DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2007/19

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# Abstract

The Davis Strait High is an important positive structural feature straddling the Greenland–Canada border in the centre of the Davis Strait (66° 30′ N, 57° 30′ W). The crustal affinities (oceanic *vs* continental) of this structure have been debated for several decades but recent work suggests that this feature is of continental origin and forms the outer edge of a belt of stretched continental crust that extends east to the Greenland craton proper. Dredging campaigns between 2003 and 2006 aimed to contribute to this debate by sampling from the eastern flank of the high where eastward-dipping reflectors are evident on seismic data. The ten dredges to date in this region yield very similar results, being dominated by sedimentary rock types, with subordinate igneous and gneissic basement clasts. The sedimentary dredge samples are overwhelmingly dominated by carbonates and this clast assemblage from two dredge sites (DANA 04-03D, DANA 04-04D) forms the focus of this report. Biostratigraphic analysis, based primarily on conodonts, demonstrates a consistent Ordovician age and furthermore that three discrete stratigraphic ages are represented: late Early – early Middle Ordovician, late Middle Ordovician and Late Ordovician. Sedimentological analysis of the dredged carbonate suite demonstrates a spectrum of facies: lime mudstone – sparse skeletal wackestone, skeletal wackestone – packstone, grainstone–packstone, microbialite, dolostone, carbonate-cemented sandstone/siltstone. These facies record deposition on a siliciclastic-influenced carbonate shelf with environments ranging from shallow-water lagoon through high-energy barrier shoals to open marine subtidal shelf. The abundance, dominance and consistent proportion of this Ordovician carbonate assemblage in dredges from a broad swathe of the eastern Davis Strait High argue, in association with regional source considerations, for an *in situ* origin for this dredged material, rather than it being ice-transported from known onshore Ordovician terrains. Comparison with such Ordovician occurrences in eastern Canada and West Greenland demonstrates the strikingly similar stratigraphic and facies development throughout this region, reflecting the persistent, uniform and low relief development of the Ordovician shelf, with discrete transgressive pulses recognisable throughout eastern Laurentia. In addition to the palaeogeographic implications, the results of this study provide further support for the proposal that the Davis Strait High is composed of continental crust.

# Introduction

The Davis Strait High is a prominent structural high lying in the centre of the Davis Strait, straddling the Greenland–Canada territorial border (Fig. 1); this roughly N–S linear horst is bounded by the Ungava Fault Zone to the west and extends at least from south of 66°N to beyond 68°N (referred to by some authors as the North Davis Strait High). The nature of this high has been under dispute for several decades (see below) and the aim of the dredge campaigns in 2003, 2004 and 2006, in conjunction with new seismic surveys, was to investigate the nature of shallow-dipping strata on the eastern side of the high that appear to extend up to the sea-floor, based on previous seismic data. Prominent amongst the samples obtained by these dredge-sampling campaigns is a distinctive suite of carbonate-dominated sedimentary rocks that display a consistent spectrum of depositional facies and biostratigraphic ages. Although an ice-rafted origin cannot be entirely ruled out, this sedimentary assemblage of dredge samples is considered most likely to be derived from the Davis Strait High itself and thus important in the discussion of the geo-tectonic nature and origin of the high. In this report, we document the biostratigraphy and facies array of this carbonate-dominated sedimentary assemblage from two dredges taken in 2004 (DANA 04-03D, DANA 04-04D). Future studies will expand this work to include the more recent samples obtained from the Davis Strait High in 2006 (see Dalhoff & Kuijpers 2007).

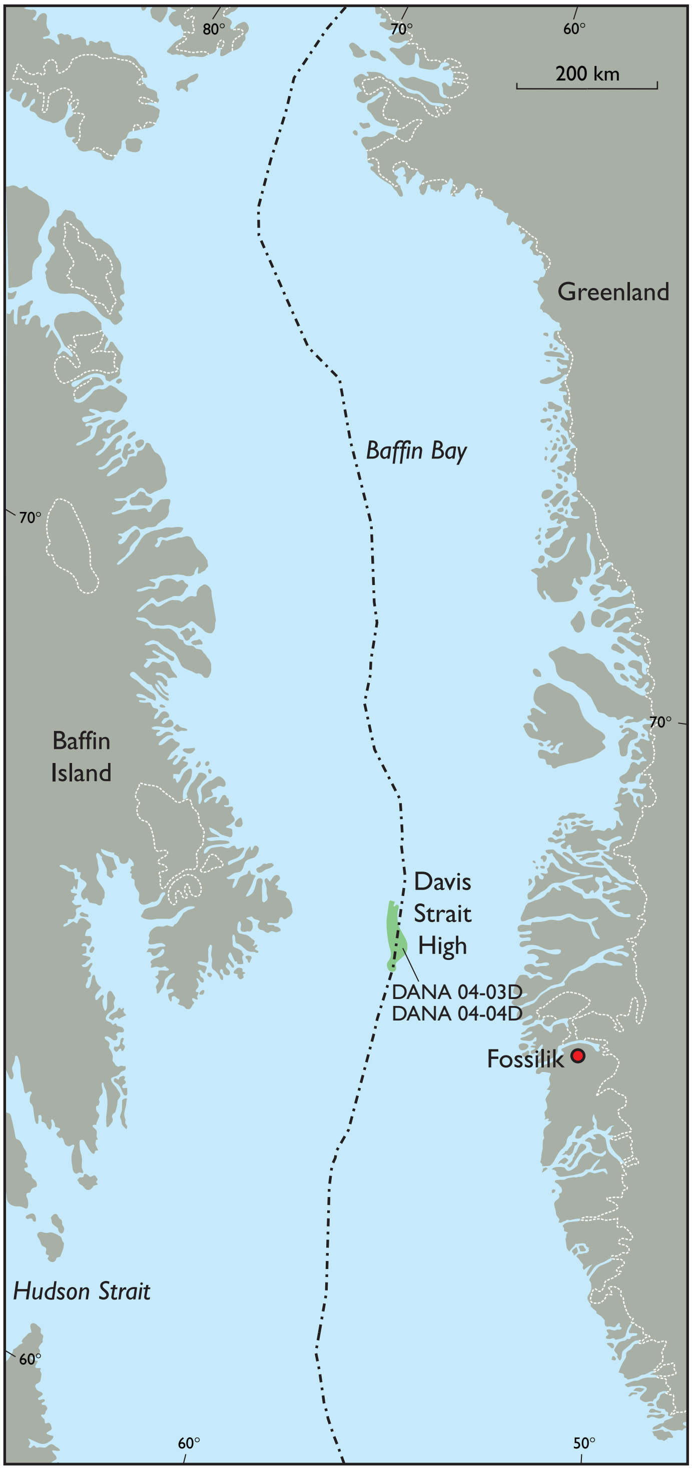



Fig. 1. Map showing the position of the Davis Strait High between West Greenland and eastern Canada and the two dredge sites, DANA 04-03D and DANA 04-04D, under focus in this report.

# Geology of the Davis Strait High

The geology and evolution of the Davis Strait High is much debated and the dredging campaign reported here represents the most recent attempt to elucidate the nature of this structural high. A detailed discussion of the debate concerning the evolution of the western Greenland margin, including the Davis Strait High, will not be repeated here; the reader is referred to Chalmers & Pulvertaft (2001) and Larsen & Dalhoff (2006) for comprehensive reviews of this debate. It suffices to state that the high has been variously reported to consist of oceanic crust (Keen & Barrett 1972), a mixture of continental crust and plume-related volcanic rocks (Keen *et al*. 1974) and a sliver of continental crust enveloped in oceanic crust (Srivastava *et al*. 1982). Seismic data, however, indicate that there is no oceanic crust east of the Davis Strait High, i.e. that the crust between the Davis Strait High and Greenland comprises extended continental crust (Chalmers & Pulvertaft 2001).

Prior to this dredge campaign, material sampled from the Davis Strait High itself was confined to shallow cores on the western side of the high that encountered basaltic rocks (Srivastava *et al*. 1982). Although the core of the Davis Strait High is largely seismically transparent, eastward-dipping reflectors are noted on the eastern flank of the high, extending close to the sea-floor (Fig. 2). This region has formed the focus of the dredge campaigns in 2003, 2004 and 2006 (Dalhoff *et al*. 2003, 2004; Dalhoff & Kuijpers 2007).

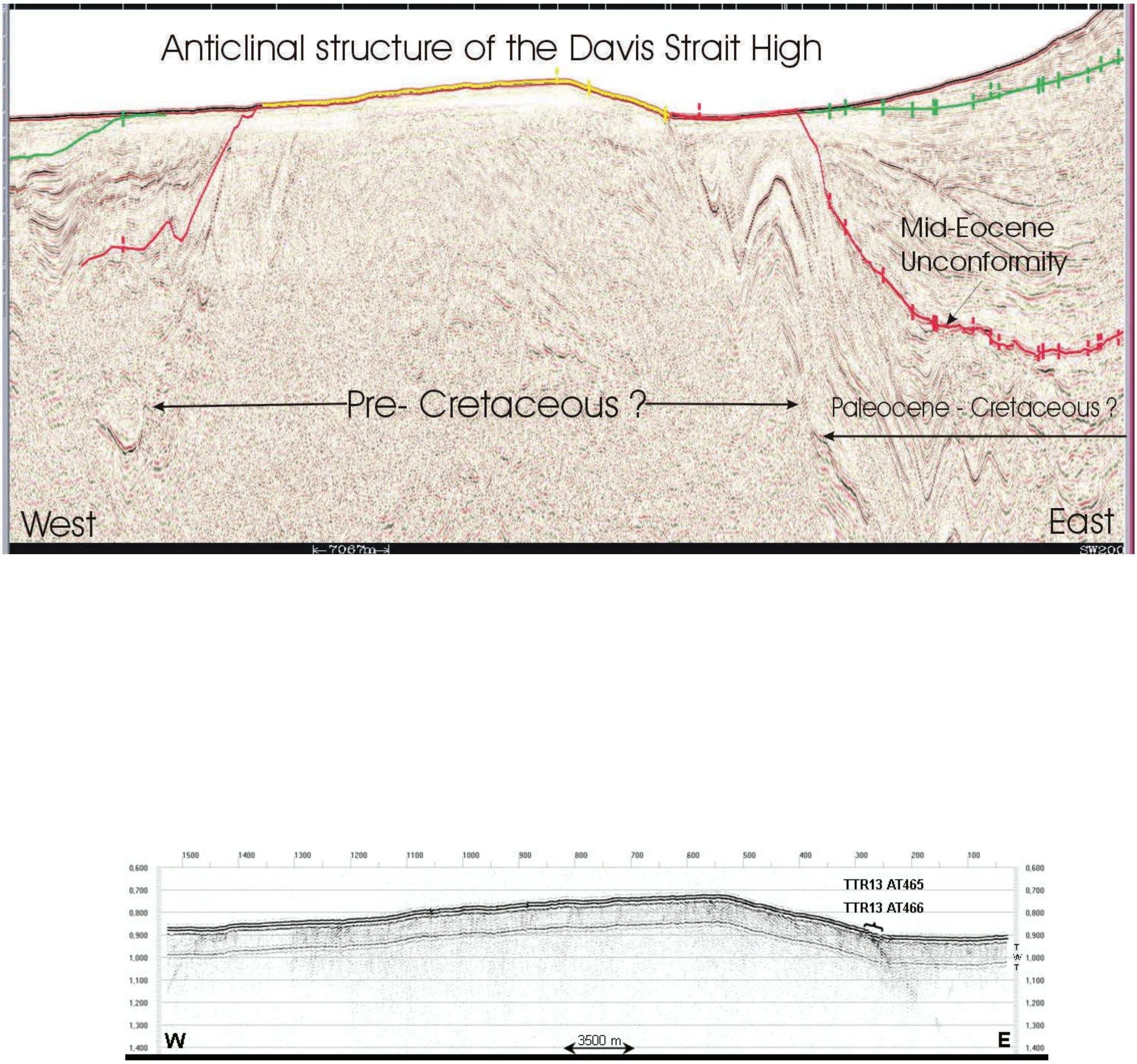



Fig. 2. Single channel seismic line (PSAT240), across the Davis Strait High, showing weak eastward-dipping reflectors on the eastern flank (enlarged in lower section) that approach close to, or reach, the sea floor. The line roughly intersects the two 2003 dredge sites, just north of the DANA 04 dredges (see Fig. 1).

# Dredge results

Prior to the 2006 season, four dredges had been undertaken on the eastern flank of the Davis Strait High where eastward-dipping reflectors are observed on seismic data (Fig. 2). The samples reported here were from two dredges in 2004 (DANA 04-03D, DANA 04-04D); these two sites were just south of dredges TTR13 AT465D and TTR13 AT466D taken in 2003 (Fig. 2). In total, these four dredges resulted in 362 rock samples, of which 254 were sediments (dominated by the Lower Palaeozoic carbonate suite under focus here), 25 were igneous rocks and 83 were Precambrian basement gneisses (Larsen & Dalhoff 2006). Although the recently-acquired data from the 2006 cruise is under ongoing study and is not reported here, it is notable that the six 2006 dredges on the Davis Strait High resulted in very similar sample suites to the previous four, i.e. are dominated by pieces of sedimentary rock of which carbonates are the dominant rock type (Dalhoff & Larsen 2007).

The consistent proportion and facies composition of the sedimentary rocks in these dredge sites on the eastern flank of the Davis Strait High, over a north–south distance of over 100 km, supports the contention that the carbonate detritus is most likely derived from the high, rather than representing ice-transported material; this topic is discussed more fully in the discussion section, below.

Detailed technical information on the cruises is given in the cruise reports (Dalhoff et al. 2003, 2004; Dalhoff & Kuijpers 2007), including the location of the 10 dredges (to date) on the Davis Strait High. The two dredge sites reported here are:

| | |
|---|---|
| DANA 04-03D | 66°35.740 N, 57°23.842 W – 66° 35.595 N, 57°25.801 W |
| DANA 04-04D | 66°32.985 N, 57°28.702 W – 66° 32.806 N, 57°29.983 W |

# Biostratigraphy of selected carbonate samples

As noted earlier, the two dredges under focus here are dominated by a suite of mainly fine-grained silty limestones, dolomitic limestones and dolostones, together with inferred associated carbonate-cemented fine-grained siliciclastics. The carbonate samples are macroscopically commonly clearly fossiliferous, containing carbonate skeletal material attributable to brachiopods, ostracods, trilobites, crinoids and gastropods (see Plate 1). Petrographic examination confirms and expands this faunal list to include bryozoans, green and blue-green algae, stromatoporoids, sponge spicules, orthoconic cephalopods and corals. Acid digestion of selected samples for biostratigraphic purposes yielded conodonts, silicified sponge spicules and chitozoans. In the following biostratigraphic summary, only the conodont fauna is considered since this provides the best biostratigraphic control, given the nature of the sample material.

