of Finney (1986).

All figured specimens are deposited in the Geological Museum, Copenhagen (MGUH prefix).

Anisograptus Zone

The Cambrian–Ordovician transition has not been seen in the graptolitiferous sequence. The presumably oldest recorded fauna is represented by GGU sample 217749 from O. B. Bøggild Fjord (fig. 1). Here only *Rhabdinopora?* and *Anisograptus* sp. (figs 4A, B, G) have been recorded.

The presence of *Anisograptus* forms is characteristic of the early Tremadoc (e.g. Berry, 1960; Cooper & Stewart, 1979; Erdtmann, 1988). Strata with a dominance of the triradiate *Anisograptus* plexus were referred to Assemblage 2 by Cooper (1979b), corresponding to La1 in the Australian sequence.

Adelograptus & Clonograptus Zone

The zone name was defined in Texas (Berry, 1960) and corresponds to La1.5 and La2 in the Australian sequence and is represented by at least four samples in the Greenland material. One of the samples (GGU 313122) contains clonograptids (?adelograptids) which are somewhat similar to *Clonograptus* sp. 1 (fig. 4E) and *Clonograptus* sp. 3 (fig. 4C) in Cooper & Stewart (1979). Both forms were reported from La1.5. The fauna also includes *Adelograptus clarki* (Hall) (fig. 4F), reported from La2 and La3 (Cooper, 1979a).

Three other samples include *Dictyonema pulchellum* Hall, *Clonograptus* sp. (fig. 4D), *Paradelograptus antiquus* (Hall) (fig. 4R), *Temnograptus magnificus* Pritchard, *Tetragraptus* sp. as the most important species. These species all indicate a high level in the Tremadoc, corresponding to La2 and the *A. antiquus* Zone of Jackson (1974). *Clonograptus ?* n. sp. (fig. 3B) is also frequent. The species is similar to *Clonograptus flexilis* (Hall) and was listed as the latter by Bjerreskov *in* Bjerreskov & Poulsen (1973).

Tetragraptus approximatus Zone

The zone is defined by the frequent occurrence of *Tetragraptus approximatus approximatus* (Nicholson) (fig. 3D), generally in association with *Tetragraptus acclinans* Keble (fig 3A) (in GGU 311308, 313123, 319793, 319794). Further associates are *Clonograptus* sp., *Adelograptus* sp., *Paradelograptus* sp., *Tetragraptus quadribrachiatus* Hall (fig. 3C), *Tetragraptus* sp. and *Didymograptus* sp. *Etagraptus ?harti* (Hall) (fig. 40) is found in GGU 313125 with *T. approximatus*. Both *T. approximatus* and *T. acclinans* are reported to range into the overlying *P. fruticosus* Zone, e.g. in Arctic Canada (Lenz & Jackson, 1986), but are much less common at this level. It is possible, therefore, that some of the present samples might represent the *T. fruticosus* Zone.

Graptolites indicative of the *T. approximatus* assemblage have been found in many samples (e.g. GGU 311308, 313123, 319793 and 319794), and this assemblage is apparently widespread and well developed throughout North Greenland. *T. acclinans* was reported from the *T. approximatus* and *T. akzharensis* Zones in

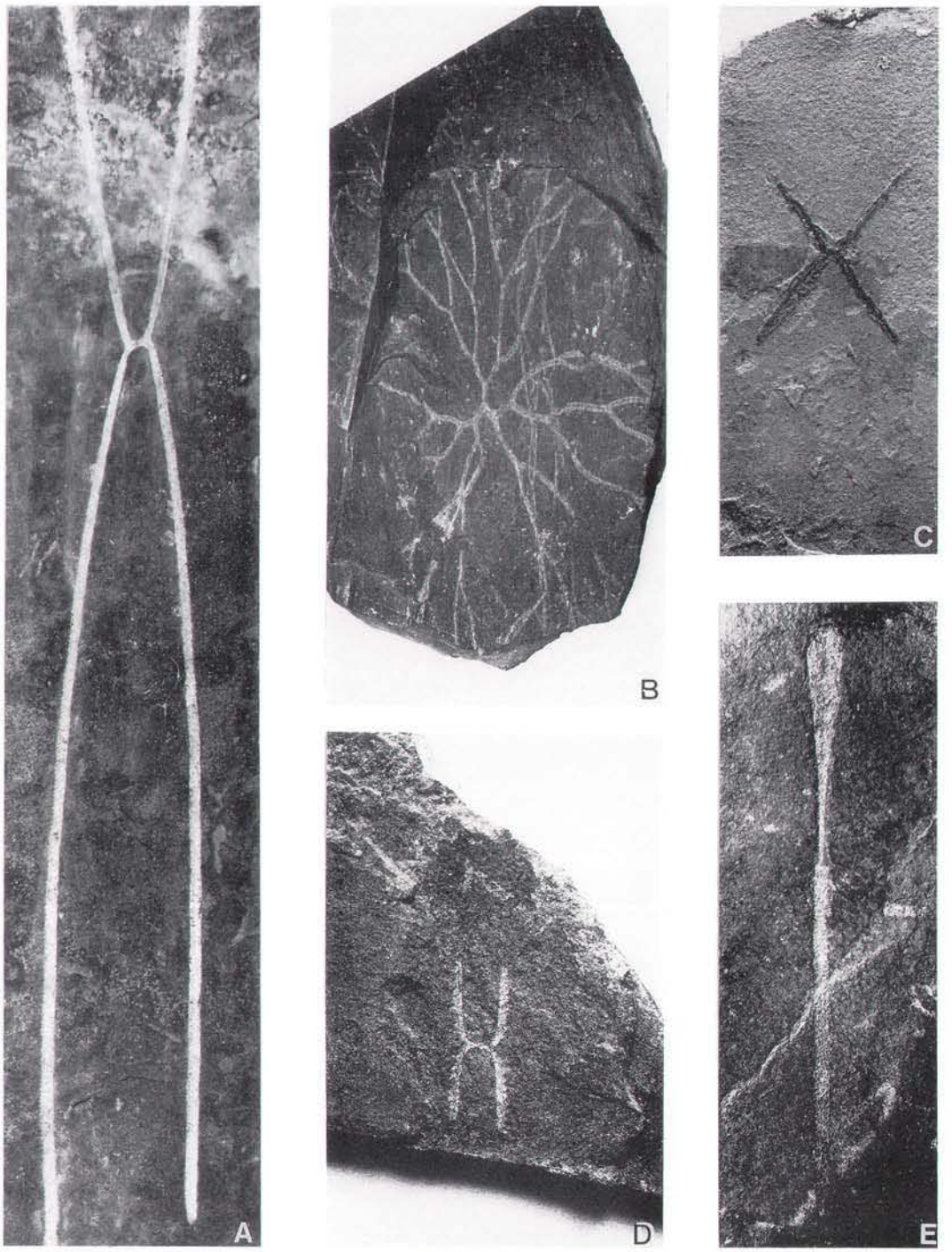

Fig. 3. A. *Tetragraptus acclinans* Keble, very large specimen. MGUH 19362 from GGU 319794, northern Nyeboe Land. × 0.57. B. *Clonograptus* n. sp. ?. MGUH 19363 from GGU 53491.10, north of Harebugt, Peary Land. C. *Tetragraptus quadribrachiatus* Hall. MGUH 19364 from GGU 53485.2, Kap Bopa, Peary Land. D. *Tetragraptus approximatus approximatus* (Nicholson). MGUH 19365 from GGU 319815, northern Nyeboe Land. E. *Climacograptus* (*Climacograptus*) *tubuliferus* Lapworth. MGUH 19366 from GGU 319681, Nares Land. figs B-E, nat. size.

