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Foraminifera and Ostracoda in the St Andrew's Bay Member (Forth Formation; Holocene), offshore Montrose

Internal Report IR/07/014

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Foraminifera and Ostracoda in the St Andrew's Bay Member (Forth Formation; Holocene), offshore Montrose

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Cover picture

Ammonia beccarii a foraminifer from the Holocene of Borehole 56-03/587, depth 1.05m

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Summary

The St Andrew's Bay Member from three localities off eastern Scotland were examined: two vibrocores 56-03/586 and 56-03/587 and borehole 74/15. Microfaunal results are tabulated in figures 1-6. From an ecostratigraphical point of view, and taking into account the radiocarbon dates obtained, the cold water fauans of parasequence 2 are placed into the Younger Dryas interstadial. The low Boreal to Lusitanian faunas of parasequence 3 are placed in the climatic ameliaration immediately following the interstadial. By comparison with the Lusitanian to low boreal faunas in Geordie Trough, parasequence 4 is postulated to have been deposited 4000-7000 years ago, although the highest part contains faunas comparable with the assemblages dated to 1158 years BP and younger, not very different from the radiocarbon date of 1782 years BP for the base of parasequence 4 (although this date may be too young).

1 Introduction

The St Andrew's Bay Member (Forth Formation) is situated 10–30 km offshore between Fife Ness and Inverbervie. The member comprises up to 17 m of mainly medium- to very fine grained sand and silt, largely quartz-rich, but with subordinate lithics and mica, and scattered shells and shell fragments. Upward-fining grading is observed and shelly lags are locally developed. The member rests on the Forth Formation (Largo Bay Member), St Abbs Formation, Wee Bankie Formation and pre-Quaternary strata. It forms a seaward-prograding sediment wedge comprising four parasequences, 1 to 4 (in ascending stratigraphic order).

(extracted from M. Stoker, 2006, a personal communication).

Three localities were examined, two vibrocores 56-03/586 and 56-03/587 and borehole 74/15. Microfaunal results are tabulated in figures 1-6 respectively. Their distribution is discussed and the assemblages are compared with other localities in the North Sea region.

2 Sample details

Locality	Position	Sample numbers
Vibrocore 56-03/586	Lat. 56.51576°N, Long. 2.42089°W	MPA55491-55497
Vibrocore 56-03/587	Lat. 56.65023°N, Long. 2.42221°W	MPA55498-55502
Borehole 74/15	Lat.56.468°N, Long. 2.458°W	MPA55503-55506

3 Foraminifera

3.1 LATE GLACIAL-HOLOCENE FORAMINIFERA IN THE NORTH SEA BASIN

In the Oslofjord area, the Pleistocene/Holocene boundary in the Yoldia Clay is not well defined by the foraminifera (e.g. Feyling-Hanssen 1972). The late glacial (Younger Dryas) faunas were dated to 10,400±325 BP and 10,700±275 BP (corrected). They are dominated by *Elphidium excavatum clavatum*, with frequent *Cassidulina reniforme* (assigned to *C. crassa* by Feyling-Hanssen) and Nonion labradoricum, with rarer *Virgulina schreibersi*, *Astrononion gallowayi*, *Virgulina loeblichi* and *Islandiella teretis*. A Holocene (Preboreal) fauna dated to 9650±325 BP (corrected) was dominated by Elphidium excavatum clavatum with rare *Cassidulina reniforme*, *Astrononion gallowayi*, *Nonion labradoricum* and *Virgulina schreibersi*.

Further south in Frederikshavn, Denmark, faunas recovered from boreholes show a marked change across the Weichselian/Holocene boundary, although absolute dates are unknown (Knudsen & Nordberg, 1987). Diverse late Weichselian faunas are dominated by *Elphidium excavatum* (presumably *clavatum*) with frequent *Cassidulina reniforme* and in some samples *Nonion labradoricum*, *Stainforthia schreibersiana* and *Elphidium albiumbilicatum*. Holocene faunas are dominated by *Ammonia beccarii* (*Ammonia batavus* of many authors) with frequent *Bulimina marginata* together with frequent *Textularia sagittula* (in the lower Holocene) and frequent *Nonion germanicum* (=*Haynesina anglica*) and *Eggerelloides scaber* (in the upper Holocene). *Elphidium excavatum* was present throughout the Holocene, but considered to be entirely reworked.

At Neuwerk, on the North Sea coast of Southern Denmark, a similar Holocene fauna was described by Knudsen (1988). Overlying glacigenic deposits, clays and silts yielded a diverse foraminiferal fauna, including common to abundant (up sequence) *Ammonia beccarii*, frequent to common (upsequence) *Nonion germanicum*, frequent *Elphidium williamsoni* and less numerous *Nonion depressulum* and *Elphidium gunteri*. The warmer water *Elphidium excavatum selseyense* was also present in the base of the Holocene.

Moodley & van Weering (1993) indicated that subtidal conditions were established in the southern North Sea, off The Netherlands, about 6240 years BP. At this time there was an abrupt sedimentological change from clays through silts to fine-grained sands and it was with the accumulation of the sand that abundant *Ammonia beccarii* appeared, accompanied by *Elphidium excavatum, Eggerelloides scaber* and smaller proportions of *Bulimina gibba/elongata, Stainforthia fusiformis, Buccella frigida* and *Nonion depressulus*. The change in sedimentation was also accompanied by the appearance of a large proportion of reworked, late Cretaceous foraminifera associated with erosion in the southern part of the basin. There has been little significant change in the foraminiferal assemblages in the last 6240 years (Moodley, 1990; Moodley & van Weering, 1993).

Uffenorde (1982) recognised eight ecozones in the Holocene of the German Bight:

Ecozone	Environment	Comments
Ammonia batavus var *a*	lagoonal; miohaline-?mesohaline	Monospecific. Probably *A. aberdoveyensis*
Elphidium gunteri	mio-brachyhaline/ euhaline	*E gunteri* 5%+. *Miliammina fusca* also present. Marsh species such as Jadammina
Elphidium williamsoni	Estuarine-low marsh. Pliohaline-euhaline	*Haynesina germanica* also present and sometimes over 20%
Elphidium excavatum selseyense	Euhaline-brachyhaline	*Haynesina germanica* common. *Ammonia batavus* and *Elphidium gunteri* present
"Allochthone küstennahe Biofazies"	High energy, nearshore	Fragments of robust foraminifera
Ammonia batavus "Abroll Foraminiferen"	Shallow subittoral coastal sands and shelf	*A. batavus, Quinqueloculina seminulum, Elphidium williamsoni, E. excavatum* and *Haynesina germanica*
"Übergangzone"	"Offshore-beach transition"	*Eggerelloides scaber*, with *Asterigerina mamillata, Bolivina pseudoplicata, Bulimina gibba/elongata, Brizalina pseudopunctata, Stainforthia fusiformis*
Eggerelloidea scaber	Quiet shelf milieus below wave base	*E scaber* 5%+

Similar faunas were noted at Vendsyssel, southern Denmark, in deposits dated to between 8000 and 5000 years BP (Penney, 1985). Although details were not given, the basal part of this Holocene succession was characterised by *Ammonia beccarii* and *Elphidium gunteri* and the higher part of the succession by A*mmonia beccarii, Haynesina germanica, Elphidium williamsoni* with, at some horizons, *Elphidium macellum* and *Quinqueloculina seminulum*.

Agglutinated marsh species appear at the very top, including *Trochammina inflata* and *Jadammina macrescens,* indicative of a regressive phase.

Marsh foraminifera were also reported by Coles & Funnell (1981) in Broadland, eastern Norfolk, where evidence for two Holocene marine incursions were indicated by the appearance of hyaline taxa including *Elphidium* and *Ammonia* (although details of the Holocene foraminifera were not given). Peats were horizons were separated by a 'lower clay' with a foraminiferal succession of marsh- intertidal flats-estuarine- intertidal flat-marsh; dated approximately to between 7500 BP and 4500 BP. Above fresh water lagoonal deposits, the 'upper clay' shows a succession of foraminiferal assemblages through sheltered estuarine to open estuarine and estuarine channel conditions, culminating in a strong incursion of marine waters before a return to marsh conditions. This second marine incursion took place between 1973±50 years BP, reaching a maximum extent 1609±50 years BP and had ended by about 1500 BP. Andrews et al. (2000) traced the Holocene faunas of northern Norfolk from uper saltmarsh assemblages dominated by *Trochammina inflata* and *Jadammina macrescens,* through lower saltmarsh faunas with *Milliamina fuscata* and *Elphidium williamson,i* to upper mudflat assemblages dominated by *Haynesina germanica, Haynesina depressula* and *Ammonia beccarii*. In Lincolshire, Holocene high marsh enviroment are characterise by *Jadammina macrescens* and *Trochammina inflata*, whereas low marsh and estuarine conditions supporte a large population of *Haynesina anglica* (assigned to *H. germanica*), together with *Ammonia becarii, Elphidium williamsoni* (Wilkinson, 1993).