## Material

A total of 29 samples of sedimentary rocks from the DANA 04-03D and DANA 04-04D dredges on the Davis Strait High have been processed to date for acid-resistant microfossils; of these, 28 were selected from the overtly fossiliferous limestone-dominated group while the remaining sample (DANA 04-03-17) is one of the large but rare dolomicritic blocks (barren of organic remains). Of the former 28 samples, 17 samples yielded conodonts, permitting relative age dating (Tables 1–5); the remaining 11 samples yielded no conodont fossils although four of these were small samples (< 100 g) which clearly reduces the chance of conodont recovery. It is notable that the skeletal wackestones and packstones (facies 2, see below) most consistently yield conodont faunas, followed by lime mudstones and grainstones (facies 1, 3); silty, sandy carbonates, carbonate-cemented sandstones/siltstones (facies 6) and microbial carbonates rarely yielded conodonts.

At this stratigraphic level, the standard sample-size routinely adopted is 2–5 kg; in this study, the samples available for dating are relatively small, generally ranging from 50 g to c. 1000 g. Consequently, the yield and diversity of the microfauna from the dredge samples of the Davis Strait High are low.

## Previous conodont research on the Ordovician rocks of western and northern Greenland and eastern Arctic Canada.

Stouge & Peel (1979) described a Late Ordovician (Kirkfeldian–Mayswillian) conodont fauna from a limestone block in a fault zone ('Fossilik') within the Precambrian Shield of West Greenland (see also Smith & Bjerreskov 1994). Aldridge (1982) described *Besselodus arcticus* from the Alequatsiaq Fjord Formation of Washington Land based on fused cluster material. Ibexian conodont faunas were described by Stouge *et al*. (1985) from talus material collected from Kap Clay, Washington Land. Smith & Peel (1986) illustrated members of a fauna dominated by *Colaptoconus quadraplicatus* from the Danmarks Ford Member of the Wandel Valley Formation. Ineson *et al*. (1986) reported a *Phragmodus polonicus*

Zone conodont fauna within the Sjælland Fjelde Formation of eastern North Greenland. Armstrong (1990) described Upper Ordovician to Silurian conodonts from North Greenland. Smith & Bjerreskov (1994) provided an overview of the Ordovician conodont biostratigraphy of Greenland in which they reported additional Lower and high Middle Ordovician conodont faunas from the onshore locality 'Fossilik', West Greenland. McCracken (2000, and references therein) provided an updated detailed conodont biostratigraphy of several successions in eastern Arctic Canada.

## Conodont alteration index (CAI)

The conodont elements are generally well preserved with a Colour Alteration Index (CAI; Epstein *et al*. 1977) of 1 to 1.5. Values of CAI 1 are consistent with the estimated burial temperature of the Ordovician rocks in eastern Arctic Canada and Fossilik in West Greenland. That some samples range up to CAI values of 1.5, however, suggests that the inferred Ordovician succession flanking the Davis Strait High may have been more deeply buried than its correlatives in eastern Arctic Canada.

## Conodont biostratigraphy

Several conodont assemblages are distinguished within the Ordovician rocks from the Davis Strait High. Regional biozonations (McCracken 2000) and the international standard (chrono-) zonation (Sweet 1984, 1988; Webby *et al*. 2004; Fig. 3) are adopted here for reference. Key species are illustrated on Plate 2.

### Late Early – early Middle Ordovician microfauna

The late Early – early Middle Ordovician conodont fauna was recovered from two sedimentary samples from the Davis Strait High – DANA 04-03D-19 and DANA 04-04D-1 (Table 1). The fauna is characteristic of the Midcontinent Province and may represent a protracted time period, ranging from the late Early Ordovician (latest Canadian) into the early Middle Ordovician (Whiterock).

Sample 04-03D-19 contains several diagnostic species, including *Eucharodus parallelus*, *Jumodontus gananda* and *Ulrichodina abnormalis*. These taxa are present in the *Oepikodus communis* to *Microzarkodina flabellum*/*Tripodus laevis* conodont zones (Branson & Mehl 1933; Ethington & Clark 1971; Webby *et al*. 2004). The zones represent a well-constrained time interval that equates with the upper lower Ordovician to the lower Middle Ordovician (Whiterock Series). The lower range of *Jumodontus gananda* is at the base of the *andinus* conodont Zone (Cassinian regional Stage – Lower Ordovician) and the upper range coincides within the middle of the *Periodon flabellum*/*Tripodus laevis* conodont Zone (Whiterock – Middle Ordovician) (Ethington & Clark 1982; Webby *et al*. 2004). The presence of the species *Toxodus carlae* in the DANA04-04D-1 sample suggests a general late Early Ordovician age.

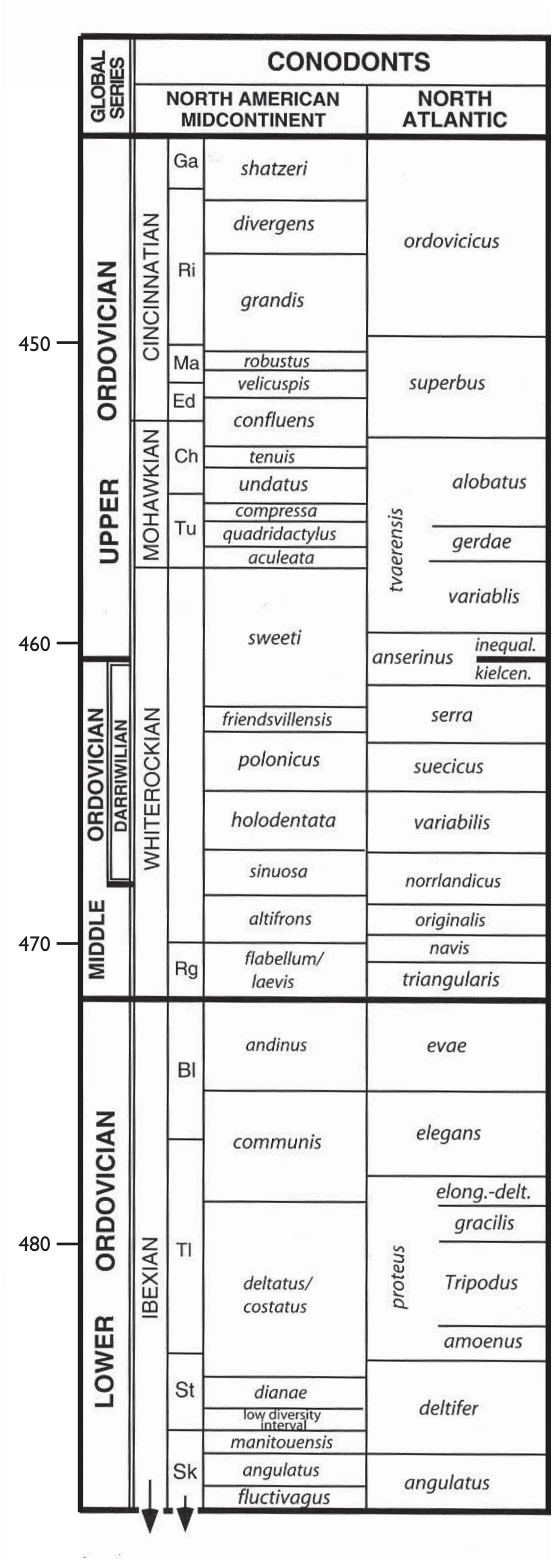



Fig. 3. Ordovician chronostratigraphic scheme (modified from Webby *et al*. 2004).

The samples have a CAI = 1, indicating that they have not been thermally altered due to burial. In North America, this faunal association is characteristic of peritidal to shallow-water subtidal facies.

***Table 1****. Late Early – early Middle Ordovician conodont species*

| GEUS locality | 04-03D-19 | 04-04D-1 |
|---|---|---|
| Sample weight (g) | 375 | 620 |
| CAI | 1 | 1 |
| Species | | |
| *Euchararodus parallelus* | 7 | |
| *Jumodontus gananda* | 1 | |
| *Parapanderodus gracilis* | 3 | 1 |
| *Toxodus carlae* | | 1 |
| *Ulrichodina abnormalis* | 1 | |
| Total specimens | 12 | 2 |

***Correlation***. This Early – early Middle Ordovician conodont assemblage is widespread over North America (Ethington & Clark 1982). In eastern Arctic Canada, it has been recorded from the Ship Point Formation of the Foxe Basin (Barnes 1974, 1977) and from the Ungava Bay Formation (Barnes in Workum *et al*. 1976) in Hudson Strait, south of Baffin Island (Fig. 4). The sample yielding the species *Toxodus carlae* is, as noted above, Early Ordovician in age. The lower Ordovician conodont fauna reported from 'Fossilik', West-Greenland (Smith & Bjerreskov 1994) corresponds to the lower part of this late Early to early Middle Ordovician interval from the Davis Strait High.

## Middle Ordovician microfaunas

The Middle Ordovician conodont assemblages recovered from the Davis Strait High dredge samples comprise taxa that are typical of the Midcontinent Province. The Middle Ordovician faunas are divided into two assemblages with a very different faunal composition.

### Conodont Assemblage MO1

The first assemblage is recorded from sample DANA 04-03D-2. The composition of conodont assemblage MO1 is given in Table 2.

This unique faunal association is exclusively composed of hyaline conodonts. It is characterized by *Multioistodus subdentus*, but is associated with a complex of hyaline conodonts

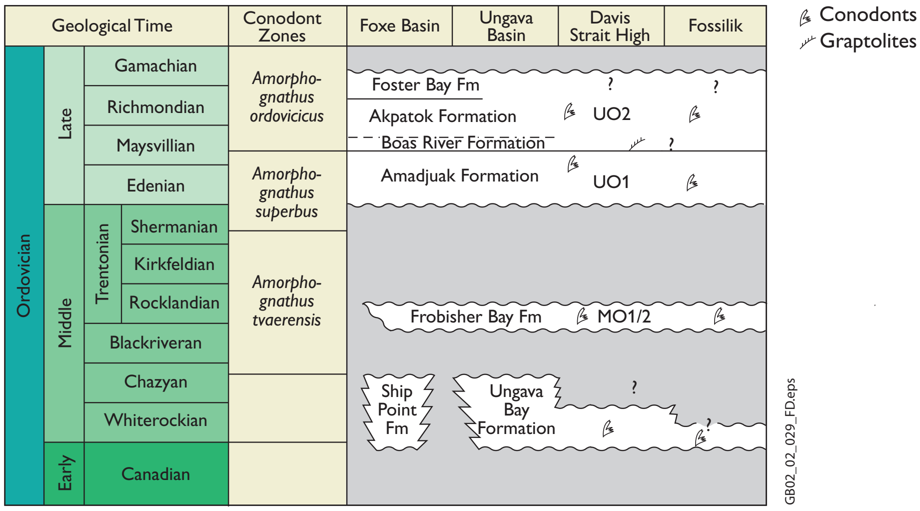



Fig. 4. Schematic correlation chart showing the chronostratigraphic position of the Ordovician succession in eastern Canada (Foxe Basin, Ungava Basin) relative to the conodont data from the Davis Strait High and Fossilik (West Greenland). Modified after McCracken (2000).

i.e. *Curtognathus typus*, *Erismodus arbucklensis*, *Leptochirognathus prima* and *Pteracontiodus sinuosus*. This type of fauna is only known from North America. *M. subdendatus* is typical of Middle and Late Whiterockian (Middle Ordovician) and early Late Ordovician (Mohawkian) strata in North America (Branson & Mehl 1933; Ethington *et al*. 1986; Sweet 1984, 1988; Bauer 1989). *Multioistodus subdentatus*, however, is constrained to the Middle Ordovician and gives a mid- and late Whiterockian age for the fauna.

***Table 2****. Conodont Assemblage MO1; Middle Ordovician conodont species*

| GEUS locality | 04-03D-2 |
|---|---|
| Sample weight (g) | 144 |
| CAI | 1.5 |
| Species | |
| *Coleodus simplex* | 1 |
| *Curtognathus typus* | 22 |
| *Drepanoistodus angulensis* | 4 |
| *Erismodus* cf. *arbucklensis* | 1 |
| *Multioistodus subdentatus* | 53 |
| *Leptochirognathus prima* | 1 |
| *Lumidens* cf. *vitreus* | 4 |
| *Pteracontiodus sinuosus* | 22 |
| *Scapulidens primus* | 4 |
| *Trigonodus* sp. | 4 |
| Total | 116 |

***Correlation.*** In Greenland, a similar but older and less diverse fauna is found in the Alexandrine Bjerge Member of the Wandel Valley Formation in Kronprins Christian Land, eastern North Greenland (Peel & Smith 1988). However, a more likely stratigraphical correlative is the Sjælland Fjelde Formation that succeeds the Wandel Valley Formation in Kronprins Kristian Land from which the *P. polonicus* conodont Zone has been identified (Ineson *et al*. 1986). The Davis Strait High fauna has not been reported from either northern or eastern Arctic Canada or from north-western Greenland. However, the assemblage is considered coeval with the fauna described from the Frobisher Bay Formation of the Ungava and Foxe basins of the southern Baffin Island region.

The CAI value is 1.5, which signifies that the sediment has suffered some thermal alteration due to burial. This faunal association is characteristic of a stressed depositional environment (Stouge 1984; Ethington *et al*. 1986; Bauer 1989).