Newfoundland (Williams & Stevens, 1988). In North Greenland it is associated with the very frequent *T. approximatus*, and *Tetragraptus akzharensis* Tzaj has not been observed. Consequently the *T. akzharensis* Zone defined by Williams & Stevens (1987, 1988) cannot be distinguished in the present material.

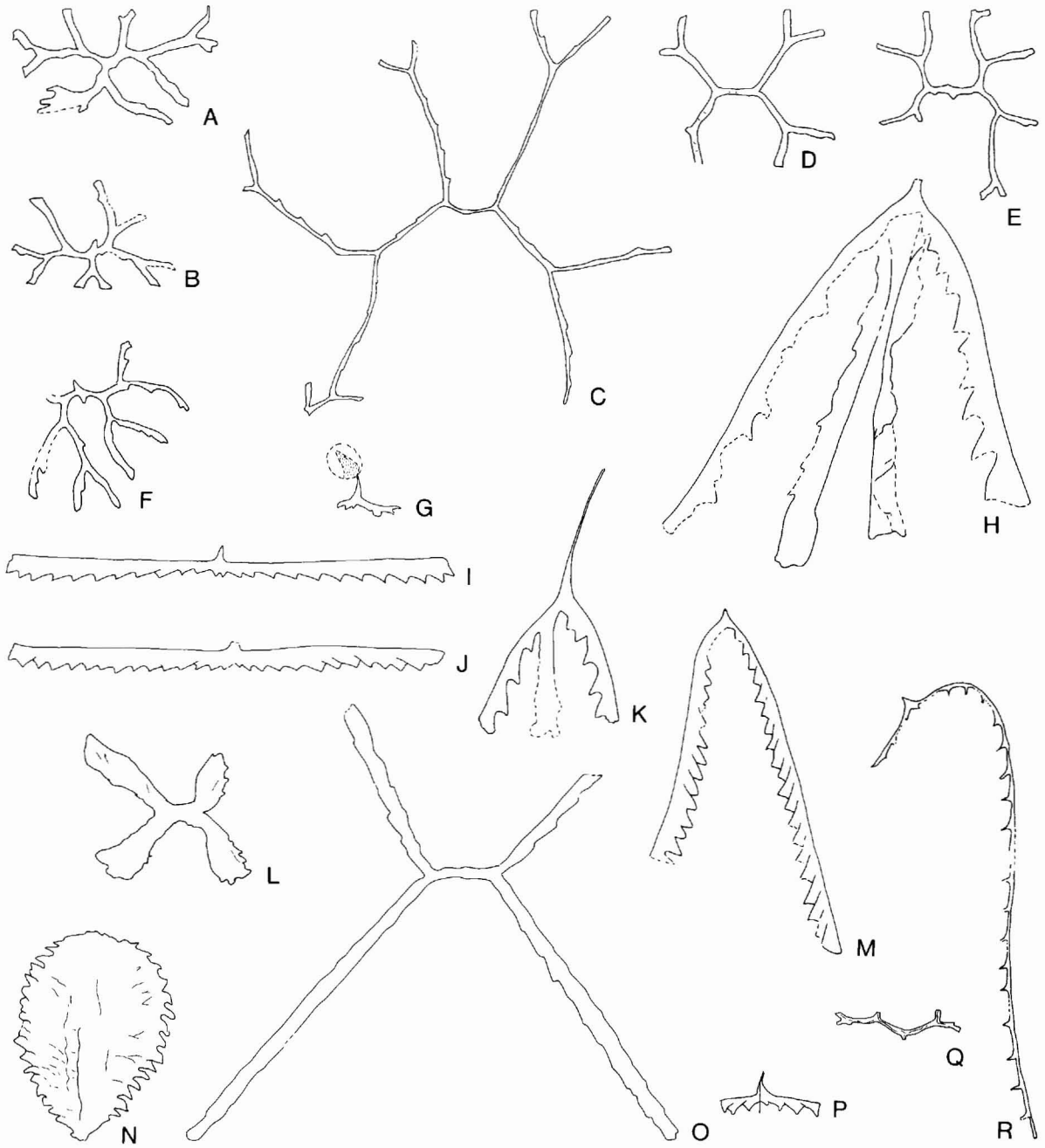

Fig. 4. A., B., G., *Anisograptus* sp. GGU 217749, O.B. Bøggild Fjord. A. MGUH 19367, B. MGUH 19368, G. MGUH 19369. C. *Clonograptus?* sp. cf. *Clonograptus* sp. 3 Cooper & Stewart. MGUH 19370 from GGU 313122. Kap Holger Danske, Johannes V. Jensen Land. D. *Clonograptus* sp. MGUH 19371 from GGU 217828. E. *Clonograptus?* sp. cf. *Clonograptus* sp. 1 Cooper & Stewart. MGUH 19372 from GGU 313122. Kap Holger Danske, Johannes V. Jensen Land. F. *Adelograptus clarki* (Hall). MGUH 19373 from GGU 313122. Kap Holger Danske, Johannes V. Jensen Land. H., K. *Pendeograptus fruticosus* (Hall). H. MGUH 19374 from GGU 313121. Kap Bopa, Peary Land. K. MGUH 19375 from GGU 313080. Nyeboe Land. I. *Didymograptus* (*Expansograptus*) *extensus* (Hall). MGUH 19376 from GGU 217745. Frederick E. Hyde Fjord, Johannes V. Jensen Land. J. *Didymograptus* (*Expansograptus*) *similis* (Hall). MGUH 19377 from GGU 217745. Nordpasset, Johannes V. Jensen Land. L. *Tetragraptus ?amii* Elles & Wood. MGUH 19378 from GGU 217715. Frederick E. Hyde Fjord, Johannes V. Jensen Land. M. *Didymograptus* (*Didymograptellus*) *bifidus* (Hall). MGUH 19379 from GGU 217715. Frederick E. Hyde Fjord, Johannes V. Jensen Land. N. *Phyllograptus ?densus* Törnquist. MGUH 19380 from GGU 217715. Frederick E. Hyde Fjord, Johannes V. Jensen Land. O. *Etagraptus ?harti* (Hall). MGUH 19381 from GGU 313125. Kap Holger Danske, Johannes V. Jensen Land. P. *Xiphograptus svalbardensis* Cooper & Fortey. MGUH 19382 from GGU 217716. Frederick E. Hyde Fjord, Johannes V. Jensen Land. Q. Fragment of *Sigmagraptus* sp. MGUH 19383 from GGU 217715. Frederick E. Hyde Fjord, Johannes V. Jensen Land. R. *Paradelograptus antiquus* (Hall) MGUH 19384 from GGU 217719. Frederick E. Hyde Fjord, Johannes V. Jensen Land. All figures × 3.