Further North in the Geordie Trough, Holocene deposits average about 5 m thick, although there is a tendency for the deposits to thicken northwards (to an average of c. 10m), and in isolated areas it can reach 22m (Brew et al., 1998). The shelly lag at the base of the succession is dated to 10310 years BP (Evans et al., 2002). Although samples were not available for foraminifera analysis from the lower part of the succession, assemblages dated to the last 7200 years BP were diverse (Wilkinson in Evans et al., 1998).

1. *Elphidium excavatum clavatum* dominated the assemblages at 7200 years BP but rapidly fell in dominance, their place being taken by *Ammonian beccarii* which formed 54% of the association by 6280 years BP. *Stainforthia fusiformis* and accessory species such as *Bulimina elongata* and *B. marginata* also increased up section. *Elphidium excavatum clavatum* is very abundant in the Weichselian and late glacial marine deposits of the North Sea and it is possible that, as in Denmark (Knudsen & Nordberg, 1987), this species is entirely reworked in the southern North Sea Basin. Its gradual decline up-section may be the result of a decline in reworking and/or the effect of sediment accumulation blanketing the late glacial deposits and consequent reduction in its availabity for reworking.
2. *Stainforthia fusiformis* and *Lagena semistriata* peaked at 5800 years BP and *Bulimina elongata, Ammonia beccarii* and *Stainforthia fusiformis* form a characteristic association between 5869 and 3987 years BP.
3. *Fissurina lucida, Cibicides lobatulus* and *Bulimina marginata* become more numerous between 3987 and 2032 years BP, in contrast to *Ammonia beccarii,* which shows a marked decline in abundance.
4. Between 2032 and 1158 years BP, *Stainforthia fusiformis* and *Lagena semistriata* rise in proportion, but *Ammonia beccarii* becomes quite rare. *Elphidium excavatum clavatum,* on the other hand does not show an increase, as might be expected if this were a cold phase, in fact it shows a steady decline through to the top of the succession. It is suggested here that this supports the notion that its presence is due to the fact that this species is entirely reworked from the Weichselian/Late Glacial interval, as it is in Denmark (Knudsen & Nordberg, 1987).

5. Between 1158 years BP and the present, *Eggerelloides scaber, Hyalinea balthica, Stainforthia fusiformis, Bulimina marginata* and *Ammonia beccarii* show increased proportions. Evans et al (2002) suggested that this was caused by the onset of stratification in the Southern North Sea Basin.

There has been little recent work carried out on the Holocene microfaunas of eastern Scotland. In the Forth Approaches, the upper part of the Forth Formation appears to be close to the Pleistocene/Holocene boundary. Gregory et al. (in Thomson, 1978) recorded faunas dominated by arctic taxa such as *Elphidium excavatum clavatum, Cassidulina reniforme* (as *obtusa*) with *Buccella frigida* and *Elphidium subarcticum* in the lower part of the Forth Beds. However, "species of southern origin" appeared in the middle part of the unit and increased in proportion up section; these included *Ammonia beccarii, Virgulina fusiformis, Bulimina marginata* and *Elphidium exoticum*.

In the Inner Cromarty Firth, the upper part of the Ardullie Beds show an influx of species of southern origin, and although originally believed to be late glacial based on the large number of (?reworked) cold water species (Peacock et al., 1980), the middle part of the unit was later dated to 10,000 years BP. As a result Peacock & Harkness (1990) suggested that the upper Ardullie Beds accumulated during a cool phase in the early Holocene. The overlying Lower Cromarty Beds, which were deposited between about 7000 and 7800 years BP (rounded dates) are dominated by *Elphidim excavatum clavatum*, although "species of southern origin" were beginning to appear in greater numbers within this unit, including *Ammonia beccarii, Elphidium macellum, Protelphidium anglicum* and *Bulimina* spp (Peacock et al., 1980). It is considered here that the specimens of *Elphidium excavatum clavatum* were probably reworked.

The Tayside boreholes, are dominated by cold water species, with the exception of the Kingston Sand (which overlies the Sub-Carse Peat with radiocarbon dates of 9640 to 8616 years BP) (Paterson et al., 1981). Here *Ammonia beccarii, Cibicides lobatulus, Elphidium williamsoni, Elphidium macellum, Protelphidium anglicum* and *Buliina* spp form a characteristic assemblage compared to the older deposits dominated by arctic taxa such as *Elphidium excavatum clavatum, E. bartletti* and *Cassidulina reniforme*.

3.2 FORAMINIFERA FROM THE ST ANDREW'S BAY MEMBER

The foraminiferal assemblages recovered from the the two vibrocores 56-03/586 and 56-03/587 and the borehole 74/15 are tabulated in figure 1-3 respectively.

3.2.1 Parasequence 1

This is known only from its seismic record and no samples were available for analysis.

3.2.2 Parasequence 2

This parasequence was obseved in vibrocore 56 -03/587 (Fig.2). Foraminifera are extremely rare and no attempt was made to calculate species percentages. Of those species recorded, *Elphidium excavatum clavatum* and *Buccella frigida* are characteristic of cold, shallow water condition such as those associated with the lateglacial and the presence of the miliolid, *Quinquloculina seminulum,* suggests the presence of fully marine salinities. However, the sample size is too small to draw meaningful conclusions and the specimens present may all be reworked from older Pleistocene deposits. The assemblage is considered to be pre-Holocene.

3.2.3 Parasequence 3

In Borhole 74/15, faunas associated with this parasequence were observed in two samples at 5.5 and 3.5-5.0 m. The assemblages are impoverished (36 and 38 specimens, respectively, which

should be born in mind in figure 3) and realtively low in diversity (6 and 4 species respectively). However, the assemblages are dominated by *Ammonia beccarii*, with rarer specimens *Elphidium excavatum clavatum, E. incertum* and *Cibicides lobatulus*. The presence of a single specimen of *Bulimina elongata* in the higher sample is probably significant environmentally.

In the context of the Quaternary faunas of the North Sea Basin, *Ammonia beccarii* has been considered a "species of southern origin" and it is a good indicator of post-glacial conditions at the Pleistocene/Holocene boundary. Its modern distribution in the southern North Sea is in brackish marine, with salinities of 22‰ through to fully marine (35‰), and in water depth generally less than 10m although it is known to occur down to 60 m. It has a high tolerance to water temperature and is found in temperatures between 1 and 29°C, although the optimum temperatures range is 15-20°C and reproduction does not take place in temperatures belowabout 15°C (Murray, 1991). It is commonly found along the Enlish Channel coast, Cardigan Bay and into Lusitanian waters, but its northern limit of endurance appears to be Oslofjord.

Bulimina elongata is often found in temperate waters of mid-latitudes, both north and south of the equator. In European waters, it is at its northern limit of endurance in the North Sea and has been recorded living around the coast of Scotland, it is not recorded living further North. Its presence in the higher sample in the borehole may indicate slightly warmer conditions compared to the basal sample.

Parasequence 3 was therefore deposited in shallow, inner shelf waters in temperatures that exceded 15°C at least for part of the year, to allow reproduction of *Ammonia beccarii*. Salinities may have been brackish marine.

3.2.4 Parasequence 4

This parasequence was present in vibrocores 56 -03/586 (Fig. 1), 56 -03/ 587 (Fig. 2) and Borehole 74/15 (Fig. 3).

The succession in 56 -03/586 is considered to be entirely within Parasequence 4, but the base was not seen. Diversity is low at the base, but increases up section, although it is never great. Cold water, arctic or high boreal foraminifera are very rare and patchily distributed. These include *Elphidium bartletti* and *Haynesina orbiculare* together with more numerous and consistently present, Elphidium excavatum clavatum. It is probable that all these "northern" taxa are reworked from the lower Forth, St Abbs, Wee Bankie or Marr Bank Beds formations all of which are dominated by these taxa Gregory et al. (in Thomson, 1978).