**Conodont Assemblage MO2**

This assemblage is recorded from sample DANA 04-03D-37. The fauna consists of *Ansella nevadensis*, *Phragmodus undatus* and *Plectodina* sp. It is characterized by *Ansella nevadensis*, which ranges from the Middle Ordovician *polonicus* Zone to the Upper Ordovician *compressa* Zone (Sweet 1984). However McCracken (2000) reported the species to range higher. *Phragmodus undatus* is the nominate species of the *undatus* Zone which equates to the mid-Mohawkian. The remaining taxa listed in Table 3 are long-ranging.

***Table 3**. Conodont Assemblage MO2; Middle Ordovician conodont species*

| | |
|---|---|
| GEUS locality | 04-03D-37 |
| Sample weight (g) | 250 |
| CAI | 1–1.5 |
| Species | |
| *Ansella nevadensis* | 1 |
| *Panderodus* spp. | 27 |
| *Phragmodus undatus* | 2 |
| *Plectodina* sp. | 2 |
| Total | 32 |

***Correlation.*** Conodont Assemblage MO2 shares *Ansella nevadensis*, *Panderodus* spp. and *Phragmodus undatus* with the Frobisher Bay Formation (McCracken 2000). *Ansella nevadensis* is restricted to the Frobisher Bay Formation in eastern Arctic Canada. The Frobisher Bay Formation ranges in age from Rocklandian to late Shermanian of the late Middle Ordovician (Trentonian; Bolton 1977, 2000; McCracken 2000). The 'Fossilik' late Middle Ordovician conodont fauna (Smith 1988; Smith & Bjerreskov 1994) is Blackriveran in age, which largely corresponds to the age of the MO2 fauna; the two faunas are probably contemporaneous (Fig. 4).

## Upper Ordovician microfaunas

Most of the investigated fossiliferous samples from the two dredges are referred to the Upper Ordovician. The material shows that the samples are representative of a protracted depositional history, extending from the late Mohawkian (early Late Ordovician) to the Maysvillian/Richmondian (Late - but not latest - Ordovician). The samples have been dated by means of conodonts. Associated microfaunal elements include chitinozoans, sponges (spicules), radiolarians and scolocodonts. The Maysvillian age is confirmed by the presence of graptolites and chitinozoans in samples from elsewhere on the Davis Strait High; these data are not included in this report.

The Upper Ordovician samples are placed in two groups, UO1 and UO2, based on the faunal content. The UO1 assemblage includes samples with conodonts indicative of the Edenia–Maysvillian Stage i.e. a late Ordovician age. The UO2 assemblage is considered to suggest a younger or Maysvillian (?-Richmondian) age.

**Conodont assemblage UO1**

The conodont assemblage UO1 consists of *Panderodus* spp. (including *Panderodus gracilis* and *Panderodus panderi*), *Plectodina tenuis* s.l. and *Phragmodus undatus*. *Protopanderodus liripipus* and *Oulodus* sp. may also be present; the specimens of the genus *Oulodus* could not be positively identified to species level. The sample numbers assigned to the UO1 assemblage are given in Table 4.

***Table 4.*** *Conodont assemblage UO1. Late Ordovician conodont species*

| GEUS Locality | 04-03D-1 | 04-03D-31 | 04-04D-05 | 04-04D-51 |
|---|---|---|---|---|
| Sample weight (g) | 210 | 165 | 650 | 640 |
| CAI | 1.5 | 1 | 1–1.5 | 1–1.5 |
| Species | | | | |
| *Drepanoistodus suberectus* | 1 | | | |
| *Oulodus* sp. | | 1 | | |
| *Panderodus* spp. | 10 | 7 | 65 | 5 |
| *Phragmodus undatus* | | | | 3 |
| *Plectodina tenuis* s.l. | 1 | 1 | 51 | 1 |
| *Protopanderodus liripipus* | 2 | | | |
| Total | 14 | 9 | 116 | 9 |

All recognized species are fairly long ranging but the species association suggests that the conodont assemblage UO1 is not older than the *tenuis* Zone, which is within the Late Mohawkian (Late Ordovician), and not younger than the Maysvillian Stage, where *Protopanderodus liripipus* has its upper limit (Sweet 1984, 1988).

The CAI values vary from CAI 1 to CAI 1.5 in this collection of samples. This suggests that the rocks have suffered a modest degree of thermal alteration due to burial.

***Correlation.*** The UO1 conodont assemblage shares species with the conodont fauna reported by McCracken (2000) from the Amadjuak and Akpatok formations of eastern Arctic

Canada and broad correlation with these two units is likely. However, in the eastern Arctic Canada successions, *Phragmodus undatus* and *Plectodina tenuis* s.l. only occur together in the Amadjuak Formation. Thus, the conodont assemblage UO1 from the Davis Strait High most likely represents the lateral equivalent of the fauna recorded from the Amadjuak Formation.

The conodont fauna recorded by Stouge & Peel (1979) is similar to this assemblage and correlation with the Fossilik locality is proposed.

### Conodont Assemblage UO2

This assemblage comprises *Oulodus* cf. *velicuspis* and *O. robustus*. *Protopanderodus liripipus* and *Panderodus gracilis* are variably present. An unusual group of simple cone conodonts (here referred to *Oneotodus* sp. A in Table 5) are present in some samples assigned to this conodont assemblage. The sample numbers assigned to the UO2 assemblage are given in Table 5.

***Table 5****. Conodont assemblage UO2. Late Ordovician conodont species*

| GEUS locality (prefix 04) | 03D-10 | 03D-16 | 03D-32 | 03D-33 | 03D-81 |
|---|---|---|---|---|---|
| Sample weight (g) | 421 | 1078 | 208 | 303 | 450 |
| CAI | 1–1.5 | 1 | 1–1.5 | 1 | 1.5 |
| Species | | | | | |
| *Drepanoistodus suberectus* | 2 | | | | |
| *Oneotodus* sp. A | | | 50 | 8 | |
| *Oulodus robustus* | 10 | 5 | 2 | | 3 |
| *Oulodus cf. velicuspis* | | 7 | 5 | 1 | 1 |
| *Panderodus gracilis* | | | 6 | | 59 |
| *Protopanderodus liripipus* | 2 | | | | |
| Total | 14 | 12 | 63 | 9 | 63 |

*Oulodus velicuspis* appears in the Edenian Stage and ranges into the latest Ordovician; *Oulodus robustus* appears first in the Maysvillian (*robustus* Zone) and ranges into the latest Ordovician. *Protopanderodus liripipus* has its upper range at the end of the *robustus* Zone (Maysvillian). These species in combination suggest a Maysvillian age for the conodont assemblage UO2; this is the youngest fauna recorded from the Davis Strait High dredge samples.

***Correlation.*** *Protoprioniodus liripipus* occurs in the Akpatok Formation together with species of *Oulodus* (McCracken 2000) indicating a similarity (pars) in age between the Akpatok Formation of the Foxe and Ungava basins and the samples from the Davis Strait High yielding a UO2 conodont assemblage. The Akpatok Formation is reported to be of Maysvillian to Richmondian age (McCracken 2000).

## Late Ordovician undifferentiated

The samples DANA 04-03D-6, 04-03D-12, 04-03D-14 and 04-04D-43 yielded the species *Panderodus gracilis*. These samples cannot be precisely dated, but are tentatively referred to the Late Ordovician.

# Facies analysis

As noted above, the dredge samples from the eastern flank of the Davis Strait High are characterised particularly by sedimentary rocks (e.g. Fig. 5). The sedimentary dredge samples from the Davis Strait High are grouped into three categories:

1. A carbonate suite, with associated fine-grained siliciclastics
2. Silica-cemented glauconitic sandstones
3. Finely crystalline (dolomicritic) unfossiliferous sandy dolomites

The first group overwhelmingly dominates the sedimentary samples in the dredges, for example forming 89% of the DANA 04-03D sample set. These carbonate-dominated sediments yield consistent Ordovician ages (see above) and form the subject of the facies analysis presented below.

The glauconitic sandstones (category 2) are a minor component of the sedimentary assemblage (e.g. 6% of the 04-03D dredge). They differ from the fine siliciclastics assigned to the carbonate association in a number of respects: (1) the sandstones are coarse- to very coarse-grained, sometimes pebbly and compositionally mature (quartz-arenites); (2) they are quartz-cemented and commonly contain glauconite; and (3) they lack carbonate skeletal grains. They are thus considered to be distinct from the carbonate association and it is speculated that they may be derived from the transgressive basal Cambrian sand blanket that is so characteristic of the Laurentian continent (e.g. Swett *et al*. 1971). It is also possible, however, that this sandstone facies was derived from the base of the Ordovician succession, equivalent to the lowermost siliciclastics of the Ungava Bay Formation and the lowermost Ship Point Formation of the Baffin Island region. The silica-cemented and glauconitic nature of these dredge samples, however, contrasts with the poorly consolidated (carbonate-cemented?), non-glauconitic Ordovician sandstones described from the Baffin Island region. An Early Cambrian age is considered most likely.

The third category is a distinctive group of dark fine-grained carbonates (dolostones) that form large blocks (up to 50 cm across) in the dredges but make up only *c.* 5% of the sedimentary samples. These dolostones comprise finely crystalline dolomite (dolomicrite, 10–30 µm) and contain quartz grains of coarse silt to fine sand grade that define thin normally-graded beds that may show parallel or current ripple cross-lamination. Silty, sandy dolomite beds about 5 cm thick show coarse-tail grading, the siliciclastic grains supported in the fine-grained dolomicritic matrix. Slumping is also observed, and the soft-sediment deformation structures may be enhanced by stylolitisation. The geographic and stratigraphic origin of these blocks is unknown. The depositional structures are suggestive of deeper-water processes (turbidity currents, debris flows, slumps) and this, in combination with the dolomicritic character of this facies argues against inclusion in the Ordovician association. Indeed, no skeletal debris was observed in thin-section and a sample (DANA 04-03-17) digested in acid for biostratigraphic purposes was barren. It is tentatively suggested that these samples may be of Proterozoic age but their geographic origin is unknown. Comparable facies are not described from the Proterozoic of northern Baffin Island (Bylot Supergroup), nor from the Thule Supergroup of North-West Greenland (Dawes 1997); deeper-water fine-grained

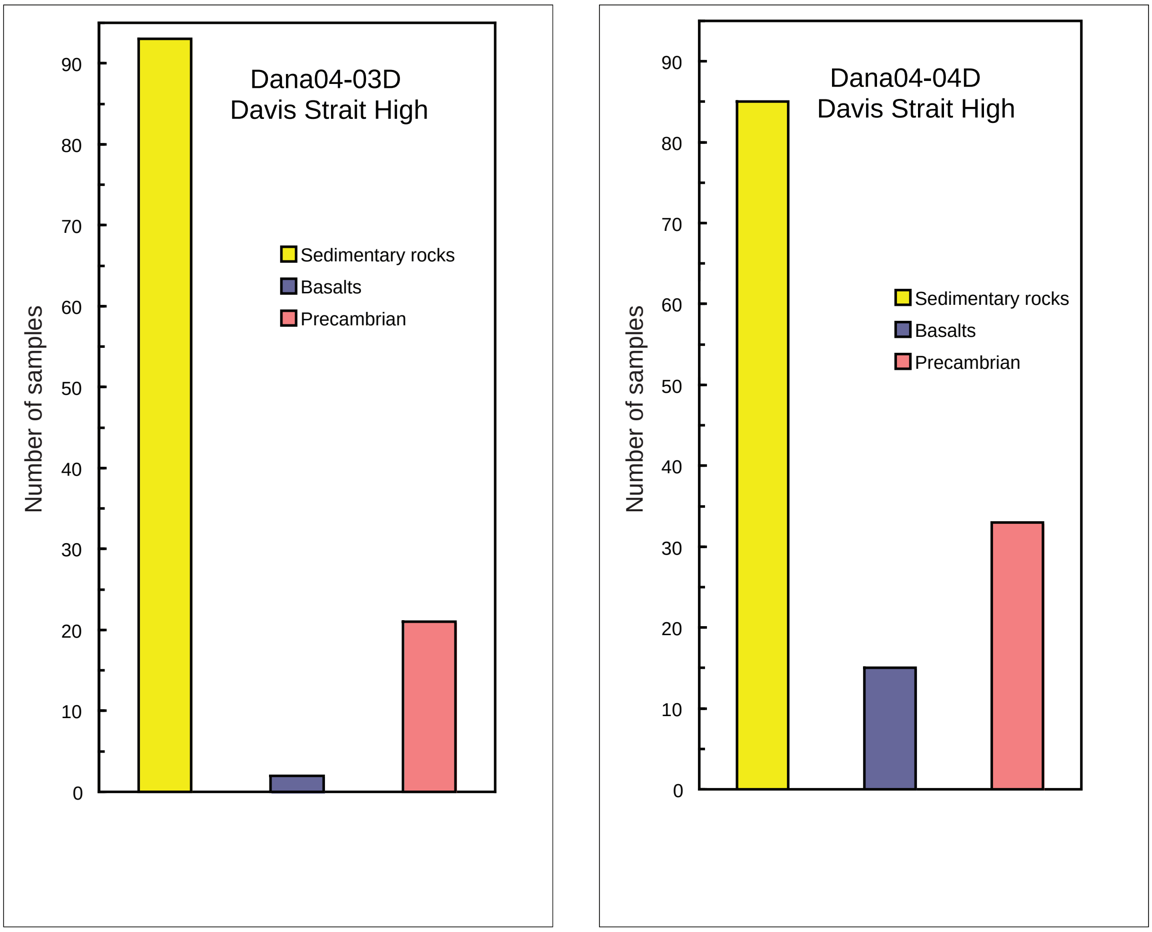



Fig. 5. Histograms showing the composition of the two dredges DANA 04-03D and DANA 04-04D.

dolomite facies are, however, described from the Proterozoic of central East Greenland (Herrington & Fairchild 1989).

## Ordovician carbonates and associated siliciclastics

This assemblage of dredge samples overwhelmingly dominates the sedimentary component of the DANA 04-03D and 04-04D dredges on the eastern flank of the Davis Strait High. Conodont biostratigraphic analysis of a broad selection of these samples indicates a consistent Ordovician age for these rocks (for details, see biostratigraphy above). Facies analysis of both the carbonates and fine-grained carbonate-cemented siliciclastics (inferred to be part of this sedimentary association) illustrates the broad sedimentological affinity of this suite of sediments, suggesting that they are genetically related and reflect different spatial/temporal variants of a common Ordovician carbonate platform setting. The sedimentary dredge samples referred to this category are subdivided into six lithofacies, described and illustrated below.