Pendeograptus fruticosus Zone

This zone is here defined by the presence of *Pendeograptus fruticosus* (Hall). The index species, however, is sparsely represented, as only one specimen with four stipes (fig. 4H) and two three-stiped forms (fig. 4K) has been recorded. *Didymograptus* (*Expansograptus*) *extensus* (Hall) (fig. 4I) and *Didymograptus* (*Expansograptus*) *similis* (Hall) (fig. 4J) from GGU 217745 are probably from this level (cf. Williams & Stevens, 1988). The scanty material of the index species does not allow any separation of a lower 4-branched *P. fruticosus* Zone and an overlying 3-branched zone, e.g. as in Ross & Berry (1963) and VandenBerg (*in* Webby *et al.*, 1981). Recently this subdivision was abandoned by Williams & Stevens (1988) who regarded the number of branches as most likely an artefact of preservation.

Didymograptus bifidus Zone

Only GGU 217715 from the Frederick E. Hyde Fjord region carries a graptolite fauna which can be referred to the *D. bifidus* Zone of Williams & Stevens (1988), corresponding to the *D. protobifidus* Zone of Cooper (1979a) and Lenz & Jackson (1986). The zonal index name was changed by Williams & Stevens (1988) who did not recognise the stratigraphic variation within *D. bifidus – D. protobifidus* described by Fortey & Cooper (1982).

The present material includes few specimens of *Didymograptus* (*Didymograptellus*) *bifidus* (Hall) (fig. 4M) which have the slender form of *D.* '*protobifidus*' of Fortey & Cooper (1982). The sample also includes *Tetragraptus ?amii* Elles & Wood, (fig. 4L), *Tetragraptus ?reclinatus abbreviatus* Bouček, *Phyllograptus ?densus* Törnquist (fig. 4N), *Phyllograptus?*, *Didymograptus* cf. *D. artus* Elles & Wood, *Didymograptus* (*Expansograptus*) sp., *Sigmagraptus* sp. (fig. 4Q) and *Laxograptus?*.

Poulsen (1927) reported *D. bifidus* and *Pseudophyllograptus angustifolius* (Hall) from the Nunatami Formation in Washington Land. *D. bifidus* reported by Poulsen (1927) is similar to the wide specimens of *D. bifidus* reported by e.g. Williams & Stevens (1988), but accordingly does not give any precise identification of the stratigraphic horizon.

GGU 206376 from the Nunatami Formation contains *Didymograptus (Expansograptus) ?nitidus* (Hall) indicating a level from the *P. fruticosus* Zone (Williams & Stevens, 1988) to the *D. bifidus*, Middle Arenig, approximately corresponding to the Chewtonian–Castlemainian interval in the Australian sequence (Fortey & Owens, 1987).

Isograptus victoriae lunatus Zone

Two GGU samples (217829, 313081) include *Isograptus victoriae lunatus* Harris (fig. 5A, B) which is regarded as indicator of the internationally well recognised *I. victoriae lunatus* Zone (Cooper, 1979a; Lenz & Jackson, 1986; Williams & Stevens, 1988). The index species is associated with *Pseudophyllograptus ?angustifolius* (Hall), *T. ?reclinatus abbreviatus*, (fig. 5F), *Didymograptus?* and *Isograptus* sp. The present sparse material does not add any new information to this stratigraphic level.

? Isograptus victoriae victoriae Zone

Only GGU 217716 contains *Isograptus victoriae victoriae* Harris (fig. 5E) and this occurs together with *Didymograptus?* With the limited material available, the presence of this zone is inconclusive. The *I. victoriae victoriae* Zone was recorded by Webby *et al.* (1981) and Williams & Stevens (1988), but was not distinguished by Cooper (1979a) and Lenz & Jackson (1986). Thus it might be a zone with a limited, possibly regional, strati-

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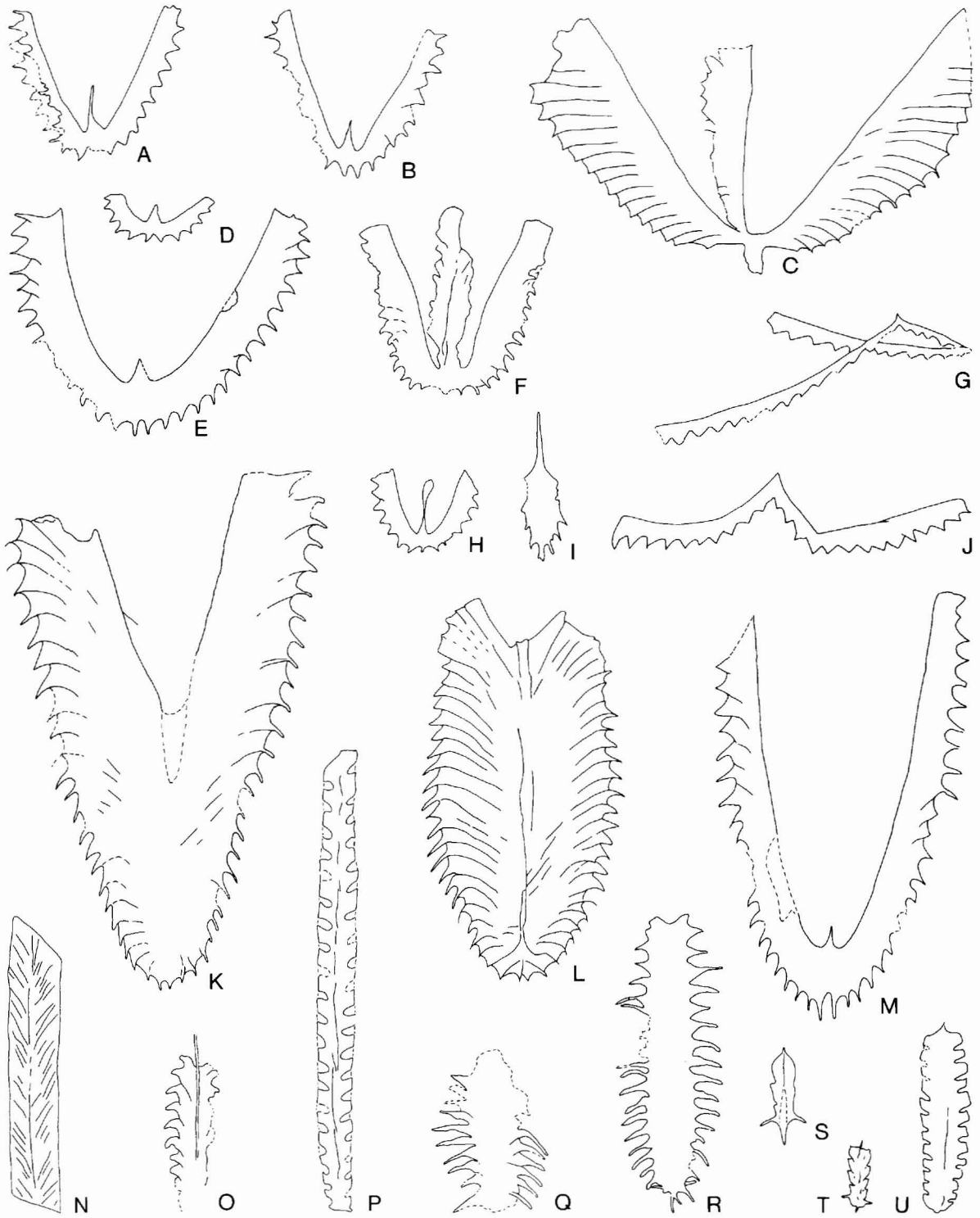
Fig. 5. A, B. *Isograptus victoriae lunatus* Harris A. MGUH 10385 from GGU 313081. B. MGUH 19386 from GGU 313081. C. *Tetragraptus ?serra* (Brongiart). MGUH 19387 from GGU 313173. Navarana Fjord, Freuchen Land. D., H. *Isograptus? dilemma* Williams & Stevens. D. MGUH 19388 from GGU 217807. Frederick E. Hyde Fjord, Johannes V. Jensen Land. H. MGUH 19389 from GGU 217829. Frederick E. Hyde Fjord, Johannes V. Jensen Land. E. *Isograptus victoriae victoriae* Harris. MGUH 19390 from GGU 217716. Frederick E. Hyde Fjord, Johannes V. Jensen Land. F. *Tetragraptus ?reclinatus abbreviatus* Bouček. MGUH 19391 from GGU 217829. Frederick E. Hyde Fjord, Johannes V. Jensen Land. G. *Didymograptus* cf. *D. compressus* Harris & Thomas. MGUH 19392 from GGU 313175, West side of Navarana Fjord. I. *Skiagraptus ?gnomonicus* (Harris & Keble). MGUH 19393 from GGU 319799. Frederick E. Hyde Fjord, Johannes V. Jensen Land. J. *Xiphograptus ?declinatus* Williams & Stevens. MGUH 19394 from GGU 217760. North of Vølvedal, Johannes V. Jensen Land. K. *Oncograptus upsilon biangulatus* Harris & Keble. MGUH 19395 from GGU 217715. Frederick E. Hyde Fjord, Johannes V. Jensen Land. L. *Paracardiograptus* sp. MGUH 19396 from GGU 53485. Kap Bopa, Peary Land. M. *Isograptus caduceus australis* Cooper. MGUH 19397 from GGU 217716. Frederick E. Hyde Fjord, Johannes V. Jensen Land. N. Distal fragment of *Pseudotrigonograptus ensiformis* (Hall) MGUH 19398 from GGU 217759. Western Peary Land. O. *Cryptograptus* cf. *C. inuitilis* Hall. MGUH 19399 from GGU 217759. Nordpasset, western Peary Land. P. '*Climacograptus*' cf. *C. riddellensis* Harris. MGUH 19400 from GGU 217727. Vølvedal, Johannes V.