Ammonia beccarii is dominant throughout the succession, often occuring in flood proportions (over 75% of the total assemblage). This is a temporate species and, importantly, requires temperatures above about 15°C for reproduction reproduction to take place in (Murray, 1991). This indicates that parasequence 4 was probably deposited in temperatures similar to those of the North Sea, but that waters did not fall below 15°C for much of the time.

Rare *Bulimina marginata* is found in the lower part of the parasequence, although it is rare. This species may indicate slightly cooler water temperatures during deposition of this part of the succession. It has a distribution in mediterranean, temperate and boreal waters and has been found as far north as Nova Scotia, Iceland and Møre (Norway) and appears to show a preferrence for water temperatures in excess of 5°C and is generally associated with water depths greater than about 10-15 m. Studies on glacio-marine successions would interpret this as an indication of amelioration, however, in the present succession , it is replaced by *Bulimina elongata* in the middle part of the succession, a species with a higher water temperature requirement and not known further north than the North Sea and the coast of Scotland.

The higher part of the succession in 56 -03/586 is characterised by the appearance of *Eggerelloides scaber* and *Haynesina anglica* two "species of southern origin".

Arctic records of *Eggerelloides scaber* appearing in the literature may be the result of erroneous identification (probably Eggerella advena) as its modern distribution extends from the Mediterranean and Lustanian regions as far north as the North Sea, and possibly the Skagerak. It is often found in water depths of less than about 30 m, but in the Southern North Sea it has been found down to 97m. It has a broad tolerence to water temperature (between 1 and 20°C), but reproduction takes place on sandy substrates where temperatures exceed 13°C for at least part of the year. It shows a preference for brackish marine salinities (it requires about 24‰ for most of the year, but will tolerate salinities of about 17-29‰).

Haynesina anglica (H. germanica of some authors) is not common in 56 -03/586, but is significant in that it indicates brackish water conditions and is typically found in lagoons, tidal flats, and into low marsh environments around Britain, Belgium and The Netherlands. It seems to have its northern limit in the southern North Sea and in the Cape Cod/Long Island part of the eastern seaboard of the USA.

Parasequence 4 in 56 -03/586 was therefore deposited in shallow (probably less than 30 m) brackish marine (generally about 24‰) conditions and in temperatures in excess of 15°C for much of the year, such that *Ammonia beccarii* could reproduce. There is a little evidence supporting the notion that environmental conditions during accumulation of the upper part were warmer than those pertaining during sedimentation of the lower part.

In 56 -03/587, parasequence 4 contained similar faunas compared to 56 -03/586 (Fig 2), with abundant *Ammonia beccarii, Eggerelloides scaber* and smaller numbers of *Bulimina elongata*. The samples appear to be more closely comparable to the upper part of the 56 -03/586 succession than the lower part.

The two samples from parasequence 4 of Borehole 74/15 contain abundant Ammonia beccarii together with rare *Bulimina marginata, B. elongatum* and *Eggerelloides scaber*. It is thus essentially similar to the other two sites. The presence of *E scaber* suggests closer similarities to the upper part of the 56 -03/586 succession.

3.3 COMPARISON WITH OTHER SITES

The foraminiferal faunas recovered show similarity with a number of Holocene sites around the North Sea Basin. *Ammonia beccarii* is a characteristic feature of many of them, but the widespread presence of *Stainforthia fusiformis* (*Virgulina fusiformis* or *Fursenkoina fusiformis* of some authors) at a number of localities contrasts with the sites off Montrose. The latter species is found from Greenland and Labrador south to Buzzards Bay (eastern seaboard of the USA) and in Gulmarfjord, Skagerrak, Baltic Sea and around the U.K.. It appears to be a boreal species with its southern limit of endurance in the English Channel and so its geographical distribution overlap s those of other dominant species in the St Andrew's Bay Member. However, this appears to be a species that does not tolerate reduced salinities; all the modern references indicate salinities of 34-35‰. It is suggested that low salinities during the accumulation of the St Andrew's Bay Member, precluded *S. fusiformis*. The majority of foraminifera are euryhaline and will tolerate brackish marine conditions, but none were characteristic of high –middle marsh conditions

The St Andrew's Bay Member contains a Holocene foraminiferal fauna essentially similar to those at Frederikshavn (Knudsen & Nordberg, 1987), Neuwerk, (Knudsen, 1988) and the 8000 and 5000 years BP faunas at Vendsyssel (Penney, 1985). Abundant *Ammonia beccarii* and the presence of species such as *Bulimina elongata, Haynesina anglica* and *Eggerelloides scaber*, but with cold water indicators such as (reworked) *Elphidium excavatum clavatum* is comparible with foraminiferal zone 2 of the Geordie Trough, which accumulated between 7200 and 5869 years BP (Evans et al., 2002).

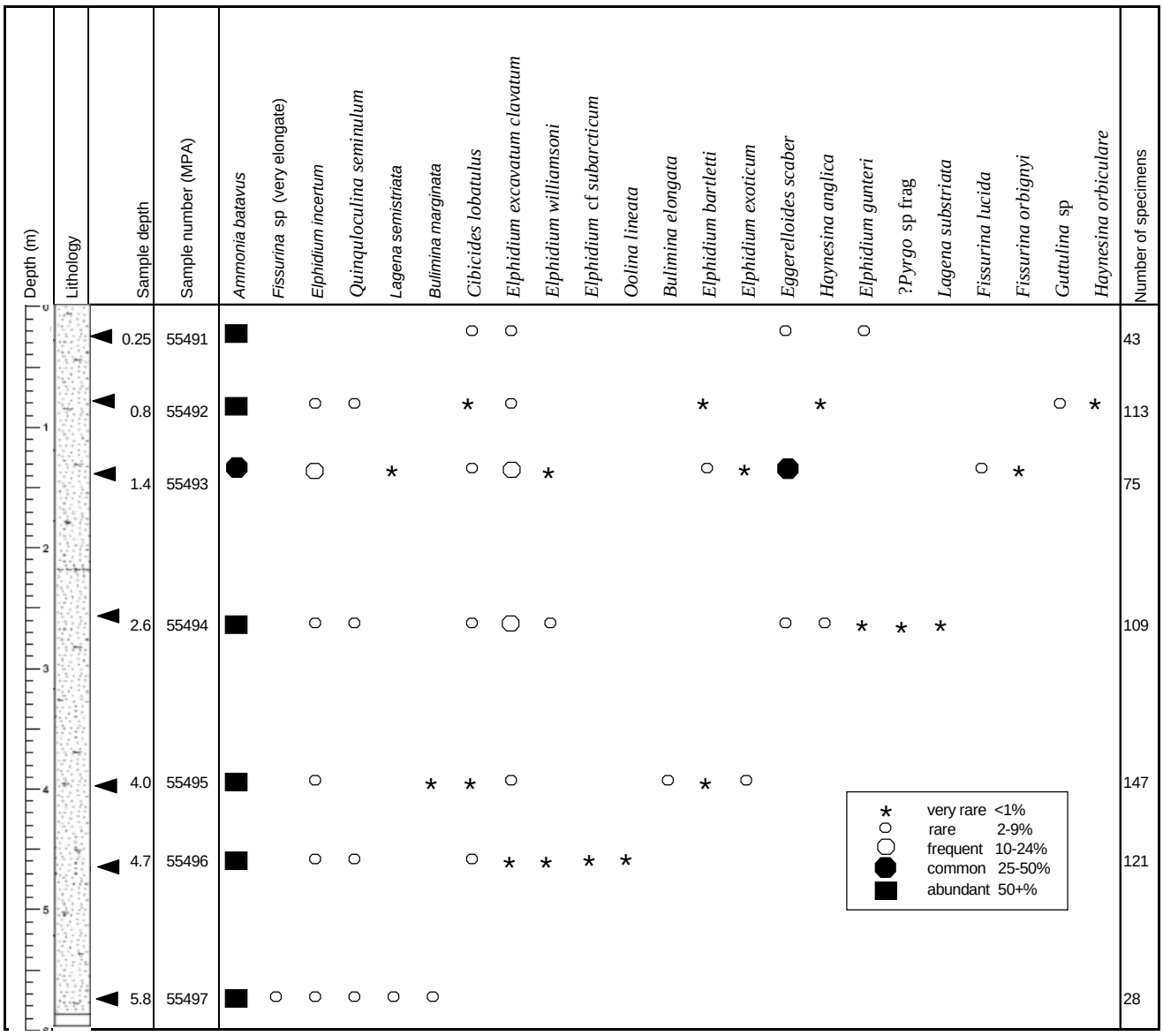


Figure 1. The distribution of foraminifera in vibrocore 56-03/586.