### Facies 1: Lime mudstone – sparse skeletal wackestone

**Samples**

Samples analysed petrographically in bold, those analysed biostratigraphically underlined.

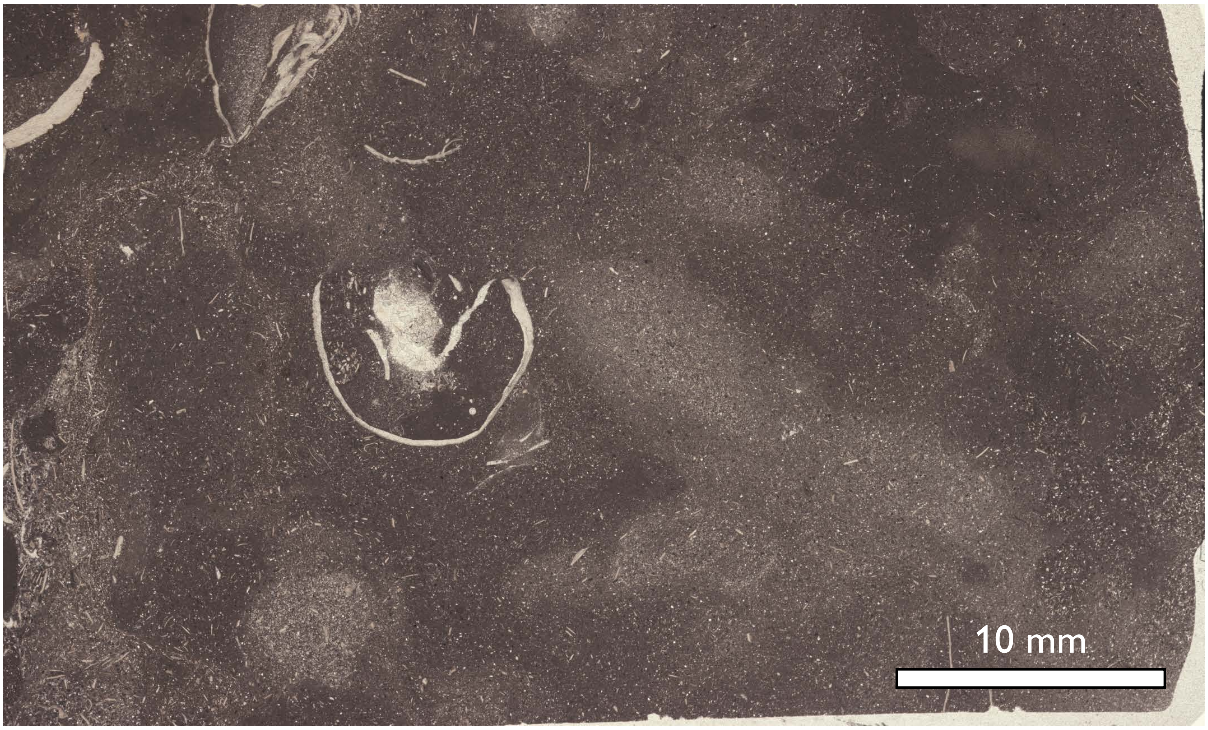
DANA 04-03D: 3, **12**, 15, **16**, 22, 28, 35, **36**, 37, 43, 46, **47**, 49, 52, 53, 54, 65, 66, 85

DANA 04-04D: 2, 3, 4, 6, 7, 8, 9, 11, 12, 13, 14, 17, 18, 19, 20, 21, 28, 30, 32, 33, 34, 35, 36, 37, 41, 43, 52, 53, 54, 60, 62, 64, 65, **66**, 67, 70, 73

**Description**

This facies forms roughly a quarter (26%) of the inferred Ordovician sedimentary suite in the DANA 04-03D dredge but over half (54%) of those in 04-04D. These lime mud-rich sediments commonly have a light grey, fawn or beige weathered crust, sometimes up to 0.5 cm thick, but on fresh surfaces are typically medium to dark brownish-grey in colour. Discontinuous argillaceous flasers and solution seams are common together with a marked nodular, mottled fabric attributed in large part to bioturbation (Fig. 6). Depositional lamination is rare to absent in this facies; silt and very fine sand is common, forming as much as 20% of the rock in some cases. Most of the samples assigned to this facies show signs of dolomitisation, ranging from a few scattered euhedral dolomite rhombs to dolostones with a relict burrow-mottled mudstone/wackestone fabric. Most samples, however, show 10–20% dolomite, typically concentrated along the argillaceous flasers and solution seams.

In thin-section (Fig. 6), the facies displays a lime mud-supported framework with up to 20% skeletal grains and, in some cases, peloids. The chaotic, random orientation of skeletal fragments testifies to ubiquitous bioturbation; small (1–2 mm) spar-filled, sub-circular vugs probably represent *Chondrites* isp. burrows. The skeletal allochems are typically fragmen



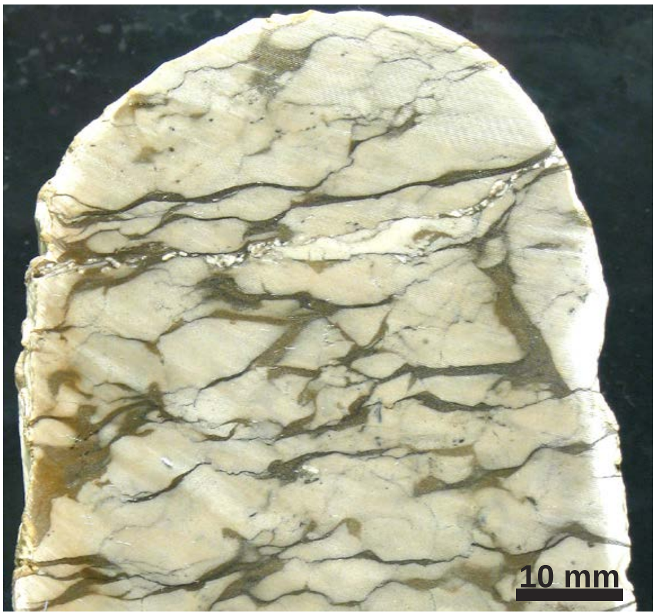




Fig. 6. Facies 1. Polished slab (left) shows the nodular, burrow-mottled character of this facies with dark argillaceous solution seams. Thin-section (above) shows a burrow-mottled skeletal wackestone (DANA 04-04D-45); the coarser skeletal fragments are largely brachiopod.

tary but where identifiable include crinoid, gastropod, brachiopod and trilobite fragments. Also recognised locally are green algae (?*Nuia*) and fenestrate bryozoans. The argillaceous flasers are typically silty and marked by concentrations of dolomite rhombs and stylolites, the latter often delineate the boundary between the solution seams and the more micritic matrix limestone.

**Interpretation**
The lime mud-rich nature and the skeletal content of this facies indicate subtidal deposition on a fully marine carbonate shelf, below normal wave-base in a low-energy setting but probably receiving coarser detritus (skeletal grains, quartz sand/silt) by means of weak storm currents. The ubiquitous bioturbation indicates a well-oxygenated environment with an active infauna. A mid-shelf (or ramp) setting is deemed most likely (Fig. 7).

## Facies 2: Skeletal wackestone – packstone

**Samples**
Samples analysed petrographically in bold, those analysed biostratigraphically underlined.

DANA 04-03D: <u>1</u>, <u>**10**</u>, 29, **30**, <u>31</u>, <u>32</u>, <u>33</u>, **44**, 45, 48, 50, **51**, 65, 69, 70, 71, **72**, 73, **74**, **78**

DANA 04-04D: 27, **31**, 44, **45**, 46, 47, 48, 55, 56, 59, 63, 75

**Description**
This facies forms about a quarter of the carbonate suite in both dredges (27% of DANA 04-03D, 17% of 04-04D); as with facies 1, the weathered surfaces of these lime mud-rich carbonates are commonly pale-coloured but fresh surfaces are mid- to dark grey. Burrow-mottling is also observed in this facies, the burrows often picked out by dolomite, but is not as prominent as in facies 1. Quartz sand and silt is present as a minor component in some samples but in general the siliciclastic content of this facies is low in relation to facies 1.

The lime mud matrix forms up to 80% of the rock but is variable in proportion, also on the scale of an individual thin-section. A heterogeneous distribution of allochems is typical, most likely due to bioturbation; discrete spar-filled *Chondrites* burrows are evident in some thin-sections. Skeletal grains dominate the allochem component (Fig. 8); these are characterised by gastropods, crinoids, brachiopods, trilobites, ostracods and sponge spicules. Also represented in some thin-sections are bryozoans, both fenestrate (trepostome) and encrusting (fistuliporoid) forms, green dasycladacean algae, rare tabulate corals, orthoconic cephalopods and stromatoporoids. Additional allochems (subordinate and only represented in a few samples) are peloids and subrounded micritic intraclasts up to a few mm across. Although micrite (locally microspar) is ubiquitous in this facies, irregular vugs (resembling stromatactis in sample 04-03D-78), shelter structures and skeletal geopetals (in gastropod chambers etc) are occluded by coarse blocky calcite spar cements; no early marine fringing

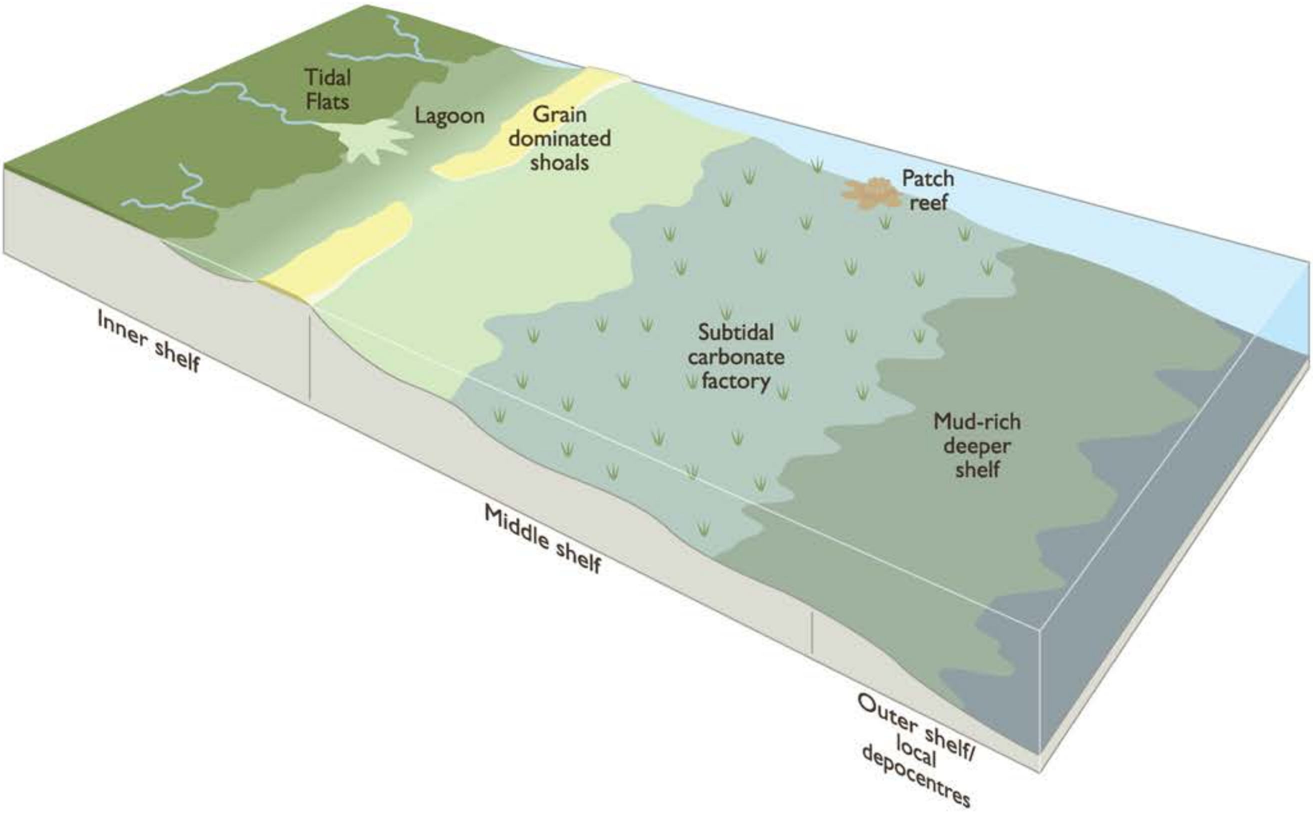



Fig. 7. Schematic block diagram of a carbonate-dominated shelf showing the relationship of the broad facies belts discussed in the text.


Fig. 8. Facies 2. Thin-section (DANA 04-03D-78) showing a dense wackestone to packstone fabric; the skeletal elements are dominated by crinoid, brachiopod and mollusc elements – note fenestrate bryozoan, top right. Spar-filled cavites resemble stromatactis suggesting that this sample may be derived from biohermal carbonates.

cements have been observed. Dolomite in this facies is less common but is prominent in burrow structures in certain samples, and in rare cases the micritic matrix is largely replaced leaving calcite skeletal grains floating in a subhedral dolomite mosaic.

**Interpretation**

The skeletal composition of this facies clearly indicates an open marine shelf, supporting a relatively diverse benthic fauna. The coarse nature of the skeletal elements, in contrast to the more fragmented skeletal detritus in facies 1, suggests that the facies probably represents the heart of the carbonate factory where a diverse benthic (and nektonic) fauna proliferated in well-lit, well-ventilated shallow shelf waters. The presence of lime mud, albeit in varying proportions, indicates deposition below fairweather wave-base although some samples are heterogeneous with skeletal grainstone lenses or beds also represented. In such cases, the environment may have approached fairweather wave-base such that the shelly muds were periodically winnowed during inclement weather.