Jensen Land. Q., R. *Paraglossograptus tentaculatus* (Hall). Q. MGUH 19401 from GGU 217759. Nordpasset, western Peary Land. R. MGUH 19402 from GGU 311244. Navarana Fjord, Lauge Koch Land. S. *Cryptograptus* cf. *C. tricornis* Carruthers. MGUH 19403 from GGU 217727. Frederick E. Hyde Fjord, Johannes V. Jensen Land. T. *Oelandograptus? austrodentatus* (Harris & Keble). MGUH 19404 from GGU 311244. Navarana Fjord, Lauge Koch Land. U. '*Climacograptus*' *?differtus* Harris & Thomas. MGUH 19405 from GGU 319803. Northern Nyeboe Land. All figures × 3.

graphical significance. Only *I. victoriae victoriae* and *Pseudisograptus hastatus* (Harris) were reported by Williams & Stevens (1988) to have their first occurrence at this level.

? *Isograptus victoriae maximus* Zone

The *I. victoriae maximodivergens* Zone of Cooper (1979a) (Ca3) and Lenz & Jackson (1986), corresponding to the lower part of the *I. victoriae maximus* Zone of Williams & Stevens (1988), cannot be proved with certainty in North Greenland as the index species has not been recorded. The level is probably represented by graptolites in two samples. One sample (GGU 217807) contains *Isograptus* ex gr. *victoriae* Harris and *Isograptus? dilemma* Williams & Stevens (figs 5D, H) (= *Didymograptus* cf. *D. hemicyclus* of Cooper 1973). The other sample (GGU 217760) includes proximal specimens of *I.* ex gr. *victoriae* together with a fauna of *Paradelograptus?*, *Xiphograptus ?declinatus* Williams & Stevens (fig. 5J), *Xiphograptus* sp. and *Goniograptus* sp.

Oncograptus Zone

The *Oncograptus* Zone, which is here supposed to correspond to the Yukon *Oncograptus* Zone (Lenz & Jackson, 1986), is sparsely represented and there is no possibility of subdivision. The index genus is observed only in one sample (GGU 217715), represented by *Oncograptus upsilon biangulatus* Harris & Keble (fig. 5K); *Paracardiograptus* sp. (fig. 5L) and *Cardiograptus* sp. are also found in one sample (GGU 53485). Other species probably representing this level are *Isograptus caduceus australis* Cooper (fig. 5M), *Isograptus caduceus* s.l. (Salter), *I.? dilemma* and *Skiagraptus ?gnomonicus* (Harris & Keble) (fig. 5I). *Cardiograptus* and *Oncograptus* are not present in Newfoundland (Williams & Stevens, 1988) and in the northern part of the Canadian Cordillera (Lenz & Jackson, 1986). The occurrence of *Cardiograptus* and *Oncograptus* might be facies controlled. The present samples are from slope facies in northern Nyeboe Land, and from the trough sequence in Johannes V. Jensen Land and at Kap Bopa, Peary Land. These genera, which are confined to the oceanic isograptid fauna (according to Fortey & Cocks, 1986), are also preserved in deposits from the deeper parts of the basin in North Greenland.

Paraglossograptus tentaculatus Zone

The base of the zone is generally defined as the incoming of biserial graptolites together with the zone fossil (Lenz & Jackson, 1986; Williams & Stevens, 1988). The zone is correlated with the Australasian *O.? austrodentatus* Zone, Da1, and the *G. intersitus* Zone, Da2. Available faunas indicative of this zone are sparse, and a subdivision into the two Australasian zones is not possible.