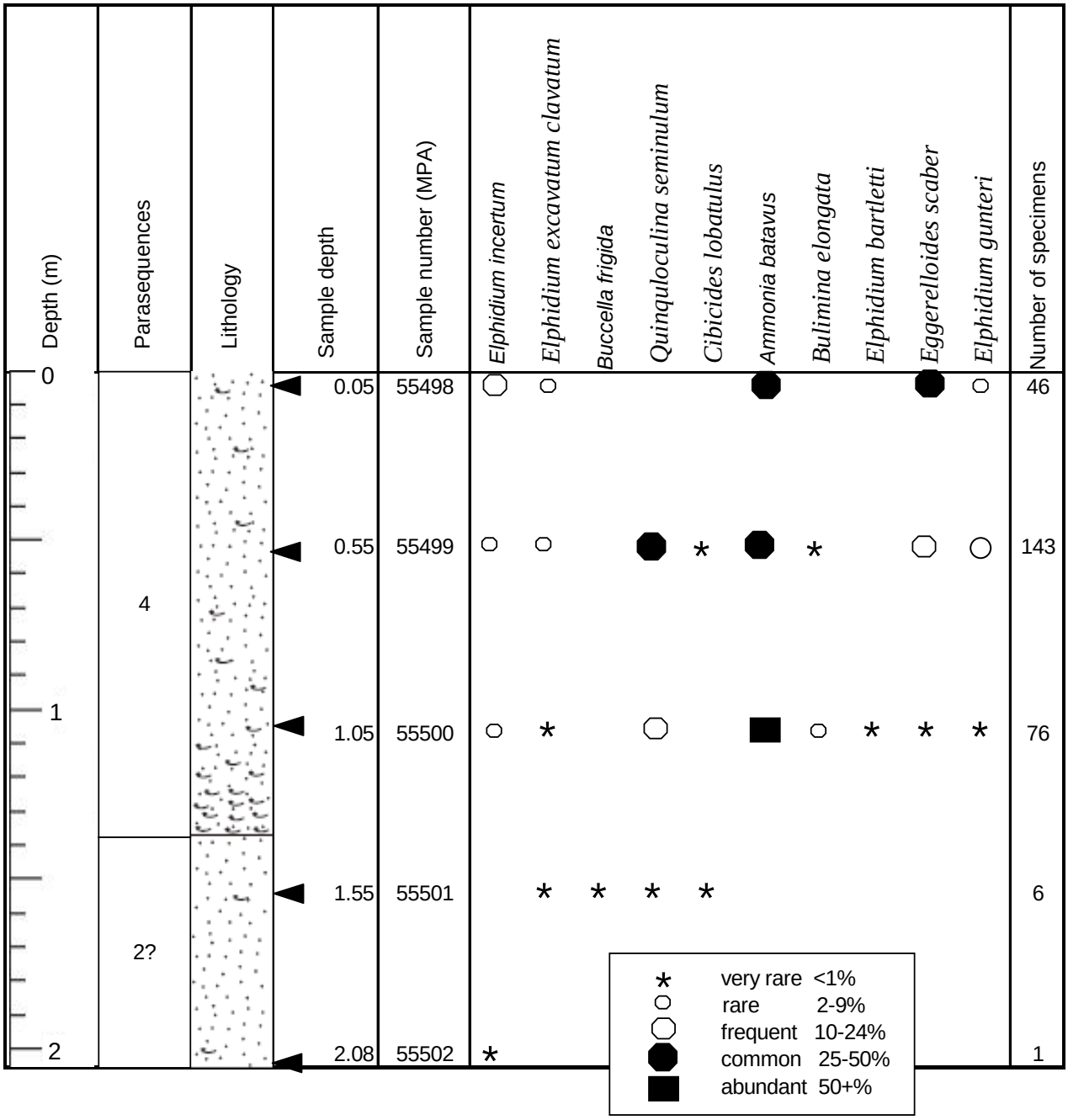


Figure 2. Distribution of foraminifera in vibrocore 56-03/587.

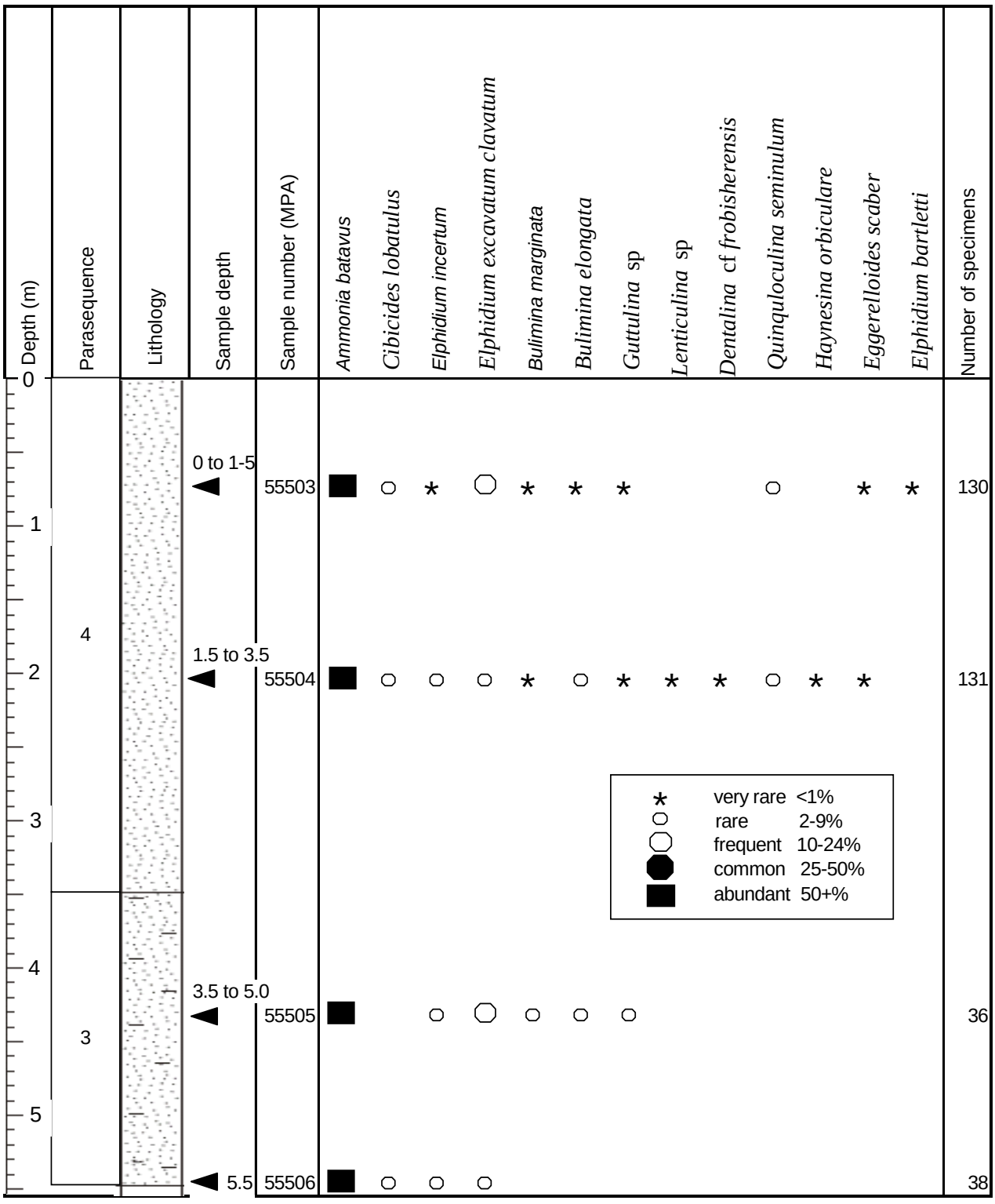


Figure 3. Distribution of foraminifer in borehole 74/15.