Although the overall suggestion from this facies is of a soft-bottom subtidal environment, certain samples show features resembling stromatactis (e.g. DANA 04-03D-78) and sample DANA 04-03D-74 shows a succession of encrusting forms (bryozoan encrusting a tabulate coral). Such features may indicate that mounds or patch reefs also developed in this facies belt (see Fig. 7). Such an interpretation can only be hypothetical, based solely on dredge samples and without any evidence of stratal architecture, though it is noteworthy that biohermal features have been described from the Upper Ordovician Foster Bay Formation of the Baffin Island region (Sanford & Grant 2000).

## Facies 3: Grainstone–packstone

**Samples**

Samples analysed petrographically in bold, those analysed biostratigraphically underlined.

DANA 04-03D: <u>2</u>, 5, <u>**6**</u>, <u>19</u>, 26, **27**, 34, **38**, 39, 41, 42, **55**, 58, 67, **75**, **76**, **80**, <u>**81**</u>
DANA 04-04D: <u>51</u>, 57, 58, 61, **68**, 71, 72

**Description**

This facies forms about a quarter (24%) of the Ordovician carbonate suite in dredge DANA 04-03D and about 10% in the DANA 04-04D dredge. Although generally lighter coloured (fawn/brown) than facies 1 and 2, the appearance of these coarse carbonates is largely dependent on the nature of the allochems, the peloid and micritic intraclast grainstones being darker coloured than the skeletal-rich grainstones and packstones. This facies consists of three end-members – peloidal grainstones/packstones, intraclast grainstones and skeletal grainstones/packstones – and a complete spectrum of transitional lithologies.

The peloidal grainstones/packstones commonly contain up to 10% very fine quartz sand and silt and subordinate skeletal grains. The latter may form up to 20% of the allochems and include recognisable crinoid, brachiopod, gastropod and trilobite fragments. In a few samples, however, where skeletal grains make up only a few percent of the allochems, the faunal groups represented are restricted to gastropods and ostracods.

Many of the heterogeneous grainstones/packstones contain micritic intraclasts, but a few samples are intraclast-rich, typically comprising elongate, well-rounded lime mudstone or silty peloidal wackestone/packstone clasts in a skeletal grainstone matrix; the clasts are tabular in form and up to several cm across. Both clast- and matrix-supported intraclast conglomerates are represented. In the sample illustrated in Fig. 9, the clasts show blackened rims. The matrix gainstone resembles that described below in the intraclast-poor skeletal grainstones, i.e. a coarse shell-hash of abraded, micritised skeletal elements, often dominated by robust shell fragments such as crinoid, brachiopod and gastropod grains though fragments of trilobite, ostracod and sponge spicules are also represented.

Skeletal grainstones and packstones assigned to this facies comprise relatively coarse, abraded skeletal fragments showing well-developed micrite envelopes (Fig. 10). Skeletal fragments represented typically include brachiopods, gastropods, crinoids, sponge spicules, ?ostracods and trilobites while laminar stromatoporoids, fenestrate bryozoans and dasycladacean green algae (cf. *Mastapora* sp.) were noted rarely. Superficial ooids occur in one rather atypical sample (DANA 04-03D-55) but in general coated grains are absent or rare from this carbonate suite. The allochems with primary aragonitic mineralogies (e.g. gastropods) are defined by their micrite envelopes and the leached shell is preserved as blocky calcite spar cement. In most cases, shell morphology is faithfully preserved indicating a rigid framework at the time of aragonite dissolution, but deformation and collapse of micrite envelopes due to compaction is noted in a few cases.

Dolomite is present locally in this facies (up to 10% is typical), often concentrated in burrows in some of the peloidal grainstone/packstone samples, and the facies also includes several wholly dolomitised samples that are assigned to the facies on the basis of a relict grainstone fabric.

**Interpretation**

The scarcity of lime mud (except within skeletal cavities, i.e. in gastropod whorls) and the coarse, abraded nature of the allochems indicate deposition in an energetic environment, above normal wave-base. Such a shallow-water setting may have been on shoals or bars, either forming a barrier between the deeper open-marine shelf and a more restricted lagoonal environment (Fig. 7) or close to the shoreline. It is likely that the peloid-dominated subfacies with a restricted gastropod-ostracod skeletal content accumulated in a more restricted setting, perhaps as intra-lagoonal bars, whereas the skeletal subfacies contains a fully marine suite of skeletal components suggestive of a barrier setting. The blackened fine-grained intraclasts in sample 04-03D-76 (Fig. 9) are indicative of derivation of the clasts from the mud-cracked pavements of the supratidal or high intertidal zone.

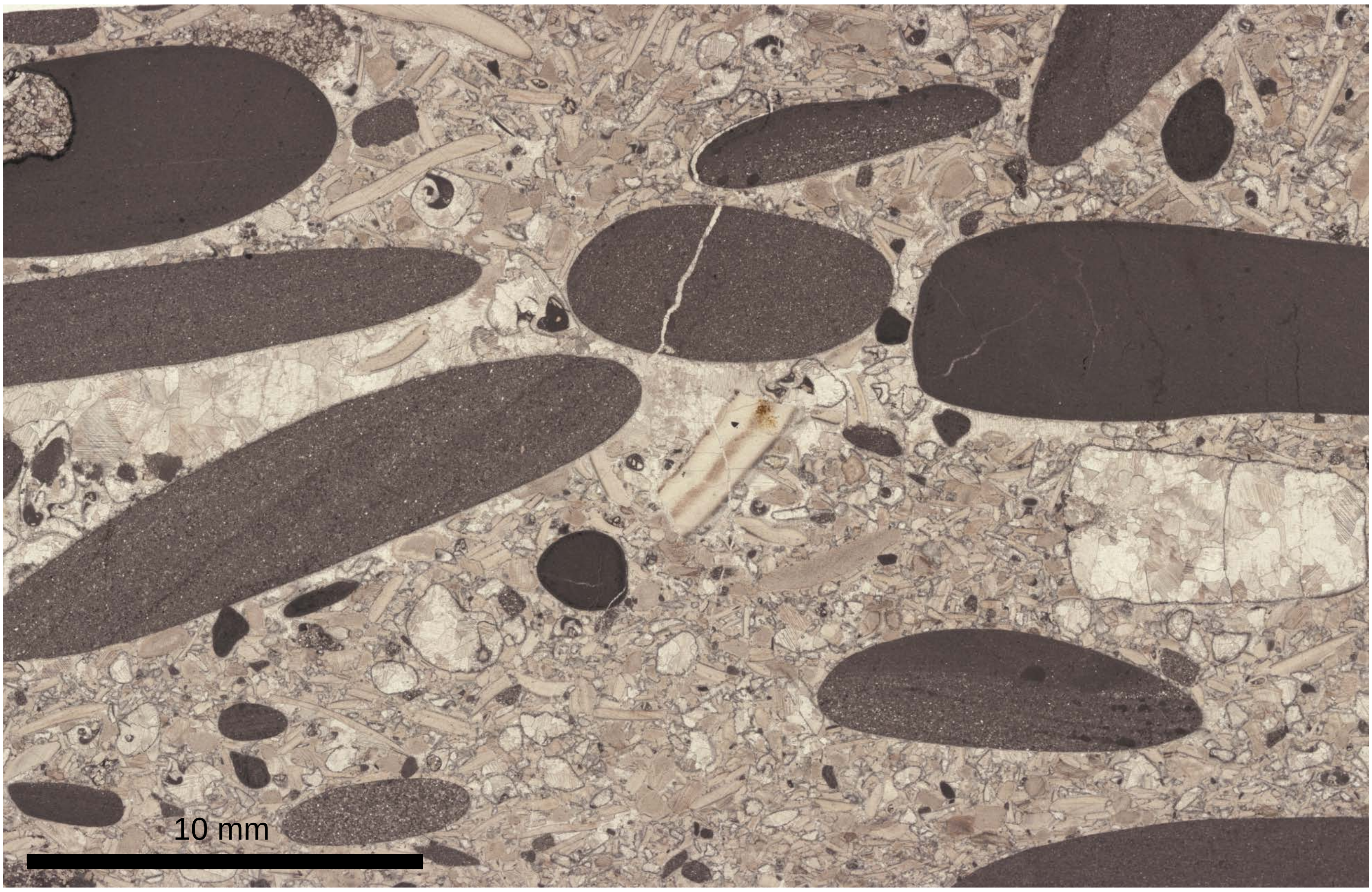



Fig. 9. Facies 3. Thin-section showing rounded tabular micritic intraclasts with blackened margins in a skeletal sand matrix (DANA 04-03D-76).

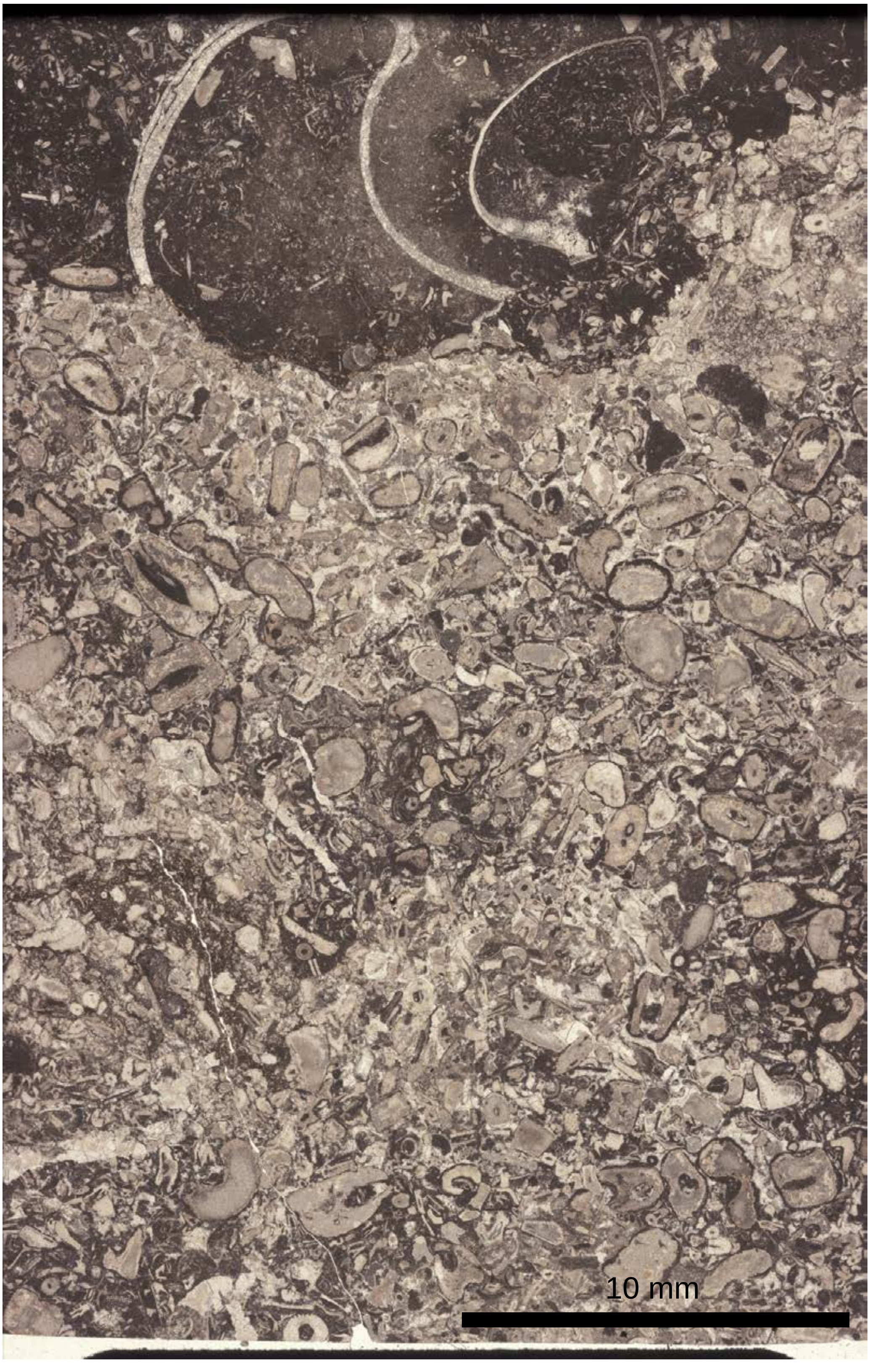



Fig. 10. Facies 3. Thin-section (DANA 04-03D-81) of a skeletal sand (grainstone) showing the abraded nature of the skeletal grains, dominated by crinoids. Most clasts have well-developed micrite envelopes. Lime mud is locally preserved in skeletal chambers, such as the large gastropod in this section.

## Facies 4: Microbialite

### Samples

Samples analysed petrographically in bold, those analysed biostratigraphically underlined.

DANA 04-03D: 13
DANA 04-04D: 5, 16, **49**, 78

### Description

This facies is uncommon, represented by just one sample (1%) of the Ordovician carbonate suite in the DANA 04-03D dredge and four samples (5%) in the 04-04D dredge. It is characterised by samples showing recognisable stromatolitic or oncolitic fabrics; irregular wispy lamination in a number of lime mudstone/wackestone/packstone samples referred to facies 1 and 2 may be of microbial origin but are ambiguous in small samples and are thus not included here. Four of the five samples assigned to this facies from the two dredges show stromatolitic fabrics, and two of these show clear columnar forms (Fig. 11). The remaining sample (DANA 04-04D-49; Fig. 12) displays *c*. 10 mm diameter oncoids in a matrix of skeletal peloidal wackestone–packstone containing gastropod and thin ?ostracod shell fragments. The oncoids show the characteristic irregular concentric cortex; the blue-green algae *Girvanella* sp. occurs in places in the oncoid coatings and bryozoans also locally encrust the oncoid core. More typically, however, the irregular concentric layers consist of fenestral pelleted micrite, locally incorporating fine skeletal detritus.

### Interpretation

This facies forms only a minor proportion of the association of dredge clasts but it is significant in that it documents a rather different depositional setting within a restricted lagoon. The columnar stromatolites probably record a low to moderate energy setting within the lagoon; such microbial structures are commonly considered to record higher energy conditions than the continuous flat and domal mat structures (e.g. Logan *et al.* 1964). The oncolitic sample, with its skeletal-rich matrix, testifies to moderate energy levels resulting in gentle rolling of the accreting microbial ball: the skeletal content of the matrix is an indication of the restricted nature of the lagoon.