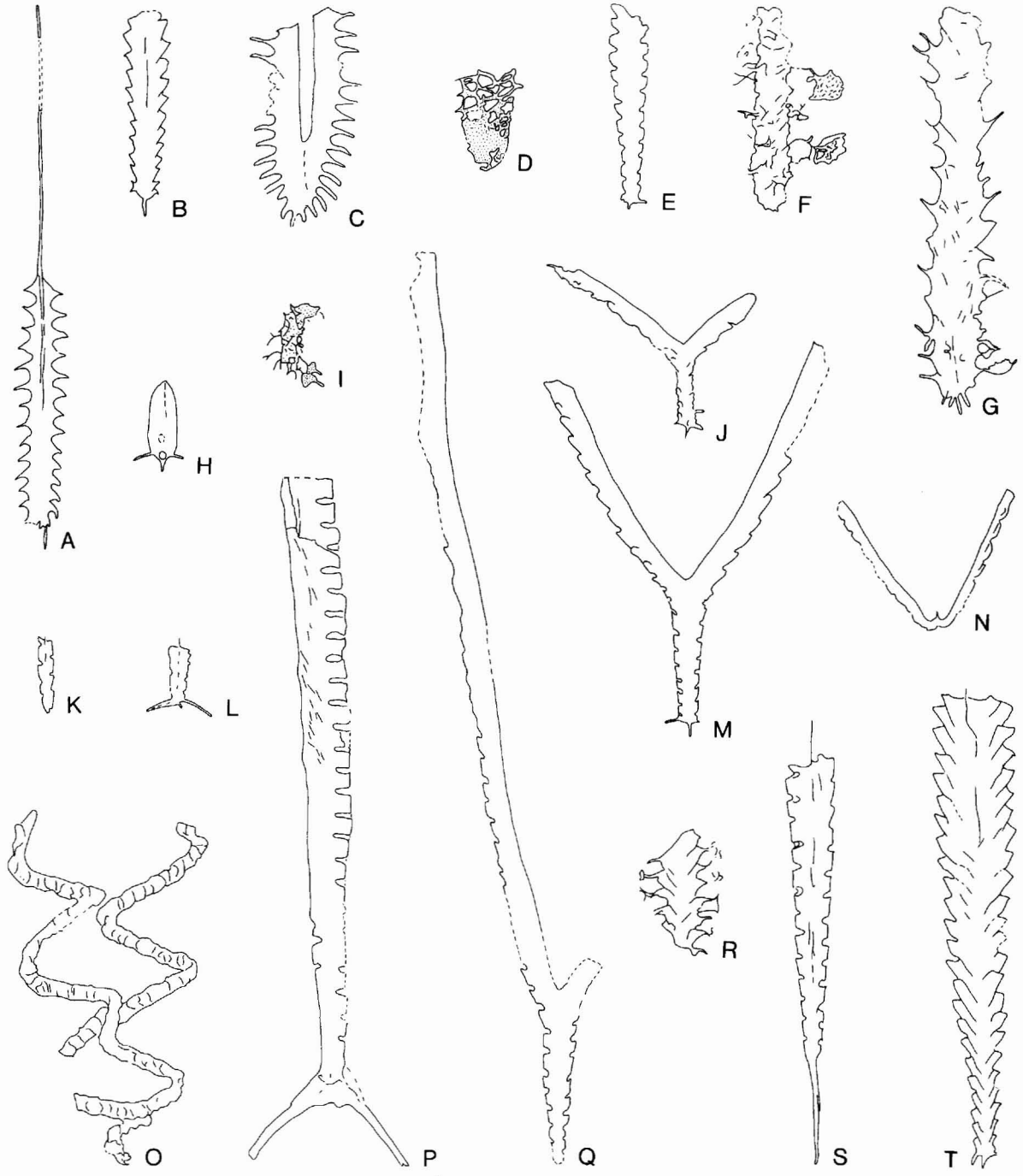
Oelandograptus? austrodentatus (Harris & Keble) (fig. 5T) has been observed in two samples (GGU 217759 and 311244), together with *Paraglossograptus tentaculatus* (Hall) (figs 5Q, R) (the present specimens are similar to *P.* cf. *tentaculatus* described by Cooper (1979a)), *Didymograptus* cf. *D. cognatus* Harris & Keble, *Pseudotrigonograptus ensiformis* (Hall) (fig. 5N), *Cryptograptus* cf. *C. tricornis* Carruthers, *Cryptograptus* cf. *C. inuitilis* Hall (fig. 5O), *Cryptograptus* sp., '*Climacograptus*' *?modicellus* (Harris & Thomas), '*Climacograptus*' cf. *C. riddellensis* Harris, *Pseudoamplexograptus* cf. *P. confertus* (Lapworth) and '*Diplograptus*' sp. *Cardiograptus*, *Oncograptus* and *Isograptus caduceus* continue into the lower part of the *O.? austrodentatus* Zone in Australia (VandenBerg *in* Webby *et al.*, 1981) and it is possible that the samples with these genera might instead indicate the base of the Darriwilian.

? '*Diplograptus*' *decoratus* Zone

This zone level is hardly recognisable in North Greenland. Only one sample (GGU 217727) includes a specimen probably referable to '*Diplograptus*' *decoratus* Harris & Thomas, similar to the specimen figured in Lenz & Jackson (1986, fig. 10S). Further associates are *Didymograptus?*, *Cryptograptus* cf. *C. tricornis* (Carruthers) (fig. 5S) and the long-ranging '*C.*' *riddellensis* (fig. 5P).

→

Fig. 6. A. *Cryptograptus schaferi* Lapworth. MGUH 19406 from GGU 311244. Navarana Fjord, Lauge Koch Land. B. *Hustedograptus teretiusculus* (Hisinger). MGUH 19407 from GGU 313175. Navarana Fjord, Freuchen Land. C. *Kalpinograptus lyra* (Ruedemann). MGUH 19408 from GGU 313117. J. P. Koch Fjord. D. *Reteograptus geinitzianus* Hall. MGUH 19409 from GGU 313175. Navarana Fjord, Freuchen Land. E. *Pseudoamplexograptus* cf. *P. maxwelli* (Decker). MGUH 19410 from GGU 313118. J. P. Koch Fjord. F. *Hallograptus* sp. MGUH 19411 from GGU 313118. J. P. Koch Fjord. G. *Hallograptus mucronatus* (Hall). MGUH 19412 from GGU 313118. J. P. Koch Fjord. H. *Cryptograptus insectiformis* Ruedemann. MGUH 19413 from GGU 313023. western Peary Land. I. *Hallograptus?*. MGUH 19414 from GGU 313023. Western Peary Land. J. *Dicranograptus* cf. *D. nicholsoni* Hopkinson. MGUH 19415 from GGU 313023. Western Peary Land. K. *Glyptograptus brevis* (Elles & Wood).



MGUH 19416 from GGU 313023. Western Peary Land. L., P. *Climacograptus* (*Climacograptus*) *bicornis* (Hall). From GGU 313118, J. P. Koch Fjord. L. MGUH 19417. P. MGUH 19418. M. *Dicranograptus nicholsoni* Hopkinson. MGUH 19419 from GGU 313023. Western Peary Land. N. *Dicellograptus* cf. *D. pumilis* Lapworth. MGUH 19420 from GGU 313110. Wulff Land. O. *Dicranograptus contortus* Ruedemann. MGUH 19421 from GGU 313118. J. P. Koch Fjord. Q. *Dicranograptus ramosus* (Hall). MGUH 19422 from GGU 313176. Kap Bopa, Peary Land. R. *Neurograptus magaritatus* (Lapworth). MGUH 19423 from GGU 313023. Western Peary Land. S. *Climacograptus* (*Climacograptus*) *caudatus* Lapworth. MGUH 19424 from GGU 313023. Western Peary Land. T. *Orthograptus amplexicaulis* (Hall). MGUH 19425 from GGU 313023. Western Peary Land. All figures × 3.