4 Ostracoda

4.1 LATE GLACIAL-HOLOCENE OSTRACODA IN THE NORTH SEA BASIN

In the Firth of Forth and its approaches, the Forth Beds show a transition from cold water taxa such as *Rabilimis mirabilis* and *Roundstonia globulifera*, species of *Normanicythere leioderma* and *Finmarchinella angulata* to warmer water associations in the middle to upper Forth Formation , including *Elofsonella concinna, Sarsicytheride punctillata, Cytheropteron lattissimum, C nodosum, Hemicythere villosa, Hemicytherura clathrata, Jonesia simplex, Loxocthere guttata* and *Robertsonites tuberculata*, all of which are known to occur in modern seas around the coasts of the North Sea. (Gregory et al., in Thomson, 1978)

The late and post-glacial succession of the Cromarty Firth also show a change from low diversity, colder water assemblages in the Findon Beds to the appearance of common warmer marine and brackish marine *Acanthocythereis dunelmensis, Hirschmannia viridis* (as *H. tamarindus*), *Leptocythere* spp and *Loxoconcha rhomboidea* in the Cromarty Formation (Peacock et al., 1980).

The Holocene deposits of northern Norfolk show variations in the ostracod faunas associated with environmental change (Boomer, 1998; Andrews et al., 2000). Brackish ostracods (typically 10-25‰) include *Cyprideis torosa, Leptocythere castanea, Leptocythere porcellanea* and *Loxoconcha elliptica*. These were replaced in lower saltmarsh environments, with euryhaline assemblages including He*micythere rubida, Leptocythere lacertosa, L. psammophila, L. baltica, Cytherois fischeri, Hirscmannia viridis* and *Leptocythere baltica*. Marine incursions were chracterised by *Pontocythere elongata, Leptocythere pellucida, Loxoconcha rhomboidea* and *Hemicythere villosa*; ostacods that do not tolerate long term reduction from fully marine salinities.

Further afield, the ostracod fauna of the early Holocene succession in the Løkken area of Vendsyssel, Denmark, is characterised by *Loxoconcha elliptica, Cytherois fischeri, Hirschmannia viridis, Xestocythere nitida, Semicytherura nigrescens*. The basal part f the succession contains freshwater ostracods and *Cypirideis torosa*. (Penney, 1985).

4.2 OSTRACODA FROM THE ST ANDREW'S BAY MEMBER

Ostracoda were recorded in all three localities as indicated in 56-03/586 (Fig. 4), 56-03/587 (Fig. 5) and Borehole 74/15 (Fig. 6). As ostracods are never very common, no attempt has been made to plot percentages, all figures show presence/absence.

4.2.1 Parasequence 1

Parasequence 1 was unavailable for examination; it is known only as a seismic unit.

4.2.2 Parasequence 2

Parasequence 2 was almost devoid of ostracods in 56-03/587. The single specimen of *Cytheropteron nodosum* in the higher sample (Fig. 5). This shallow sublittoral, marine species has a widespread distribution from the Bay of Biscay to northern Norway, but the provenance of this specimen must be questioned.

4.2.3 Parasequence 3

Parasequence 3 was almost devoid of ostracods, the only specimen observed being from the base of Borehole 74/15 (Fig. 6). *Elofsonella concinna* is an arctic to boreal species, being widely

distributed on the continental shelf of Canada, Iceland, Spitsbergen, Norway and ranges as far south as Scotland, northern England and southwestern Ireland, although showing a preference for inner sublittoral depths. It is thus a cold water species, but can tolerate water temperatures up to about 19°C, but Hazel (1970) considered that the southern distribution of *E. concinna* was restricted by the 14°C summer thermocline. Again, the provenance of this species in parasequence 3 is questionable.

4.2.4 Parasequence 4

Parasequence 4 has larger assemblages of ostracoda, although diversity is low and none of the assemblages contained a rich fauna. Vibrocore 56-03/586 has the best fauna (Fig. 4), but the basal assemblage is particularly small fauna. *Elofsonella concinna* is discussed above. *Sarsicytheridea bradii* is an arctic and boreal species being found in marine, sublittoral waters of Novaya Zemlya, Spitsbergen, Norway, Baltic and Denmark, and extends as far south as Scotland and the northern England. It tolerates water temperatures between 0 and 18°C. Both species are close to their southern limit of endurance in British waters.

An increase in diversity can be seen in the sample at 4.7 m depth, with the appearance of a number of shallow marine species:*Acanthocythereis dunelmensis, Robertsonites tuberculatus, Palmoconcha guttata* and *Pterygocythereis jonesii.* These species are geographically widespread. The first is common off northeastern England, Scotland, Norway to eastern Greenland often in water depths of 20-30 m but deeper (50-100 m) towards the south of its range. The second occurs in sublittoral waters, generaly less than 50 m deep, but it is known to occur deeper, and is more common in Arctic waters, although it rangesScotland and eastern Englan as far south as the ThamesEstuary (Athersuch et al., 1989). The third species, is found aroud the UK and Scandinavia in waters of about 10 m down to 90 m.. *Pterygocythereis jonesii* is a common, sublittoral marine species found at all depths down to 200 m. It is essentailly a warm water form, having been found living in the Mediterranean, and the Atlantic continental shelf of Spain, France and the UK. Its most northerly record is the Kattegat and Skagerak. This sample also yielded small numbers of *Leptocythere pellucida*, which is commonly found living in the southern North Sea, around Britain and as far north as southern Norway and western Baltic.

In the upper part of the unit, *Cytheropteron latissimum* is consistently present. This marine species is found living on the UK continental shelf in waters deeper than about 5 m, but extends northwards to northern Norway and eatern Greenland and there is a record in the southern part of Spitsbergen. It is therfore tolerant to a waide range of temperatures from 0 to 22°C.

The fauna in vibrocore 56-03/587 (Fig. 5) is more patchy, but is essentially similar to that of 56-03/586. The most diverse fauna was found at 0.55m where *Robertsonites tuberculatus, Elofsonella concinna, Palmoconcha guttata, Cytherois fischeri, Leptocythere pellucida, Krithe glacialis* and *Eucythere declivis* were found.

In Borehole 74-15 (Fig. 6), the same species were again recorded, although the more diverse assemblages also included rare *Finmarchinella angulata* and *Leptocythere psammophila* and, in the highest sample, *Rabilimis mirabilis* (fragment), *Hemicytherura clathrata, Hirschmannia viridis* and *Celtia quadridentata.* These species include a mix of Arctic, Low Boreal and Lusitanian forms, and it is assumed that the colder water specimens are reworked. The distribution of living representatives of these species are briefly summarised below:

- *Finmarchinella angulata* is a cold water species that lives off northen Canada, Greenland Novaya Zemlya, the entire coast of Norway, in the Barents Sea and Norwegian Sea (Neale.1974). It has been recorded around Briain, but never alive. Reproduction is known to occur in mesohaline conditions (10-18‰).
- *Rabilimis mirabilis* is an Arctic species with a modern distribution on the continental shelf around Eastern Greeenland, Novaya Zemlya, Franz Joseph Land, Spitsbergen and

the northern coast of Norway. Records from the Skagerrak (Elofson, 1943) and northern Scotland (Brady, 1868) are considered to be reworked as only a single, dead valve was found in each locality (and only a single damaged valve was preent in the Holocene off Montraose. According to Robinson (in Paterson et al., 1981) the species is confined to water temperatures of less than 14°C.

- *Hemicytherura clathrata* occurs off Nova Scotia and in the Bay of Fundy, north to Ellesmere Island and Greenland, Franz Joseph Land, Spitsbergen and the northern coast of Norway. Hazel (1970) shows its distribution around the coast of Britain, but Athersuch et al. (1989) did not find this species living, suggesting that Hazel's record refers to late glacial and early Holocene specimens.
- *Hirschmannia viridis* is one of the most common phytal species around Britain and ranges from SW France, north to the Baltic Sea, where it survives in salinities of only 2 or 3‰, and to Arctic Norway.
- *Celtia quadridentata* is a sublittoral marine species that lives down to 75m depth in the waters of the Bay of Biscay in the south to Shetland and southern Norway in the north. This is one of the more geographically restricted species found in the Holocene off Montrose, suggesting that the St Andrew's Bay Member accumulated in temperatures not very different from the North Sea of today.
- *Leptocythere psammophila* is a species characteristic of brackish, outer estuarine conditions with sandy substrates. It lives off the coast of France around the coast of Britain and Ireland and as far north as the Balic.