## Facies 5: Dolostone

### Samples

Samples analysed petrographically in bold, those analysed biostratigraphically underlined.

DANA 04-03D: 4, **14**, 60, **91**
DANA 04-04D: 10, 22, 23, 24, 26


Fig. 11. Facies 4. Polished slab showing bifurcating columnar stromatolites (DANA 04-04D-78).

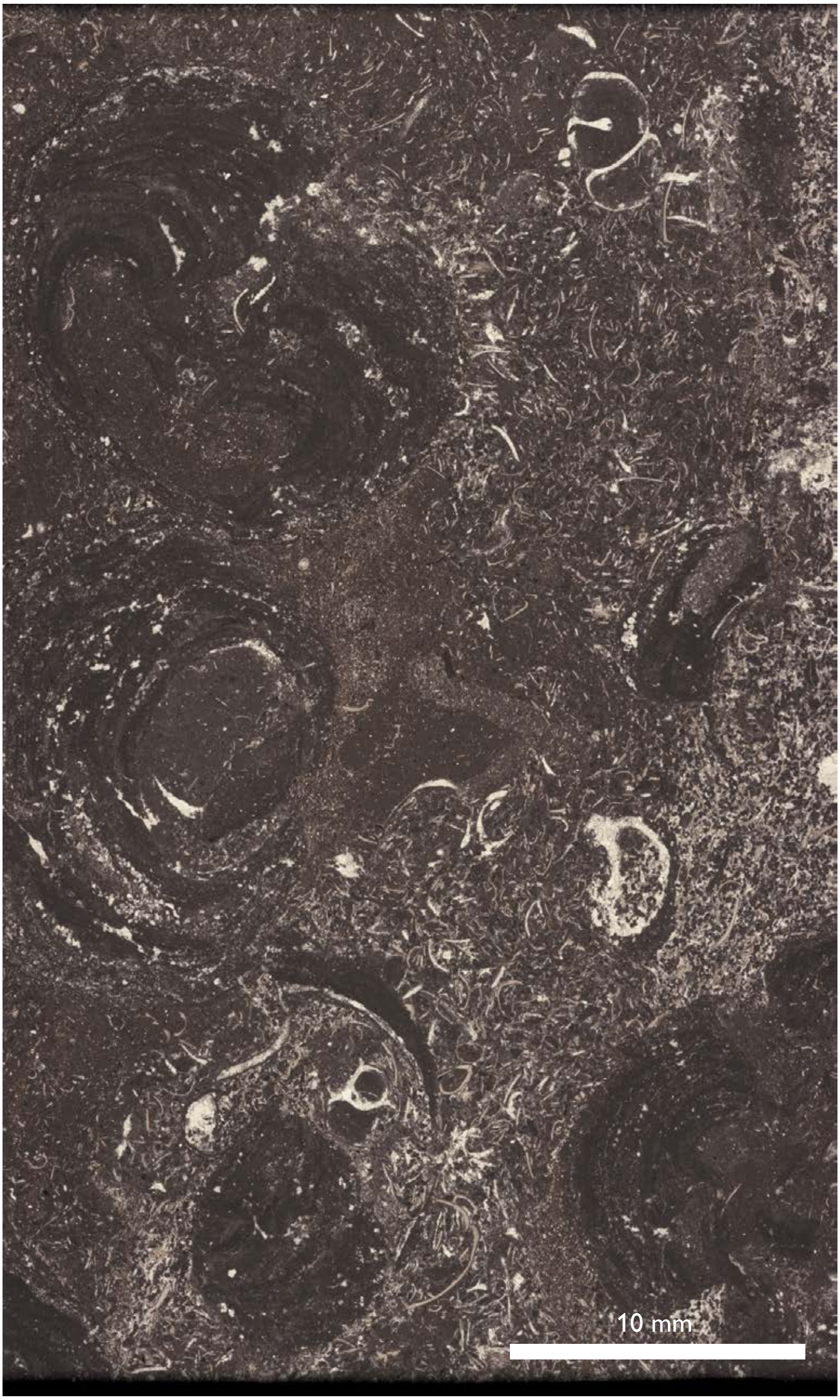



Fig. 12. Facies 4. Oncolitic–skeletal packstone (DANA 04-04D-49). See discussion of this sample in the text.

**Description**
This facies is characterised by pale weathering, medium to coarse crystalline dolostones that display no clear relict features that would permit them to be confidently assigned to facies 1–4. They form a minor proportion of the carbonate suite (5% of 04-03D; 7% of 04-04D). Relict skeletal grains are evident in some samples, and 'ghost' fabrics in some thin sections suggest that much of this group may represent dolomitised grainstone/packstones (i.e. equivalent to facies 4). Some samples contain a scatter of fine sand or silt.

**Interpretation**
The coarse recrystallisation of this facies precludes detailed environmental interpretation. It is likely, however, that the majority of these samples represent wholly dolomitised, recrystallised packstones and grainstones, equivalent to facies 4, and thus accumulated in shallow-water under moderate–high energy conditions.

## Facies 6: Carbonate-cemented sandstone/siltstone

**Samples**
Samples analysed petrographically in bold, those analysed biostratigraphically underlined.

DANA 04-03D: 8, <u>9</u>, <u>18</u>, <u>21</u>, <u>22</u>, <u>23</u>, 24, 40, **59**, 77, 86, 87
DANA 04-04D: 25, 29, 39, 42

**Description**
These pale-coloured fine-grained siliciclastic sediments form a minor proportion of the carbonate suite (16% of 04-03D; 6% of 04-04D). They are included in this suite, and excluded from the coarser-grained, quartz-cemented, glauconitic sandstones (see facies introduction, above), since they often contain carbonate allochems (peloids, skeletal grains) and are characteristically carbonate-cemented. They are considered to form an end-member in a continuous facies spectrum from calcareous sandstones and siltstones to silty/sandy peloidal packstones and grainstones. Indeed, quartz sand, silt and argillaceous laminae are a common feature of all the carbonate facies in this association of dredge clasts and indicate a consistent siliciclastic component to the Ordovician depositional system.

The facies typically consists of well-sorted, very fine sandstones to coarse siltstones, sometimes with silty mudstone flasers. They are commonly micaceous, rarely glauconitic and are calcite- or dolomite-cemented (roughly equal proportions of each). Most samples contain rare carbonate allochems – crinoid ossicles, brachiopod fragments and indeterminate shell material. Parallel to wavy lamination is common and ripple cross-lamination is evident on a number of samples. Although the samples are relatively small, in at least one case asymmetry is evident on a rippled bedding surface indicating a current ripple origin. Bioturbation is observed in a few samples.

**Interpretation**
The presence of carbonate grains in these well-sorted sandstones and siltstones suggests that the facies forms a component of the carbonate-dominated Ordovician shelf, and probably represents sediment derived from the shoreline or from minor deltaic systems bordering the craton (Fig. 7). It is noteworthy, in this respect, that the lowermost sediments in the transgressive Ordovician succession onlapping the Precambrian basement in the Foxe and Ungava basins of the Baffin Island region are siliciclastic in nature (see discussion below).

Depositional processes are difficult to interpret on the basis of such small samples, but they may represent storm sands, derived from the shoreface and dispersed seawards thus incorporating offshore carbonate sediment.

# Discussion and Conclusions

## *In situ* or ice-transported material?

As discussed by Larsen & Dalhoff (2006), a critical question in the interpretation of these dredge rock samples is the degree to which they are representative of in situ (albeit degraded) outcrop. In this particular geographic location, close to the actively draining Greenland icecap, it is of course highly possible that loose sea-bed detritus may be ice-transported, either in recent times as IRD or as relict Pleistocene sediment as the direct consequence of glaciers or ice-shelves extending from Canadian or Greenland ice-caps during the last glacial maximum. Larsen & Dalhoff (2006) listed the following lines of evidence: lithology of sample populations; sample size, shape and condition (i.e. degree of abrasion); occurrence of lithologies not present in potential source onshore areas; petrography, chemical composition and age of igneous rocks.

As indicated in Fig. 13, the present iceberg drift pattern demonstrates two major sources of icebergs and two potential routes for IRD to be transported to the Davis Strait region. Central to North-East Greenland is a prominent ice-calving area and ice drifts south down the east coast with a minor proportion continuing north along the south-west coast. Based on modern observations, it is unlikely that such ice-rafting would impact on the Davis Strait High, although some workers have suggested that ice-rafting from this source may have extended farther north up the West Greenland coast in earlier times ( Linthout *et al*. 2000; Belan *et al*. 2004). With respect particularly to the Ordovician sample assemblage documented here from the Davis Strait High, ice-rafting from North-East or East Greenland is not considered a feasible explanation. Although the facies spectrum described here may well be replicated to large degree in Lower Palaeozoic strata of North-East and East Greenland, the biostratigraphic results do not support such an origin. Upper Ordovician strata are absent in this region, at present exposure levels at least, making this an unlikely source for the rich haul of Upper Ordovician dredge samples on the Davis Strait High.

The second major source of ice today is the central West Greenland region – ice initially drifts west and north before catching the southward bound Baffin Bay current following the east coast of Canada (Fig. 13). West Greenland is not a potential source of Lower Palaeozoic rocks (disregarding the isolated fault breccia at Fossilik, see under biostratigraphy, above), the nearest outcrops in Greenland being the Franklinian Basin exposed in Inglefield Land and Washington Land, in North-West and western North Greenland. As indicated on Fig. 13, there is a secondary ice drift route through Smith Sound to Baffin Bay that potentially could raft debris from the Franklinian Basin southwards. The Lower Palaeozoic is fully developed in the western Franklinian Basin, however, and glacial debris from this region would most likely include Cambrian and Silurian detritus, in addition to Ordovician clasts. Probably of more significance, then, are the Lower Palaeozoic outcrops of the Lancaster Sound and Baffin Island region. As discussed previously and below, the stratigraphic similarity between the Ordovician dredge assemblage from the Davis Strait High and the succession in the south Baffin Island region is striking. Although there is no significant ice

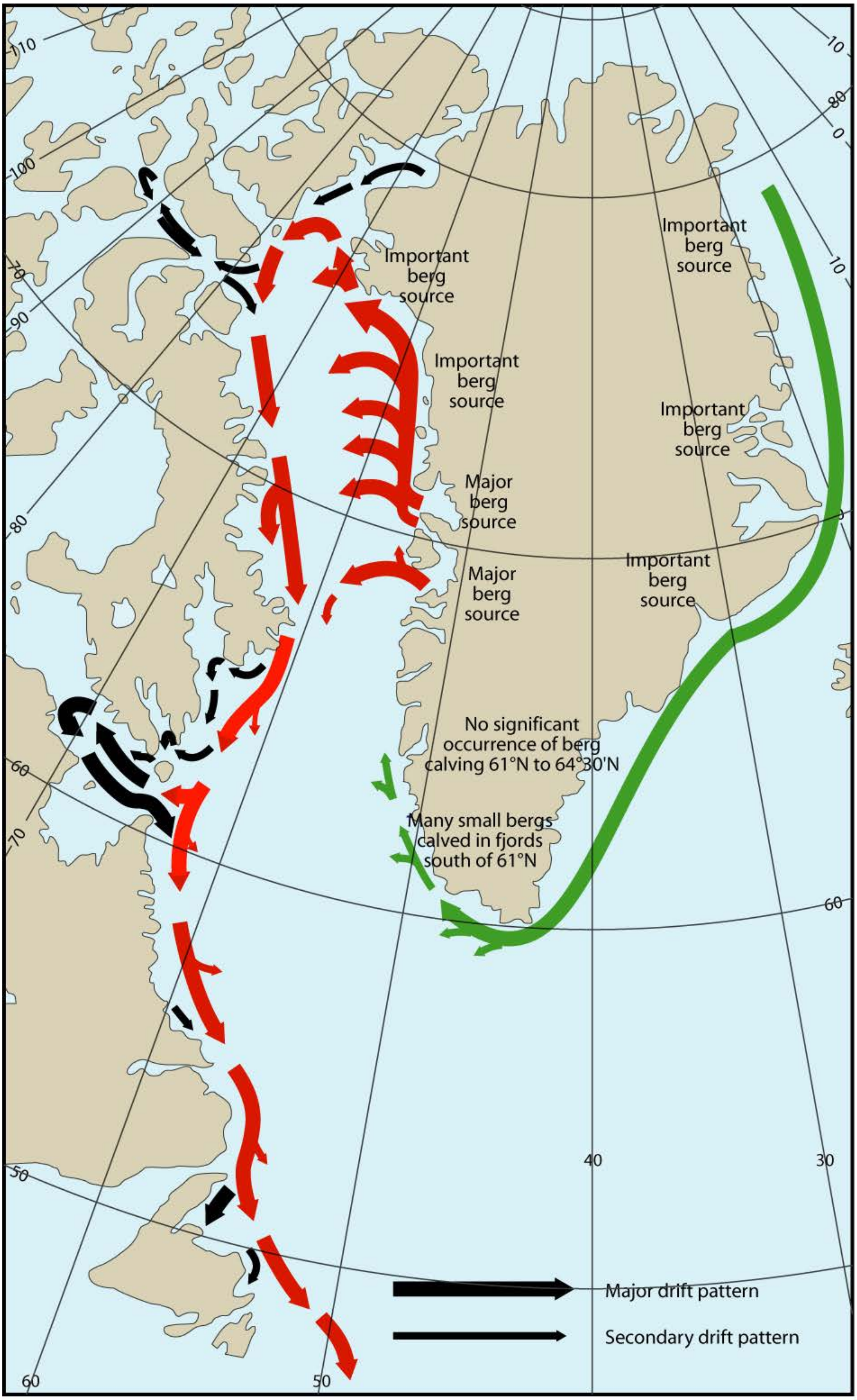



Fig. 13. Iceberg drift pattern around Greenland. From Larsen & Dalhoff (2006), after Ghexis 23, 2004.

transport from this region into the Davis Strait at present, it cannot be excluded that ice sheets (or glaciers) extended eastwards towards the Davis Strait High during the last glacial maximum, thus potentially delivering Ordovician debris from outcropping strata in the adjacent Canadian Arctic. Given, however, the dominant outcrop of Precambrian basement in the Baffin Island region, it might be expected that glacially-derived Ordovician from this source would be significantly diluted by basement clasts.