? *Hustedograptus teretiusculus* Zone

Like the underlying zone level, the *H. teretiusculus* Zone is very poorly represented in North Greenland. Only GGU 313175 contains a faunal assemblage which might be referred to this level: *Didymograptus* cf. *D. compressus* Harris & Thomas (fig. 5G), and *Glossograptus ?hincksii* Hopkinson, *Hustedograptus teretiusculus* (Hisinger) (fig. 6B), '*C.*' *riddellensis* and *Reteograptus geinitzianus* Hall (fig. 6D). However, this assemblage continues into the overlying *N. gracilis* Zone (Webby *et al.*, 1981, fig. 2; Lenz & Chen, 1985). In the latter paper a *G. euglyphus* Zone was recognised instead of the *H. teretiusculus* Zone on account of the very frequent occurrence of the index species. The fauna in North Greenland is here dissimilar to that of the northern Canadian Cordillera as *G. euglyphus* has not been observed. However, the present material from this level is too sparse to permit definite conclusions.

Nemagraptus gracilis Zone

The *N. gracilis* Zone is recognised world wide and characterized by the disappearance of the Pacific graptolite faunas and the establishment of more cosmopolitan faunas. This level can also be recognised in North Greenland, although *Nemagraptus gracilis* (Hall) has not been seen. GGU 313117 includes a fauna which most likely can be referred to this level. *Kalpinograptus lyra* (Ruedemann) (fig. 6C) is especially indicative since it has only been reported from this level (Lenz & Chen, 1985; Finney, 1986). It is associated with *Cryptograptus* sp., *G. ?hincksii*, *Pseudoclimacograptus* sp., '*C.*' *riddellensis*, *Glyptograptus brevis* (Elles & Wood), '*Glyptograptus*' sp. and *R. geinitzianus* which have earlier been reported from this zone (e.g. VandenBerg *in* Webby *et al.*, 1981).

The Greenland material referred to the *N. gracilis* Zone does not include any representatives of the dicellograptids which are usually registered from this zone (e.g. VandenBerg *in* Webby *et al.*, 1981; Lenz & Chen, 1985). However, the present material is too small for any further interpretation of the absence of slender forms such as *Nemagraptus* and *Dicellograptus*.

Climacograptus bicornis Zone

The *C. bicornis* Zone is here tentatively distinguished as a separate zone following Churkin & Carter (1977) and Lenz & Chen (1985) and not as a subzone of *N. gracilis* (Finney, 1986). Following Lenz & Chen (1985) the *C. bicornis* Zone level in North Greenland is defined by the presence of *Climacograptus* (*Climacograptus*) *bicornis* (Hall) (figs 6L, P) which is frequent in GGU 313118. Accompanying species are *Dicranograptus contortus* Ruedemann (fig. 6O), *Pseudoclimacograptus* (*Pseudoclimacograptus*) ex gr. *scharenbergi* (Lapworth), *Pseudoamplexograptus* cf. *maxwelli* (Decker) (fig. 6E), *Hallograptus mucronatus* (Hall) (fig. 6G), *Hallograptus* sp. (fig. 6F), *Hallograptus?* (fig. 6I). '*Climacograptus*' *?differtus* Harris & Thomas (fig. 5U) is possibly referable to this level. Unless the present graptolites have ranges other than earlier reported (e.g. by Finney, 1986), the *N. gracilis* and *C. bicornis* faunas are distinct in North Greenland.

The *C. bicornis* Subzone was correlated with the British *D. multidens* Zone (equivalent to the *C. peltifer* and *C. wilsoni* zones) by Finney (1986). In Australia a separate *C. bicornis* Zone has not been distinguished and *C. bicornis* occurs in the upper part of the *N. gracilis* Zone and in the *O. calcaratus* Zone (Cas & VandenBerg, 1988).

? *Orthograptus amplexicaulis* Zone

The *D. clingani* Zone in the Canadian Cordillera was placed tentatively very closely above the *C. bicornis* Zone by Lenz & Chen (1985); the *D. clingani* Zone in this area appeared here to be older than the British *D. clingani* Zone. There was no sign of a *D. multidens* Zone and an apparent gap in the faunas between the *D. clingani* and *O. quadrimucronatus* zones was described.

In North Greenland there is no direct evidence for the *D. multidens* and the *D. clingani* Zones; both index species are lacking. However, in two samples (GGU 313023, 313176) an assemblage has been recorded which correlates well with faunas earlier reported from the *D. clingani* Zone recently described by Williams & Bruton (1983) and Finney (1986). The graptolite species are: *Cryptograptus insectiformis* Ruedemann (fig. 6H), *Corynoides americanus* Ruedemann, *Dicranograptus ramosus* (Hall) (fig. 6Q), *Dicranograptus nicholsoni* Hopkinson (fig. 6M), *Dicranograptus* cf. *D. nicholsoni* (fig. 6J), *Climacograptus* (*Climacograptus*) *caudatus* Lapworth (fig. 6S), *G. brevis* (fig. 6K), *Orthograptus amplexicaulis* (Hall) (fig. 6T), *Orthograptus quadrimucronatus* (Hall) (figs 7A, B), *Orthograptus ?ruedemanni* (Gurley) and *Neurograptus magaritatus* (Lapworth) (fig. 6R). This suggests that there is no large gap in the North Greenland sequence. It is possible that the revised North American zonation (Finney, 1986) might also be applied to North Greenland. According to Finney (1986) the sequence *N. gracilis* – *O. amplexicaulis* Zones fills the gap earlier supposed for the North

American sequence. As the present faunal assemblages are in agreement with those reported by Finney (1986), his zonal division has been used.

Orthograptus quadrimucronatus Zone

The use of this zone is in accordance with practice in the Canadian Cordillera (Lenz & Chen, 1985). The *C. tubuliferus* Zone was defined by Finney (1986) from North America as roughly corresponding to the *P. linearis* Zone in the British sequence (Williams, 1982a). Graptolite species reported from the above-mentioned areas from this level are observed in at least four samples from North Greenland and comprise: *C. (C.) caudatus* and *Climacograptus* (*Climacograptus*) *tubuliferus* Lapworth (fig. 3E) (the two species are occasionally indistinguishable from each other), together with *Dicellograptus alector* Carter & Churkin, *Dicellograptus ?elegans* (Carruthers), *G. brevis*, *'Climacograptus' ?typicalis* Hall, *Orthograptus* ex gr. *calcaratus* (Lapworth), *Orthograptus pauperatus* Elles & Wood, *O. amplexicaulis* and *Orthoretiolites ?pulcherrimus* (Harris & Keble). *O. ?pulcherrimus* and *D. alector* are also reported from younger strata (Thomas, 1960; Carter & Churkin, 1977).

The graptolite fauna from this level is very similar to that reported from the Canadian Cordillera, except that *Pleurograptus linearis* (Carrruthers), which indicates this level, has not been observed in the present material.

O. quadrimucronatus and *O. amplexicaulis* are regarded as unsuitable index species for the two zones; their ranges appear to be fairly wide and for the most part the two species overlap (see also Finney, 1986). However, the present material is far too sparse to serve as a basis of revision of the two zones.