4.3 COMPARISON WITH OTHER SITES

The very impoverished faunas in parasequences 2 and 3 cannot be compared with other successions with confidence.

Parasequence 4 has a better association, dominated by species that are found in the North Sea and around the British coasts of today. There are similarities with the late Forth Formation of the Forth Approaches and Cromarty Formation of the Cromarty Firth as well as the Løkken area of Vendsyssel, Denmark. Many species are euryhaline, and most species will tolereate brackish marine salinities. Fresh water ostracods and those that show a preference for marsh environments were not observed

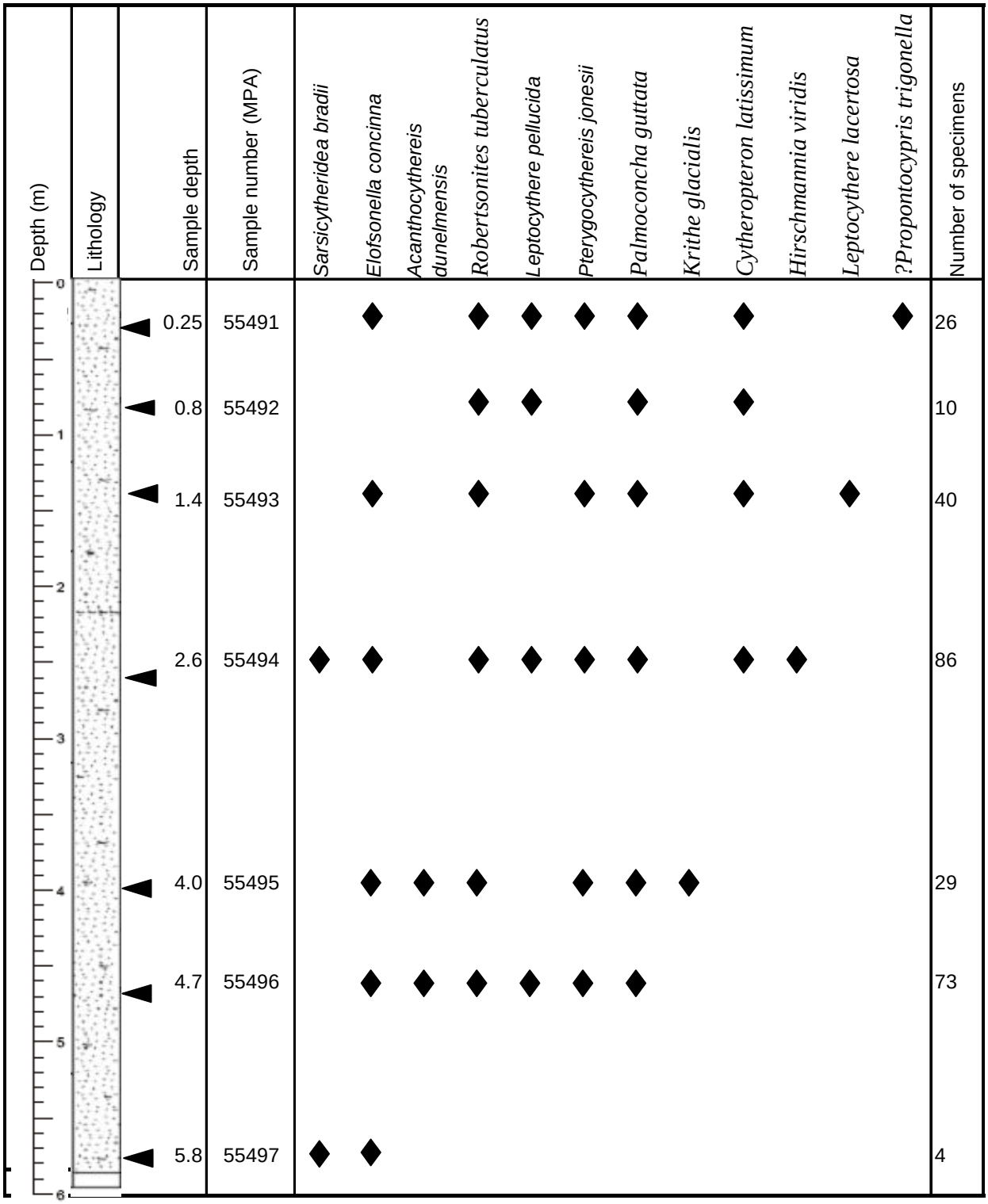


Figure 4. Distribution of Ostracoda in vibrocore 56-03/586.

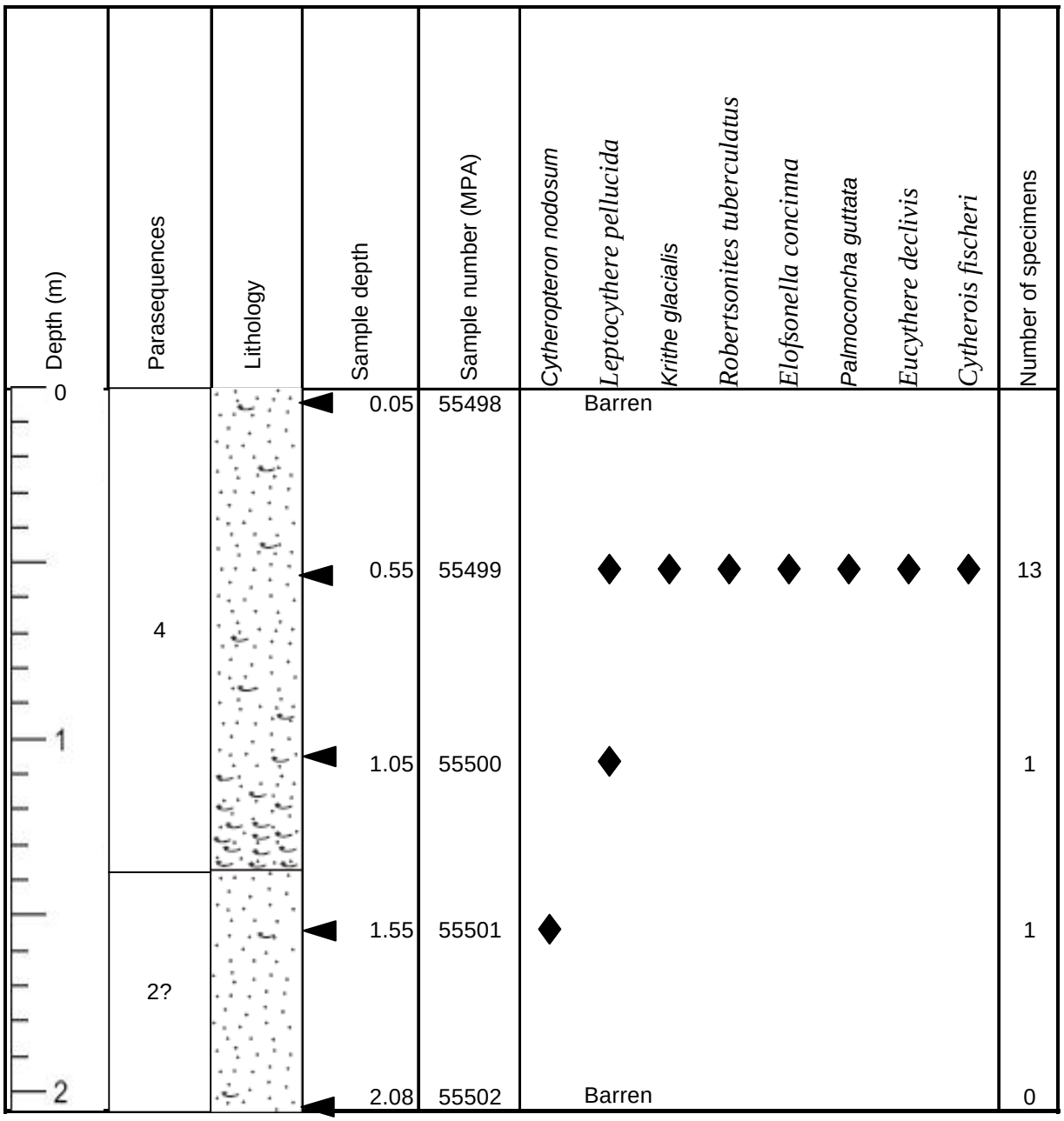


Figure 5. Distribution of Ostracoda in vibrocore 56-03/587.