It is important, in this context, to stress the overwhelming dominance of the Ordovician sedimentary suite in all the dredges from the eastern flank of the Davis Strait High, spanning a distance of over 100 km from 66° 36.4 N south to 66° 08.3 N. Furthermore, the relative proportions of the individual facies are comparable from dredge to dredge, fine-grained slightly argillaceous burrow-mottled lime mudstones and wackestones being ubiquitous and characteristic of all dredge suites studied to date. In addition, the samples are often abraded and commonly show a thick weathered crust but direct evidence of glacial scouring has not been observed. Sample size ranges from 40–50 cm blocks to pebble-sized clasts.

Lithological comparison of the Ordovician suite from the Davis Strait High dredges with the south Baffin Island succession (see also below) reveals broad similarities in facies development, but some differences are also recognised. Firstly, coarse skeletal and intraclastic grainstones are apparently scarce in the outcrop while forming an important component of the dredge samples, and secondly dolomite is a common feature of the Davis Strait High samples yet is reported sparingly from the easternmost sub-basin (Ungava Basin) of the south Baffin Island region (Sanford & Grant 2000). Confirmation of these apparent differences would require more detailed descriptions of the outcrop sections.

It is concluded therefore that the abundance, uniformity and size distribution of the carbonate suite in a series of dredges (see discussion in McMillan 1973; Johnson *et al*. 1975) argues against a long-distance ice-transport origin and suggests that this suite is representative of, and derived from, outcropping Ordovician strata on the eastern flank of the Davis Strait High. The similarities in both stratigraphic and lithological development of the dredged carbonate suite and the Ordovician succession in the south Baffin Island region are considered to reflect a comparable palaeogeographic setting and thus depositional evolution during the Ordovician (see further discussion, below). Larsen & Dalhoff (2006), in a study of the volcanic component of the dredge samples from the Davis Strait High, reached similar conclusions, viz. that the volcanic samples reflect a local volcanic bedrock on the Davis Strait High; this conclusion was supported by geochemical data from the volcanics that indicated a geochemical signature that is not replicated in the volcanic record of eastern Canada and West Greenland.

## Correlation

As discussed above, it is interpreted that the dredged Ordovician carbonate suite is essentially *in situ*, representing weathered fragments of strata outcropping on the eastern flank of the Davis Strait High. It is interesting, therefore to briefly review the known record of Ordovician strata in the region and to compare the inferred stratigraphic and facies development of the dredged carbonate suite to these occurrences.

Ordovician strata in West Greenland are restricted to limestone blocks, yielding late Early Ordovician, late Middle Ordovician and Late Ordovician conodont faunas, within a fault-zone breccia dissecting Precambrian basement gneisses near Sukkertoppen, south-west Greenland (Stouge & Peel 1979; Smith 1988; Smith & Bjerreskov 1994). Ordovician dolomites and limestones have also been recorded in boreholes in the Hopedale Basin of the southern Labrador shelf (Bell 1989). In the southernmost of six wells in this region, the Middle–Upper Ordovician is over 400 m thick, of which c. 270 m of the section is siliciclastic. Where penetrated, the Ordovician succession rests directly on Precambrian basement. The similarity of this Ordovician stratigraphic development on the Labrador shelf to that of the Baffin Island region is clear (see below).

Ordovician strata are best known in this region from the Foxe Basin and Ungava Bay – Hudson Strait area, immediately south of Baffin Island. The Ordovician succession is known both from outcrop around the Foxe Basin and from subsurface data in the Hudson Strait and offshore SE Baffin Island (MacLean *et al*. 1977; Bell & Howie 1990; Sanford & Grant 2000). Figure 14 summarizes the lithostratigraphy of the most complete section in this area – that from the Ungava Basin immediately south of southernmost Baffin Island and approximately 1000 km from the Davis Strait High.

The basal formation (Ungava Bay Formation, *c*. 180 m thick) overlies Precambrian basement and is dominantly siliciclastic, comprising poorly consolidated fine- to medium-grained sandstones and silty sandstones. This unit is of early Middle Ordovician age and is succeeded by the upper Middle Ordovician Frobisher Bay Formation, a thin (25 m) succession of calcareous shales and argillaceous micritic limestones that is bounded above and below by hiatal surfaces (see Fig. 4). The succeeding uniform succession of argillaceous lime mud-rich burrowed limestones of Upper Ordovician age is over 300 m thick and is subdivided into four formations (Fig. 14). The thin (*c*. 5m in the Ungava Basin) Boas River Formation is of particular note as it is considered to show source rock potential (Sanford & Grant 2000). The nature and full stratigraphic development of the uppermost formation, the Foster Bay Formation, is less well known since this caps the exposure window in this area. The presence of mounds in this formation, however, is noteworthy (Sanford & Grant 2000).

As noted above in discussion of the biostratigraphy of the dredged carbonate suite from the Davis Strait High, the stratigraphic development of the southern Baffin Island succession is remarkably similar to that inferred for the Davis Strait High. The conodont data clearly demonstrate that precisely those stratigraphic intervals preserved from the Canadian sections can also be recognised in the Davis Strait High data. The hiati identified in the Canadian succession are also suggested by the Davis Strait High data (see Fig. 4). In terms of facies development, detailed comparison is precluded by the lack of published petrographic information concerning facies development in the Baffin Island succession. Based on the published field descriptions in Sanford & Grant (2000), however, the argillaceous burrow-mottled lime mud-rich facies of low energy subtidal aspect is a common and dominant feature of both datasets. Less clear from the Baffin Island succession is the presence of higher energy facies, such as coarse skeletal and intraclastic grainstones, which form an impor

## South Baffin Island (Ungava Basin): Ordovician Lithostratigraphy

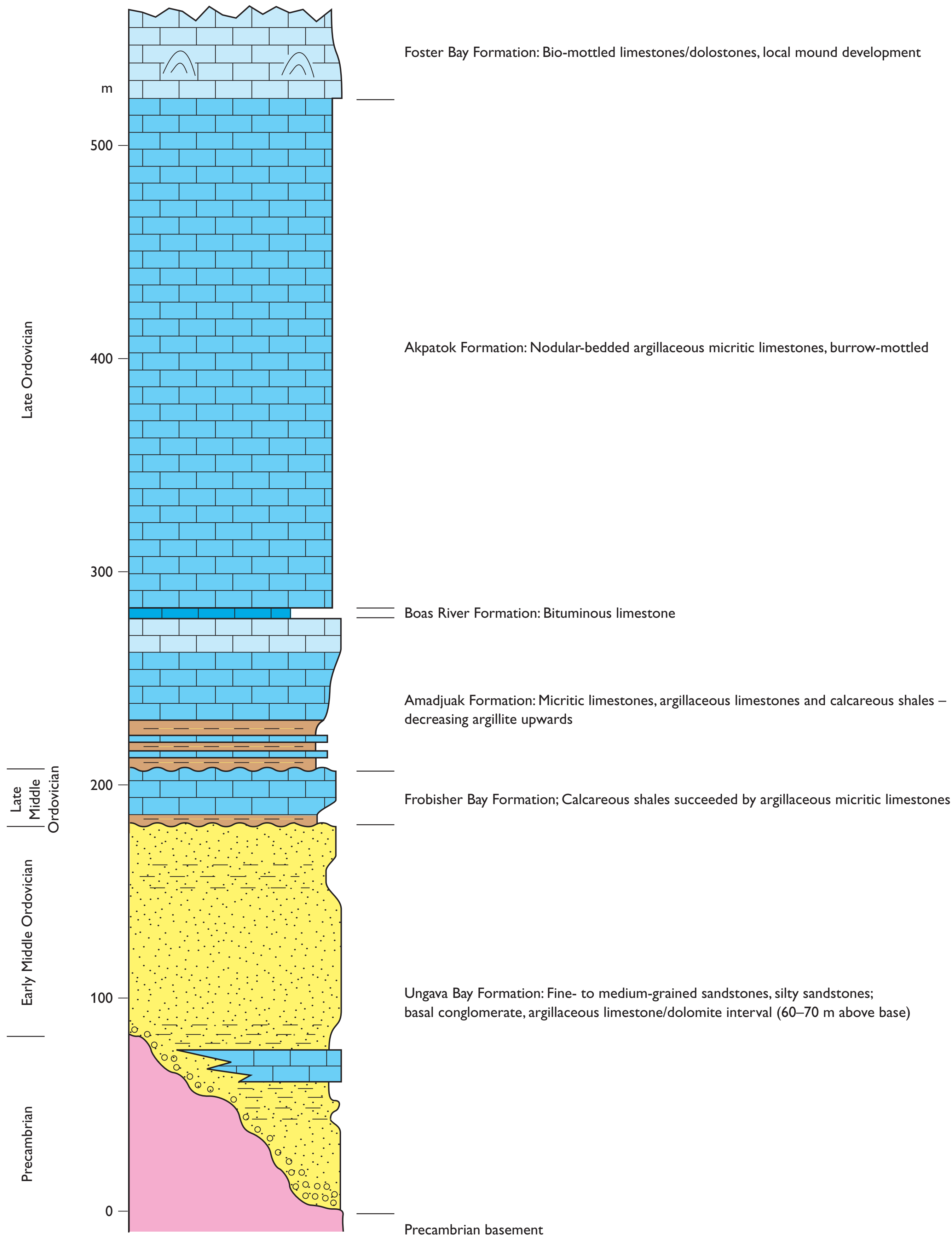



Fig. 14. Schematic log showing the stratigraphic and broad lithological development of the Ordovician succession of the Ungava Basin, south of Baffin Island, based on outcrop and subsurface data. Compiled from Sanford & Grant (2000).

tant subordinate facies in the dredge samples from the Davis Strait High. As noted earlier, dolomite is not commonly reported from the Ungava Basin, in contrast to the Davis Strait High samples.

On the basis of loose material dredged from the surface of the Davis Strait High, it is clearly impossible to reconstruct in detail the depositional evolution of the inferred Ordovician succession. The environmental facies cartoon in Fig. 7 is purely an aid to visualise the probable depositional settings of the various facies. Combining the biostratigraphic data with the facies observations, however, it is recognised that the Lower and Middle Ordovician samples include several dolostone samples whereas the Upper Ordovician samples are a uniform suite of bioturbated lime mudstones, skeletal wackestones and packstones. Furthermore, the conodont assemblages from the older samples are suggestive of more restricted and stressed conditions, compatible with the increased proportion of dolomite in these samples. The suggestion, therefore, is that an evolutionary trend is recorded in these dated dredge samples from an initial late Early to Middle Ordovician period, characterised by restricted, shallow-water deposition interrupted by periods of exposure and non-deposition, to a uniformly subsiding open marine subtidal shelf in the Late Ordovician.

# References


Aldridge, R.J. 1982: A fused cluster of conoform conodont elements from the late Ordovician of Washington Land, Western North Greenland. Palaeontology **25**, 325–430.

Armstrong, H.A. 1990: Conodonts from the Upper Ordovician – Lower Silurian carbonate platform of North Greenland. Grønlands Geologiske Undersøgelse Bulletin **159**, 151 pp.

Barnes, C.R. 1974: Ordovician conodont biostratigraphy of the Canadian Arctic. In: Aitken, J.D. & Glass, D.J. (eds.): Geology of the Canadian Arctic. Geological Association of Canada – Canadian Society of Petroleum Geologists Special Volume, 221–240.

Barnes, C.R. 1977: Ordovician conodonts from Ship Point and Bad Cache Rapids Formations, Melville Peninsula, southeastern district of Franklin. Geological Survey of Canada Bulletin **269**, 99–119.

Bauer, J.A. 1989: Conodont biostratigraphy and paleoecology of Middle Ordovician rocks in eastern Oklahoma. Journal of Paleontology **63**, 92–107.

Belan, A,B., Abbuehl, L. & Kuijpers, A. 2004: Relict iceberg ploughmarks on the western Greenland margin. In: North Atlantic and Labrador Sea margin architecture and sedimentary processes. Intergovernmental Oceanographic Commission Workshop Report **191**, 9–11.

Bell, J.S. (Co-ordinator) 1989: East Coast Basin Atlas Series Labrador Sea. Geological Survey of Canada, 112 pp.

Bell, J.S. & Howie, R.D. 1990: Paleozoic geology. In: Keen, M.J. & Williams, G.L. (eds): Geology of the continental margin of eastern Canada. Geology of North America **I-1**, 143–165. Geological Society of America. (Also Geology of Canada 2, 143–165. Geological Survey of Canada).

Bolton, T.E. 1977: Ordovician megafauna, Melville Peninsula, southeastern District of Franklin. Geological Survey of Canada Bulletin **269**, 23–75.

Bolton, T.E. 2000: Ordovician megafauna, southern Baffin Island, Nunavut. Geological Survey of Canada Bulletin **557**, 39–158.

Branson, E.B. & Mehl, M.G. 1933: Conodont studies. University of Missouri Studies **8**, 349 pp.

Chalmers, J.A. & Pulvertaft, T.C.R. 2001: Development of the continental margins of the Labrador Sea: a review. In: Wilson, R.C.L. *et al*. (eds): Non-volcanic rifting of continental margins: a comparison of evidence from land and sea. Special Publication, Geological Society, London **187**, 77–105.

Dalhoff, F. & Kuijpers, A. 2007: Togtrapport. Havbundsprøveindsamling ud fra Vestgrønland 2006. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2007/4**, 51 pp.

Dalhoff, F. & Larsen, L.M. 2007: Preliminary investigation of samples dredged from offshore West Greenland in 2006. GEUS-notat nr. 08-EN-07-06, 14 pp.

Dalhoff, F., Nielsen, T., Kuijpers, A. & Poulsen, N.E. 2003: Togtrapport, havbundsprøveindsamling offshore Vestgrønland 2003. GEUS-notat nr. 08-EN-03-10, 9 pp + appendices.

Dalhoff, F., Kuijpers, A., Nielsen, T., Lassen, S., Boserup, J., Hansen, E. & the crew on H/F DANA 2004: Togtrapport. Havbundsprøveindsamling ud fra Vestgrønland. H/F DANA 17/09/–04/10 2004. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2005/1**, 44 pp.