Dicellograptus ornatus Zone

Samples (GGU 313103, 319683, 319684) containing *Dicellograptus ornatus* Elles & Wood (fig. 7K), *Dicellograptus minor* Toghill, *Dicellograptus complexus* Davies (figs 7H, J), *Climacograptus* (*Climacograptus*) *hastatus* Hall (fig. 7N) and *Climacograptus* (*Diplacanthograptus*) ex gr. *longispinus* Hall (figs 7M, O) are here regarded as indicators of the *D. ornatus* Zone in the lower Bolindian. It has not been possible to distinguish a special *'Climacograptus' uncinatus* Zone corresponding to Bol in the Australian sequence. Additional associates are *Pleurograptus?*, *Leptograptus* sp. (fig. 7G), *Dicellograptus* cf. *D. pumilis* Lapworth (fig. 6N), *Climacograptus* sp., *Orthograptus abbreviatus* Elles & Wood and *Orthograptus socialis* Lapworth (fig. 7F). *Orthograptus* ex gr. *calcaratus* (fig. 7Q), *O.? pulcherrimus* (fig. 7C) and *D. alector* (fig. 7D) apparently continue into this level. Two specimens of an unknown form within the Dicranograptinae, possibly resembling *Diceratograptus* (fig. 7I), have also been found. The stratigraphical position of *Climacograptus* cf. *C. (Diplacanthograptus) dorotheus* Riva (fig. 7E) is uncertain.

It is not possible to correlate the present material to more precise levels, such as those observed in the Australian Bolindian zonation (fig. 2), where *'Climacograptus' uncinatus* Churkin & Carter and *O.? pulcherrimus* appear to be restricted to the lower part and *D. ornatus* to the upper part of the stage. Williams (1987) correlated the British *D. complanatus* and *D. anceps* Zones with the Australian *'C.' uncinatus* and *D. ornatus* & *C. latus* Zone. Williams (1982b) distinguished two upper subzones in the *D. anceps* Zone, the *D. complexus* and the *P. pacificus* Subzones. The presence of *D. complexus* in the present material could indicate the upper part of the *D. ornatus* Zone but the material is limited to one sample only.

The North Greenland *D. ornatus* assemblage correlates with the equivalent zone in the Canadian Cordillera (Lenz & McCracken, 1982; Lenz & Chen, 1985). Also in Canada it is not clear whether the *D. ornatus* Zone comprises most of the Bolindian or only the lower part (Lenz & Chen, 1985).

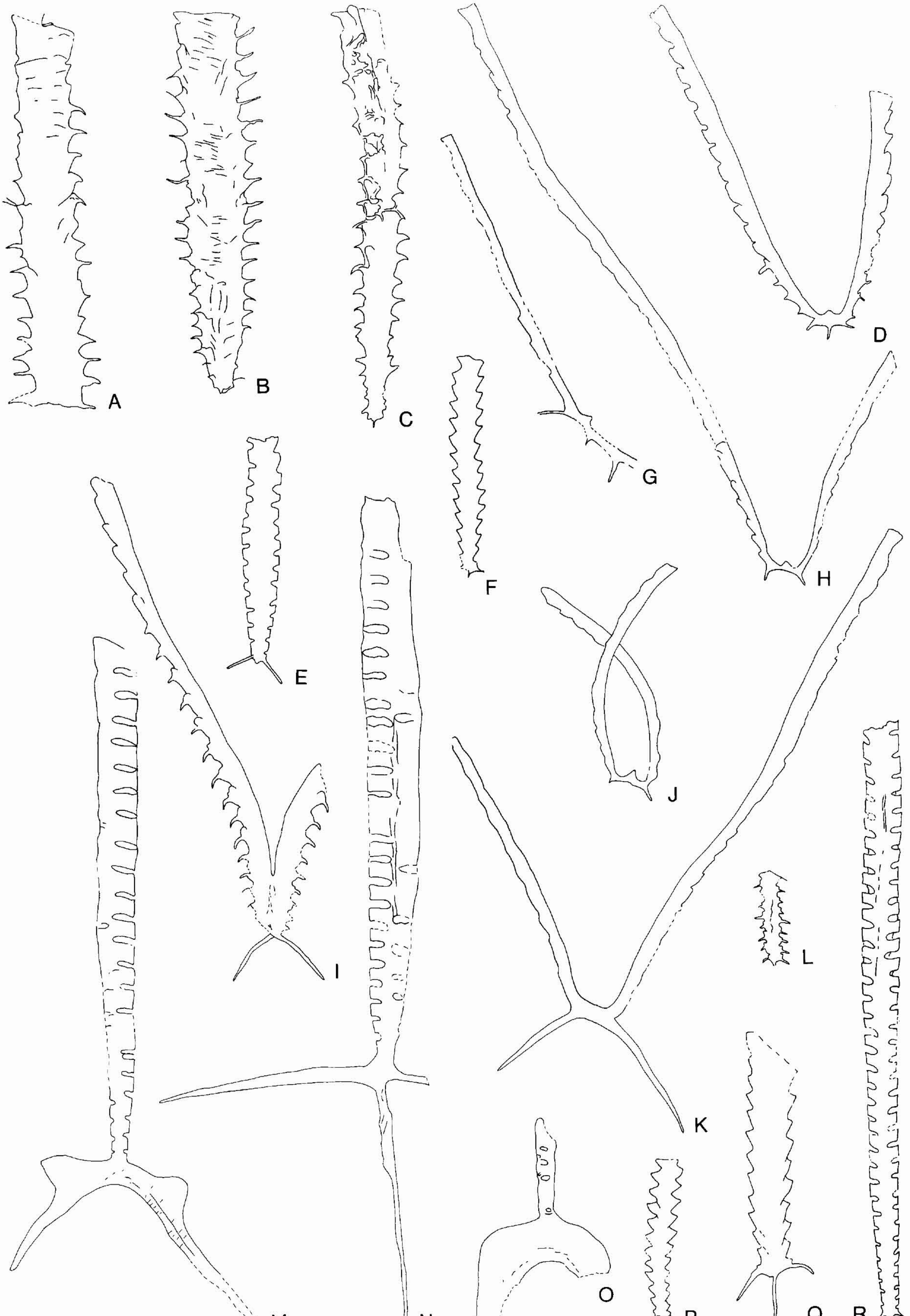
It is remarkable that the North Greenland late Ordovician graptolite faunas include numerous dicellograptids, as do those from the Canadian Cordillera (Lenz & McCracken, 1982; Lenz & Chen, 1985). This contrasts with graptolite faunas described by Melchin (1987) from the Cape Phillips Formation in Arctic Canada where the dicellograptids are absent. At this stratigraphic level only an *O. fastigatus* Zone was reported by Melchin (1987).

? Parorthograptus pacificus Zone

The *P. pacificus* Zone was distinguished as a separate zone in the northern Canadian Cordillera by Lenz & McCracken (1982). In other areas the level with *Parorthograptus pacificus* (Ruedemann) (fig. 7L) has been defined as the uppermost subzone of the *D. anceps* Zone (Williams, 1982b) or as the uppermost subzone in the *C. supernus* Zone (Koren *et al.*, 1979).

In North Greenland *P. pacificus* has only been observed in two samples of which GGU 313135 is not *in situ*. It is associated with *C. longispinus*, *Geniculograptus ?latus* (Elles & Wood) (fig. 7R), *Arnheimograptus lorrainensis* (Ruedemann) (fig. 7P) and *Orthograptus* sp.

The *P. pacificus* level is apparently the youngest Or-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dovician present in the available graptolite collections from North Greenland. Neither the *C. extraordinarius* Zone (Williams, 1982b) nor the *G. persculptus* Zone have been observed in North Greenland, and the Ordovician–Silurian boundary cannot be demonstrated by graptolites. The earliest Silurian graptolites are from the trough sequence in Johannes V. Jensen Land where a sparse fauna from the *C. atavus – C. cyphys* Zones is recorded (Surlyk *et al.*, 1981).