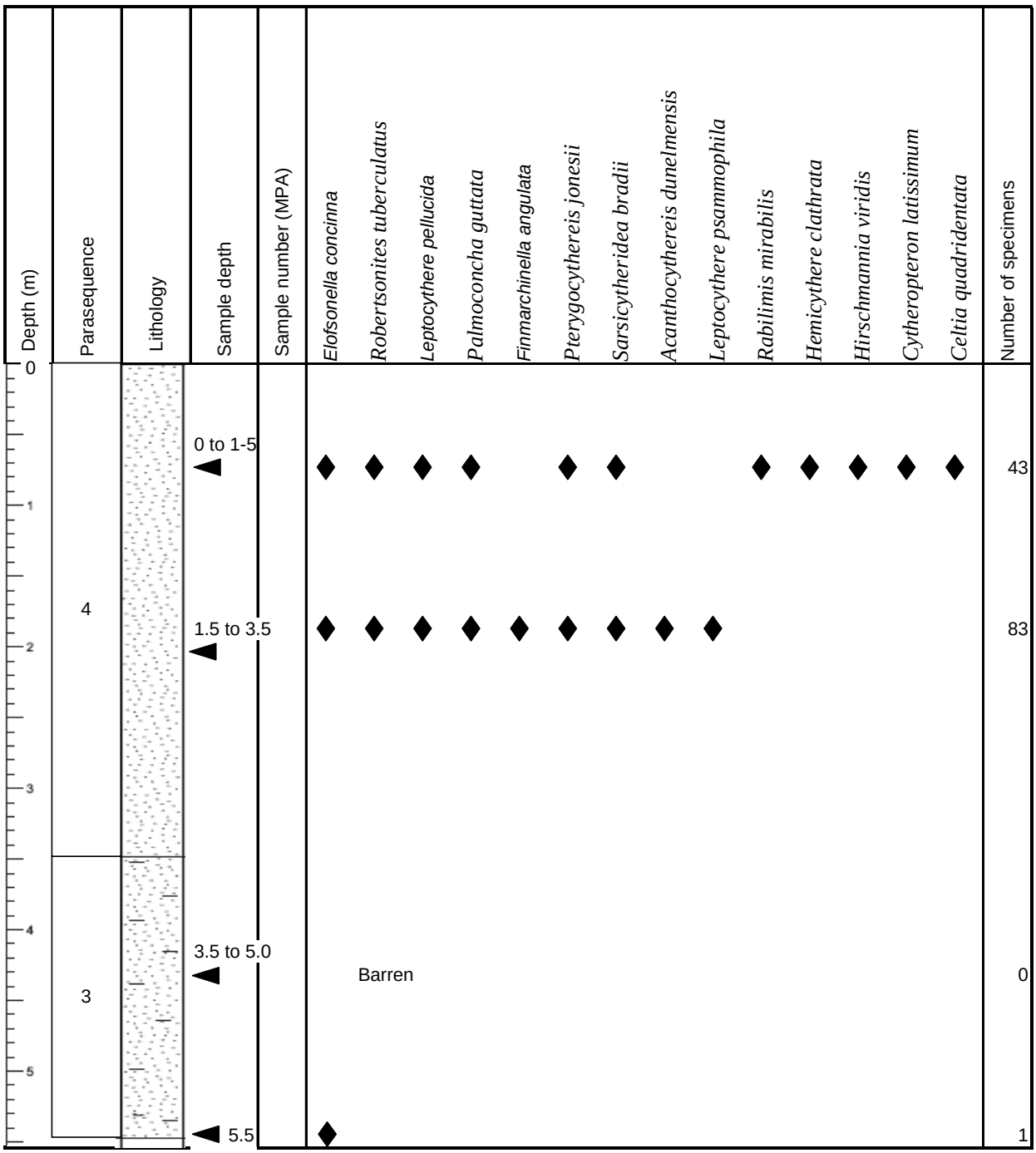


Figure 6. Distribution of Ostracoda in borehole 74/15.

5 Conclusions on the age of the St Andrew's Bay Member

Late Pleistocene and Holocene Foraminiferida and Ostracoda were found within the St Andrew's Bay Member, in the area offshore Montrose, eastern Scotland. Foraminifera were more common than ostracods, although diversity was generally fairly low in both groups. This may have been a function of salinity being slightly less than fully marine at that time; incomplete colonisation of the newly opened coastal margin enviromental niches after the period of glaciation; or environmental instabilty as the area rapidly came out of the Arctic phase and into the Lusitanian. The climatic variation and its relationship to the bioprovinces (shown in Fig. 7) is taken from a number of sources including Dansgaard et al. (1969), Peacock & Harkness (1990), Schönwiese (1995), together with data from Evans et al. (2002).

Peacock & Harkness (1990) show the fluctuations in the temperature curve for the late glacial to early Holocene times:

- The Windermere interstadial (the earliest marine sedimentation is dated to 12,795±65 BP by Holloway et al., 2002) comprised two warm phases between 12,400 and 12,800 years BP and again between 11250 and about 11,000 years BP (earlier than 10850 years BP when cold, polar waters had returned), with slightly cooler conditions between. The warm phases are characterised by faunas dominated by Ammonia beccarii
- The Younger Dryas (10,850-10,200 years BP) is characterised by its Arctic faunas.
- The Younger Dryas was followed by rapid amelioration to a plateau with mid-high boreal faunas between about 10,000-10,200 through to about 9500BP.
- An abrupt rise in temperature began at about 9500 years BP and by 9400 years BP low Boreal to Lusitanian faunas appeared in Scottish waters, and prior to about 9000 years BP the Lusitanian Zoogeographic Province had been established.

It is suggested that the microfaunas from the St Andrew's Bay Member reflect the environmental instability associates with this rapid climate change.

The age of the base part of Parasequence 2 in 56-03/587 is dated to 10,948 years BP (M. Stoker, personal communication, 2006). If this date is correct, then it places the lower part of the member into the second (later) phase of amelioration of the Windermere Interstadial of Peacock & Harkness (1990). If this were the case, then abundant Ammonia beccarii would be expected (cf. Graham et al., 1990), but the impoverished foraminiferal assemblages are composed of rare, cold, arctic water forms. An anomaly therefore exists the Arctic species fitting better into the Younger Dryas stadial. This being the case, the curve indicated by Peacock and Harkness (1990) can be modified so that the abrupt change at the end of the Windermere Interstadial and the deterioration into Arctic conditions in the Younger Dryas Interstadial must have taken place in a matter of decades, between aproximately 11,000 years and 10,948 years BP.

Parasequence 3 post-dates 10,948 years BP and although only a few samples from this parasequence were examined, the faunas indicate that that Ammonia beccarii was becoming established (colder water forms were also present, but their provenance is uncertain). Parasequence 3 is placed in the early Holocene when the low boreal and Lusitanian faunas were beginning to become established in Scottish waters (c. 9400-9000 years BP according to Peacock & Harknes, 1990)

A date of 1782 years BP for Parasequence 4 is probably too young (M. Stoker, personal communication, 2006), however a late Holocene age is not inconsistent with the faunas recovered. The ostracod asemblages predominantly comprise species found living in the modern North Sea and around the coast of Britain. The foraminiferal assemblages, are dominated by *Ammonia beccarii*, sometimes in flood abundance, with *Eggerelloides scaber* and *Haynesina*