Dawes, P.R. 1997: The Proterozoic Thule Supergroup, Greenland and Canada: history, lithostratigraphy and development. Geology of Greenland Survey Bulletin **174**, 150 pp.

Epstein, A.G., Epstein, J.B. & Harris, L.B. 1977: Conodont color alteration, an index to organic metamorphism. U.S. Geological Survey, Professional Paper **995**, 27 pp.

Ethington, R.E. & Clark, D.L. 1971: Lower Ordovician conodonts of North America. The Geological Society of America, Memoir **127**, 63–82.

Ethington, R.L. & Clark, D.L. 1982: Lower and Middle Ordovician conodonts from the Ibex area, western Millard County, Utah, Brigham Young University Geology Studies 28, 160 pp.

Ethington, R.L., Droste, J.B, & Rexroad, C.B. 1986: Conodonts from subsurface Champlainian (Ordovician) rocks of eastern Indiana. State of Indiana, Department of Natural Resources, Geological Survey Special Report 37, 32 pp.

Herrington,P.M. & Fairchild, I.J. 1989; Carbonate shelf and slope facies evolution prior to Vendian glaciation, central East Greenland. In: Gayor, R.A. (ed.): The Caledonide geology of Scandinavia, 263–273. London: Graham & Trotman Ltd.

Ineson, J.R., Peel, J.S. & Smith, M.P. 1986: The Sjaelland Fjelde Formation: a new Ordovician formation from eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **132**, 27–37.

Johnson, G.L., McMillan, N.J., Rasmussen, M., Campsie, J. & Dittmer, F. 1975: Sedimentary rocks dredged from the southwest Greenland continental margin. Canadian Society of Petroleum Geologists Memoir **4**, 391–409.

Keen, C.E. & Barrett, D.L. 1972: Seismic refraction studies in Baffin Bay: an example of a developing ocean basin. Geophysical Journal of the Royal Astronomical Society **30**, 253–271.

Keen, C.E., Keen, M.J., Ross, D.I. & Lack, M. 1974: Baffin Bay: a small ocean basin formed by sea-floor spreading. Bulletin of the American Association of Petroleum Geologists **58**, 1089–1108.

Larsen, L.M. & Dalhoff, F. 2006: Composition, age, and geological and geotectonic significance of igneous rocks dredged from the northern Labrador Sea and the Davis Strait. Danmarks og Grønlands Geologiske Undersøgelse Rapport **2006/43**, 67 pp.

Linthout, K., Troelstra, S.R. & Kuijpers, A. 2000: Provenance of coarse ice-rafted detritus near the SE Greenland margin. Geologie en Mijnbouw **79**, 109–121.

Logan, B.W., Rezak, R. & Ginsburg, R.N. 1964: Classification and environmental significance of algal stromatolites. Journal of Geology **72**, 68–83.

MacLean, B., Jansa, L.F., Falconer, R.K.H. & Srivastava, S.P. 1977: Ordovician strata on the southeastern Baffin Island shelf revealed by shallow drilling. Canadian Journal of Earth Sciences **14**, 1925–1939.

McCracken, A.D. 2000: Middle and Late Ordovician conodonts from the Foxe lowland of southern Baffin Island, Nunavut. Geological Survey of Canada Bulletin **557**, 159–215.

McMillan, N.J. 1973: Surficial geology of Labrador and Baffin Island shelves. Geological Survey of Canada Paper **71-23**, 451–470.

Peel, J.S. & Smith, M.P. 1988: The Wandel Valley Formation (Early–Middle Ordovician) of North Greenland and its correlatives. Rapport Grønlands Geologiske Undersøgelse 137, 61–92.

Sanford, B.V. & Grant, A.C. 2000: Geological framework of the Ordovician System in the southeast Arctic Platform, Nunavut. In: McCracken, A.D. & Bolton, T.E. (eds): Geology and paleontology of the southeast Arctic Platform and southern Baffin Island, Nunavut. Geological Survey of Canada Bulletin **557**, 13–38.

Smith, M.P. 1988: Conodonts from the Archaean craton of West Greenland – implications for Ordovician eustasy. Geological Society of America. Abstracts and Programme **20**, 389 only.

Smith, M.P. & Bjerreskov, M. 1994: The Ordovician System in Greenland. Correlation chart and stratigraphic lexicon. International Union of Geological Sciences Special Publication **29A**, 46 pp.

Smith, M.P. & Peel, J.S. 1986: The age of the Danmarks Fjord Member, eastern North Greenland. Rapport Grønlands Geologiske Undersøgelse **132**, 7–13

Srivastava, S.P., Maclean, B., Macnab, R.F. & Jackson, H.R. 1982: Davis Strait: structure and evolution as obtained from a systematic geophysical survey. In: Embry, A.F. & Balkwill, H.R. (eds): Arctic Geology and Geophysics. Canadian Society of Petroleum Geologists Memoir **8**, 267–278.

Stouge, S., 1984: Conodonts of the Table Head Formation, western Newfoundland. Fossils and Strata **16**, 145 pp.

Stouge, S. & Peel, J.S. 1979: Ordovician conodonts from the Precambrian Shield of southern West Greenland. Rapport Grønlands Geologiske Undersøgelse **91**, 105–109.

Stouge, S. Bagnoli, G. & Albani, R. 1985: Lower Ordovician conodonts from Washington Land, western North Greenland. Bulletin of the Geological Society of Denmark **33**, 261–272.

Sweet, W.C. 1984: Graphic correlation of upper Middle and Upper Ordovician rocks, North American Midcontinent Province, U.S.A. In Bruton, D.L. (ed.): Aspects of the Ordovician System, 23–35. Palaeontological Contributions from the University of Oslo **295**. Oslo: Universitetsforlaget,.

Sweet, W.C. 1988: The Conodonta. Morphology, taxonomy, paleoecology, and evolutionary history of a long-extinct animal phylum. Oxford: Oxford Monographs on Geology and Geophysics 10,0 212 pp.

Swett, K., Klein, G. de Vries & Smit, D.E. 1971: A Cambrian tidal sand body – the Eriboll Sandstone of Northwest Scotland: an ancient–recent analog. Journal of Geology **79**, 322–346.

Webby, B.D., Cooper, R.A., Bergström, S.M. & Paris, F. 2004: Stratigraphic framework and time slices. In: Webby, B.D., Paris, F., Droser, M.L. & Percival, I. (eds): The great Ordovician biodiversification event, 41–47. New York: Columbia University Press.

Workum, R.H., Bolton, T.E. & Barnes, C.R. 1976: Ordovician geology of Akpatok Island, Ungava Bay, District of Franklin. Canadian Journal of Earth Sciences **13**, 157–178.

# Plates

Plate 1: Macrofossils and depositional fabrics

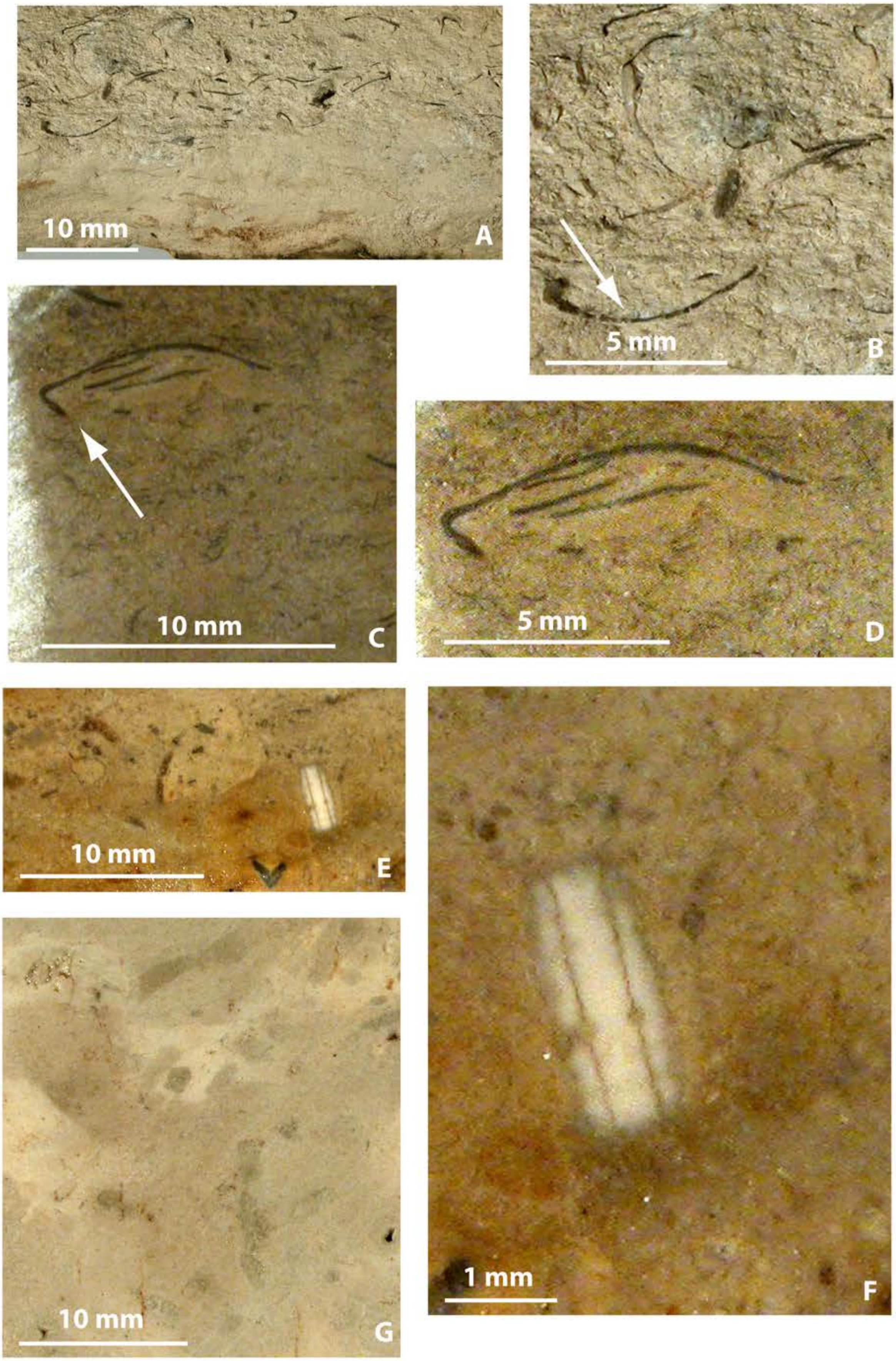



Fig. A. Sample DANA 04-04D-31. Limestone with horizontally oriented fossil shells, mainly brachiopods and probable ostracods. Naturally weathered surface.
Fig. B. Sample DANA 04-04D-31. Arrow indicates orthid(?) brachiopod.
Figs C–D. Sample DANA 04-04D-31. Arrow indicates a probable trilobite pygidium. Polished surface.
Figs E-F. Sample DANA 04-04D-71. Calcareous packstone with crinoid and indeterminate shell fragments.
Fig. G. Sample DANA 04-04D-17. Strongly burrowed dolostone.

## Plate 2: Representative microfossils

**A**. *Ulrichodina abnormalis* (Branson & Mehl), Late Early to early Middle Ordovician. GEUS sample DANA 04-03D-19. Scale-bar = 500 µm.

**B**. *Eucharodus parallelus* (Branson & Mehl), Late Early to early Middle Ordovician. GEUS sample DANA 04-03D-19. Scale-bar = 500 µm.

**C.** *Curtognathus typus* Branson & Mehl, Late Middle Ordovician, Assemblage MO1. GEUS sample DANA 04-03D-2. Scale-bar = 200 µm.

**D.** *Oulodus robustus* (Branson, Mehl & Branson), Upper Ordovician, Assemblage UO2. GEUS sample DANA 04-03D-32. Scale-bar = 400 µm.

**E.** *Oulodus robustus* (Branson, Mehl & Branson), Upper Ordovician Assemblage UO2. GEUS sample DANA 04-03D-81. Scale-bar = 400 µm.

**F**. *Plectodina tenuis* s.l. (Branson & Mehl), P-element, Upper Ordovician Assemblage UO1. GEUS sample DANA 04-04D-51. Scale-bar = 400 µm.

**G**. *Plectodina tenuis* s.l. (Branson & Mehl), P-element. Upper Ordovician Assemblage UO1. GEUS sample DANA 04-04D-05. Scale-bar = 400 µm.

**H**. *Plectodina tenuis* s.l. (Branson & Mehl), S-element. Upper Ordovician Assemblage UO1. GEUS sample DANA 04-04D-05. Scale-bar = 400 µm.

**I**. *Protopanderodus liripus* Kennedy *et al*., Upper Ordovician, AssemblageUO1. GEUS sample DANA 04-03D-1. Scale-bar = 400 µm.

**J**. *Ansella nevadensis* (Ethington & Schumacher), Middle Ordovician. Assemblage M02. GEUS sample DANA 04-03D-37. Scale-bar = 200 µm.

**K**. *Panderodus gracilis* (Branson & Mehl), Upper Ordovician. Assemblage UO2. GEUS sample DANA 04-03D-33. Scale-bar = 100 µm.

**L–N**. *Panderodus* spp.,Upper Ordovician Assemblage UO1. GEUS sample DANA 04-03D-5. Scale-bar: L, M = 100 µm; N = 200 µm.

**O**. *Oneotodus* sp. A. Upper Ordovician. Assemblage UO2. GEUS sample DANA04-03D-32. Asymmetrical specimen. Scale-bar is 300 µm.

**P, Q**. Sponge spicules. **P**. Lithistitid demosponge. Upper Ordovician. Assemblage UO1. GEUS sample DANA 04-04D-05. Scale bar is 300 µm. **Q**. Acanthohexact. Middle Ordovician. Assemblage MO2. GEUS sample 04-03D-37. Scale-bar is 200 µm.

**R–T**. Chitinozoans. **R**. Unidentified form. Middle Ordovician. MO2. GEUS sample DANA 04-03D-37. Scale bar is 200 µm. **S**. Unidentified form. Middle Ordovician. Assemblage MO2. GEUS sample DANA04-03D-37. Scale-bar is 50µm. **T**. Unidentified form. Upper(?) Ordovician. GEUS sample DANA 04-04D-43.

Plate 2: Representative microfossils