One sample from the Aleqatsiaq Fjord Formation exposed along the southern part of Newman Bugt in western North Greenland contains *Geniculograptus* cf. *G. inuiti* (Cox). The exact stratigraphic position cannot be indicated, as the type material of *G. inuiti* was reported from a level as low as the *C. manitoulensis* Zone (Riva, 1974), and the possible synonymy with *G. latus* (Riva, 1986) indicates a long range, corresponding to both the *D. ornatus* and *P. pacificus* Zones.

Discussion of the graptolite biofacies

The North Greenland Ordovician graptolites, especially those of Early Ordovician age, are clearly similar to the graptolite faunal assemblages reported from the Canadian Cordillera (Lenz & Jackson, 1986), Australasia (Thomas, 1960; Cooper, 1979; Webby *et al.*, 1981), Texas (Berry, 1960), the Great Basin area (Ross & Berry, 1963), Idaho (Carter & Churkin, 1977), Newfoundland (Williams *et al.*, 1987; Williams & Stevens, 1988), Spitzbergen (Cooper & Fortey, 1982) and parts of southern China (Sheng, 1980). These regions are traditionally referred to the 'Pacific' faunal realm.

Ordovician graptolites in North Greenland are found in outer slope and deep-water trough sediments within the Franklinian Basin. These clastic deposits are now exposed in eastern parts of North Greenland in Johannes V. Jensen Land and Amundsen Land, and in western parts of North Greenland in the northern peninsulas of Nyeboe Land, Wulff Land, Nares Land and Freuchen Land (e.g. Higgins *et al.*, in press; fig. 1).

Throughout the Ordovician sequences in North Greenland the graptolite faunas are similar to the assemblages referred to as the 'oceanic' graptolite biofacies (Fortey, 1984) and to those reported as originating from deep-water facies (Lenz & Chen, 1985; Finney, 1986). The earliest Ordovician fauna recorded here is an anisograptid assemblage. This assemblage is usually present in deposits interpreted to be from marginal oceanic areas, e.g. Lancefield, Victoria (Cooper & Stewart, 1979), Peel River (Jackson, 1974, 1975; Erdtmann, 1988).

The basal Arenig *T. approximatus* Zone is characteristic of oceanic facies, e.g. in the Victorian sequence (Fortey, 1984), and is absent in shallow water deposits, as described from the Arenig type area deposits in Wales (Molyneux & Rushton, 1988).

During the interval Arenig–Llanvirn the oceanic isograptid biofacies (Fortey, 1984) prevailed in North Greenland, characterised by the presence of *Isograptus*, *Oncograptus* and *Cardiograptus*, together with representatives of the slender many-stiped 'dichograptids' such as *Goniograptus* and *Sigmagraptus*.

During the Llandeilo–Caradoc the graptolite faunas became more cosmopolitan, probably as a result of the world-wide transgression (Fortey, 1984) or, as traditionally supposed, by the breakdown of the boundaries of the faunal provinces in connection with the closure of the Iapetus Ocean. However, during the Caradoc there are faunal differences in North America, described for example by Finney (1986). In this connection it is significant that the graptolite faunas from North Greenland are most similar to the *O. quadrimucronatus – C. tubuliferus* assemblage, reported from Nevada and Idaho, originating from deeper water deposits away from the craton. They are different from the post-*gracilis C. manitoulens – C. pygmeus* forms of the northern Appa-

←

Fig. 7. A., B. *Orthograptus quadrimucronatus* (Hall). From GGU 313023. Western Peary Land. A. MGUH 19426. B. MGUH 19427. C. *Orthoretiolites? pulcherrimus* (Harris & Keble). MGUH 19428 from GGU 313103. Nares Land. D. *Dicellograptus alector* Carter & Churkin. MGUH 19429 from GGU 313103. Nares Land. E. *Climacograptus* cf. *C.* (*Diplacanthograptus*) *dorotheus* Riva. MGUH 19430 from GGU 313135. Southern side of Kap Bopa, Peary Land. F. *Orthograptus socialis* Lapworth. MGUH 19431 from GGU 313103. Nares Land. G. *Leptograptus* sp. MGUH 19432 from GGU 319683. Nares Land. H., J. *Dicellograptus complexus* Davies. From GGU 319683, Nares Land. H. MGUH 19433. J. MGUH 19434. I. *Dicranograptine*, gen. nov.? MGUH 19435 from GGU 319683. Nares Land. L. *Parorthograptus pacificus* (Ruedemann). MGUH 19436 from GGU 313135. Southern side of Kap Bopa, Peary Land. K. *Dicellograptus ornatus* Elles & Wood. MGUH 19437 from GGU 319684. Nares Land. M., O. *Climacograptus* (*Diplacanthograptus*) *longispinus* Hall. M. MGUH 19438 from GGU 319684. Nares Land. O. MGUH 19439 from GGU 313135. Southern side of Kap Bopa, Peary Land. N. *Climacograptus* (*Climacograptus*) *hastatus* Hall. MGUH 19440 from GGU 319683. Nares Land. P. *Arnheimograptus lorrainensis* (Ruedemann). MGUH 19441 from GGU 313135. Southern side of Kap Bopa, Peary Land. Q. *Orthograptus* ex gr. *calcaratus* (Lapworth). MGUH 19442 from GGU 319683. Nares Land. R. *Geniculograptus ?latus* (Elles & Wood). MGUH 19443 from GGU 313101. Nares Land. All figures × 3.

lachians in the eastern part of North America, as described by Riva (1974).

The late Ordovician graptolite assemblages of North Greenland include numerous dicellograptids, as do those from the Canadian Cordillera (Lenz & McCracken, 1982; Lenz & Chen, 1985). These faunas differ from the graptolite assemblages reported from the Cape Phillips Formation in Arctic Canada which lack the dicellograptids (Melchin, 1987). In the Cape Phillips Formation the graptolites occur in taphocoenoses from moderate to deep shelf areas at the margin of the Franklinian Basin, and not from the outer slope environment of the graptolitiferous strata in the western areas of North Greenland (Higgins *et al.*, in press). As also mentioned by Melchin (1987) the presence of the dicellograptids might be ecologically dependent on, for example, different water masses or basin depth.

In conclusion the North Greenland Ordovician graptolite faunas represent taphocoenoses from deep oceanic, either slope or trough clastic sediments, which border shelf sequences developed around the North American craton. They agree well with the earlier recorded oceanic graptolite biofacies, recognised on the margins of former continents, as described and figured by Fortey & Cocks (1986, fig. 3).

Acknowledgements. I thank P. R. Dawes, A. K. Higgins, J. M. Hurst, S. Schack Pedersen, F. Rolle, M. Sønderholm and F. Surlyk for allowing me to work on their graptolite collections, and I am indebted to A. K. Higgins, F. Surlyk and S. Schack Pedersen for providing most of the material and for information on the geology of the area. I have benefited from discussions of a number of graptolites with K. Lindholm (Lund, Sweden). J. S. Peel is thanked for critical reading and improving the English of the manuscript. Thanks are directed to R. Larsen and A. Andersen for drawing the map and the scheme.

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