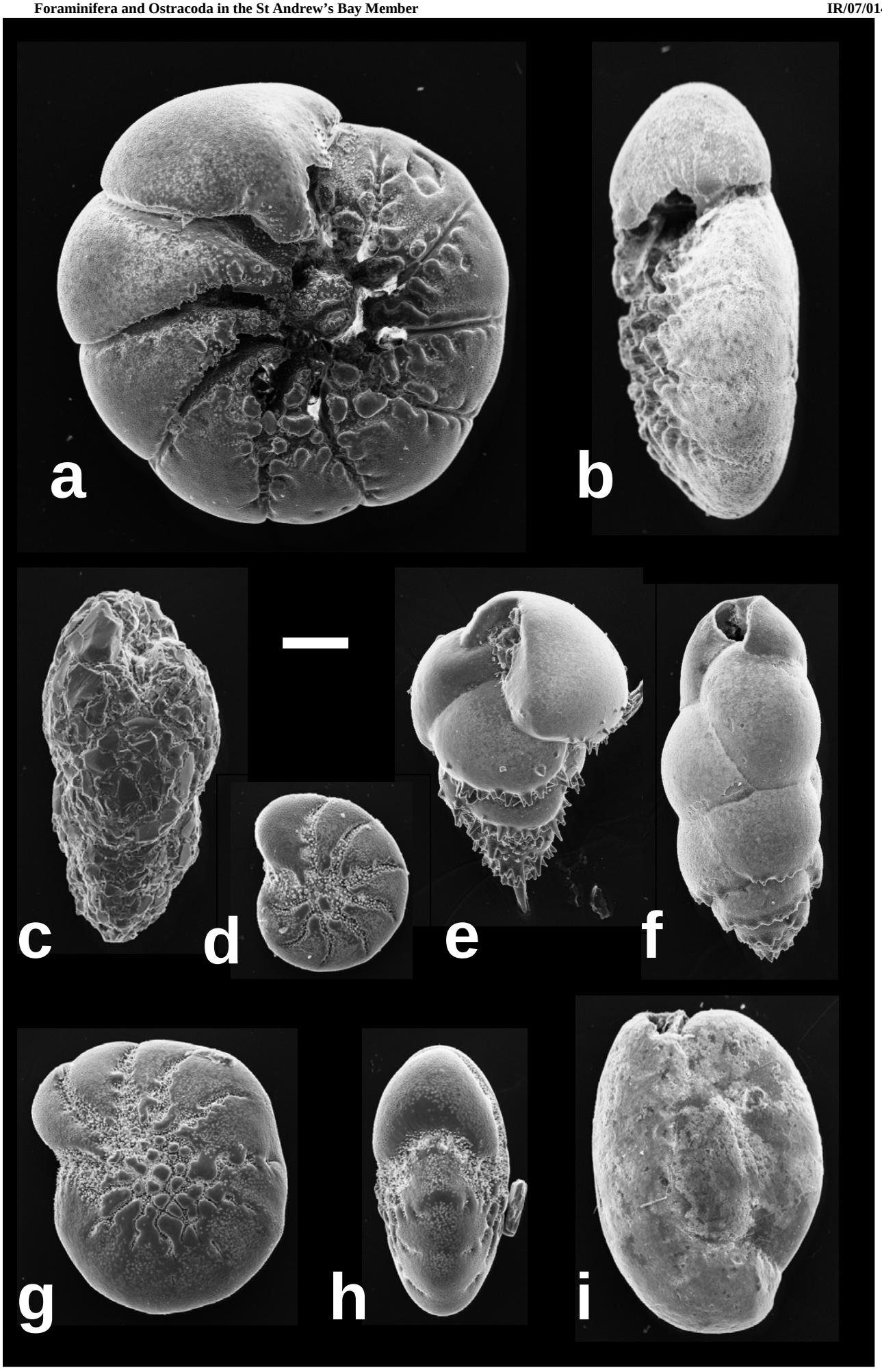
anglica present and particularly in the upper part of the parasequence. Although *Stainforthia fusiformis* is not present in the Montrose area, the faunas otherwise resemble those in the Geordie Trough in terms of the commonly occuring forms, and noteably faunas dated to 7200 – 3987 years BP by Evans et al. (2002). The faunas in upper part of parasequence 4, where E. scaber is a characteristic element, resemble those that inhabited the Geordie Trough between 1158 years BP and the present (cf. Evans et al., 2002). In other words, the supposed error for the date of 1782 years BP in Vibrocore 56-03/587, may not be great.

6 Environmental conclusions

The environment of deposition is discussed in the sections dealing with the microfaunas. In summary, the member accumulated in shallow, inner sublittoral water depths. Salinity was probably close to fully marine, although the presence of brackish marine conditions from time to time, can be postulated where, for example *Elphidium williamsoni* and *Leptocythere psammophila*, estuarine species, are found. The absence of fully marine conditions is indicated by the absence of miliolids (those that are present are generally in a fragmentary state and probably reworked) and there are no planktonic taxa, implying that connections with more open oceanic conditions had not yet been established. Water temperatures were low in parasequence 2 (upper Dryas interstadial), low boreal to lusitanian in parasequence 3 (although evidence is limited) and Lusitanian to Low Boreal in Parasequence 4, which contained assemblages dominated by species found living around the coast of Britain and in the southern North Sea Basin today. The member was deposited, at least for part of the year, in waters temperatures above about 15°C, the minimum that reproduction of *Ammonia beccarii* takes place. However, *Elofsonella concinna* and *Sarsicytheridea bradii*, both of which are often present in the Montrose samples, are near their southern limit in Scottish waters, restricted to temperatures less than 18°C.

Plate 1 Foraminifera from the Holocene succession offshore the Montrose area.
Bar represent 100 microns for all specimens except I, for whhich it represent 200 microns.

a. *Ammonia beccarii* (ex MPA55500) Borehole 56-03/587, depth 1.05m.
b. *Ammonia beccarii* (ex MPA55500)) Borehole 56-03/587, depth 1.05m
c. *Eggerelloides scaber* (ex MPA55498)) Borehole 56-03/587, depth 0.05m
d. *Elphidium excavatum clavatum* (ex MPA55503) Borehole 74/15, depth 0.0-1.5m
e. *Bulimina marginata* (ex MPA55503)) Borehole 74/15, depth 0.0-1.5m
f. *Bulimina elongata* (ex MPA55500)) Borehole 56-03/587, depth 1.05m
g. *Elphidium gunteri* (ex MPA55499) Borehole 56-03/587, depth 0.55m.
h. *Elphidium gunteri* (ex MPA55499) Borehole 56-03/587, depth 0.55m.
i. *Quinqueloculina seminulum* (ex MPA55499) Borehole 56-03/587, depth 0.55m.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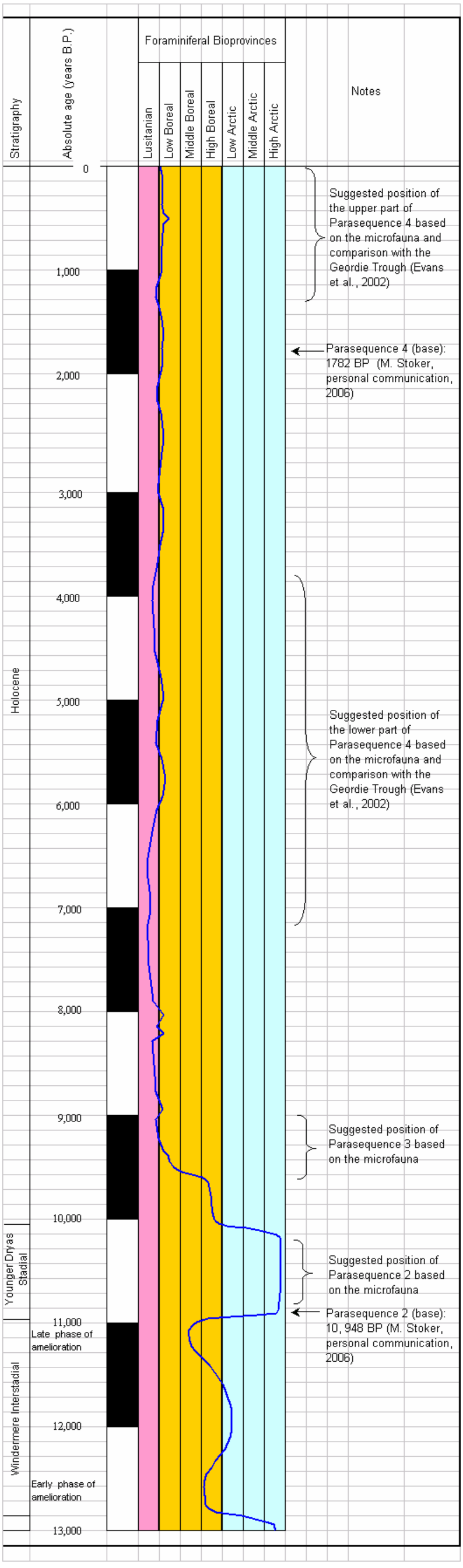

Figure 7. Generalised climatic fluctuations through the Late-glacial and Holocene of Scotland as reflected in biozones (based on data in Dansgaard et al, 1969; Peacock & Harkness, 1990; Schönwiese, 1995; Evans, 2002