BAY OF FIRTH, ORKNEY: CORING REPORT

MARCH 2012

SUMMARY

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1. **Introduction**

The investigation of the Bay of Firth (Figure 1) using a multi-disciplinary team studying the submerged landscapes of the area has been on-going since 2009. The project has developed in a phased way commencing with bathymetric survey of the seabed coupled with survey of the intertidal zone for remnants of the archaeology of the bay from the Mesolithic period to the present day. Completion of the bathymetric mapping of the bay in 2010 was followed by a study of the sub-bottom structure and sediments using a boomer system in June 2011. The integration of these information sources enabled a model of rockhead topography to be produced and the distribution of sediment bodies pertenant to the history of infilling of the Bay of Firth to be mapped.

The identification of a circular feature on the seabed south of Damsay in 2009 and its possible anthropogenic origin has focused attention on understanding the timing and nature of inundation of the bay in order to address when this feature would have been in a terrestrial context. While the bathymetric survey and boomer investigation of the structure and geology of the bay provides important clues to the history of development of the bay only direct evidence of the nature and timing of the change in the bay can provide sufficiently robust evidence to contextualise the circular feature. As a consequence a phase of coring was undertaken to provide samples for investigation.

This report describes this phase of work to core the identified sediment bodies and assess their contained palaeoenvironmental record and ages. The results of this work is presented in sections 2 and 3.

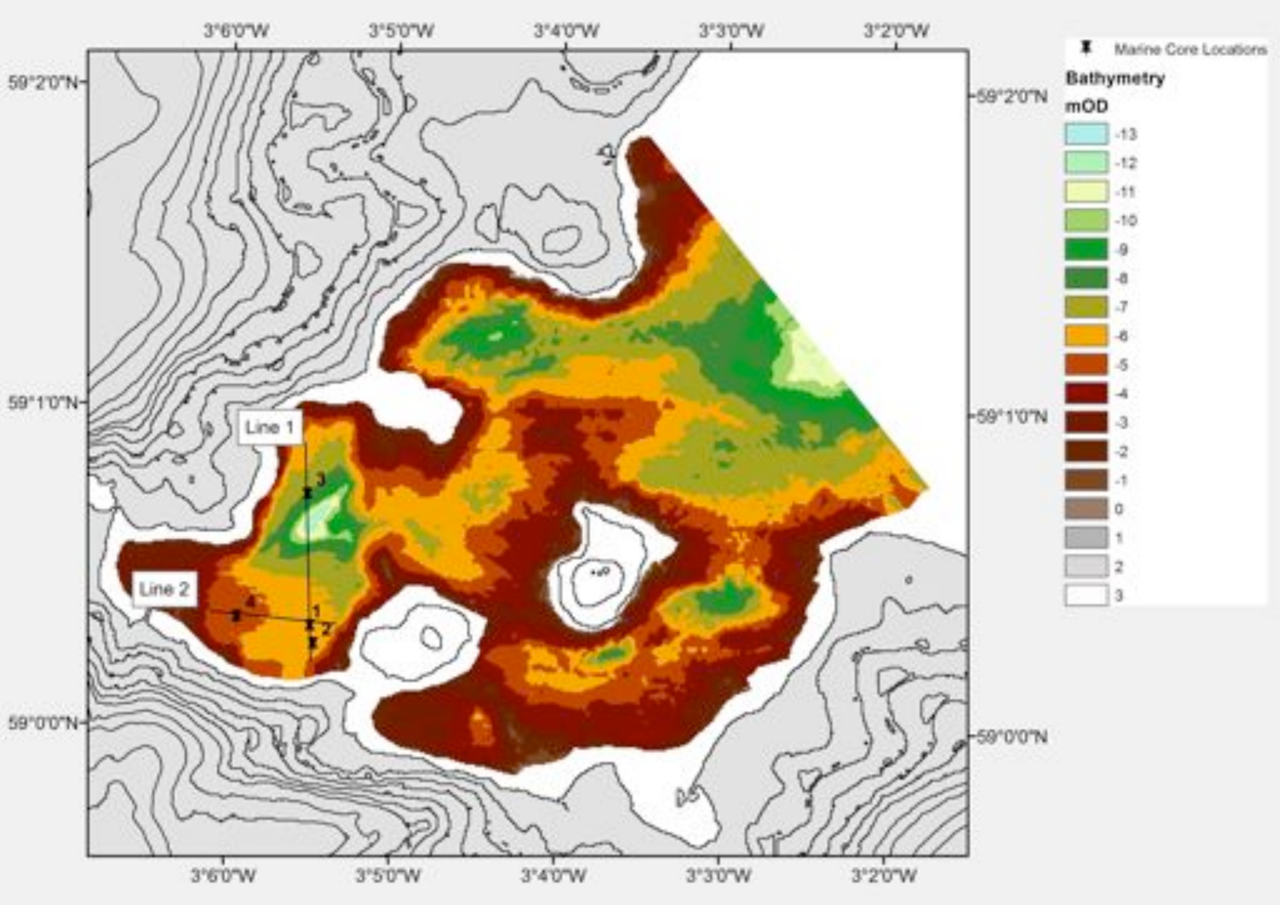

Figure 1. Site location plan

1.1 Bathymetry

The results of parts of the multibeam swath bathymetric survey (using a 468 kHz SEA Swathplus multibeam) of the Bay of Firth (Figure 2) has previously been reported and a number of significant features were identified during this survey. Of particular relevance to the current report was the discovery of a number of basin-like features (Figure 2, Areas A-C). Consideration of the origin of these features led to the suspicion that they might be repositories for sedimentary sequences that potentially would record evidence for the pre-inundation history of the bay as well as information on the nature of the flooding and post-flooding changes impacting on the study area. Completion of the bathymetric survey was a prerequisite for understanding the history of change within the bay and defining areas for sub-bottom profiling.

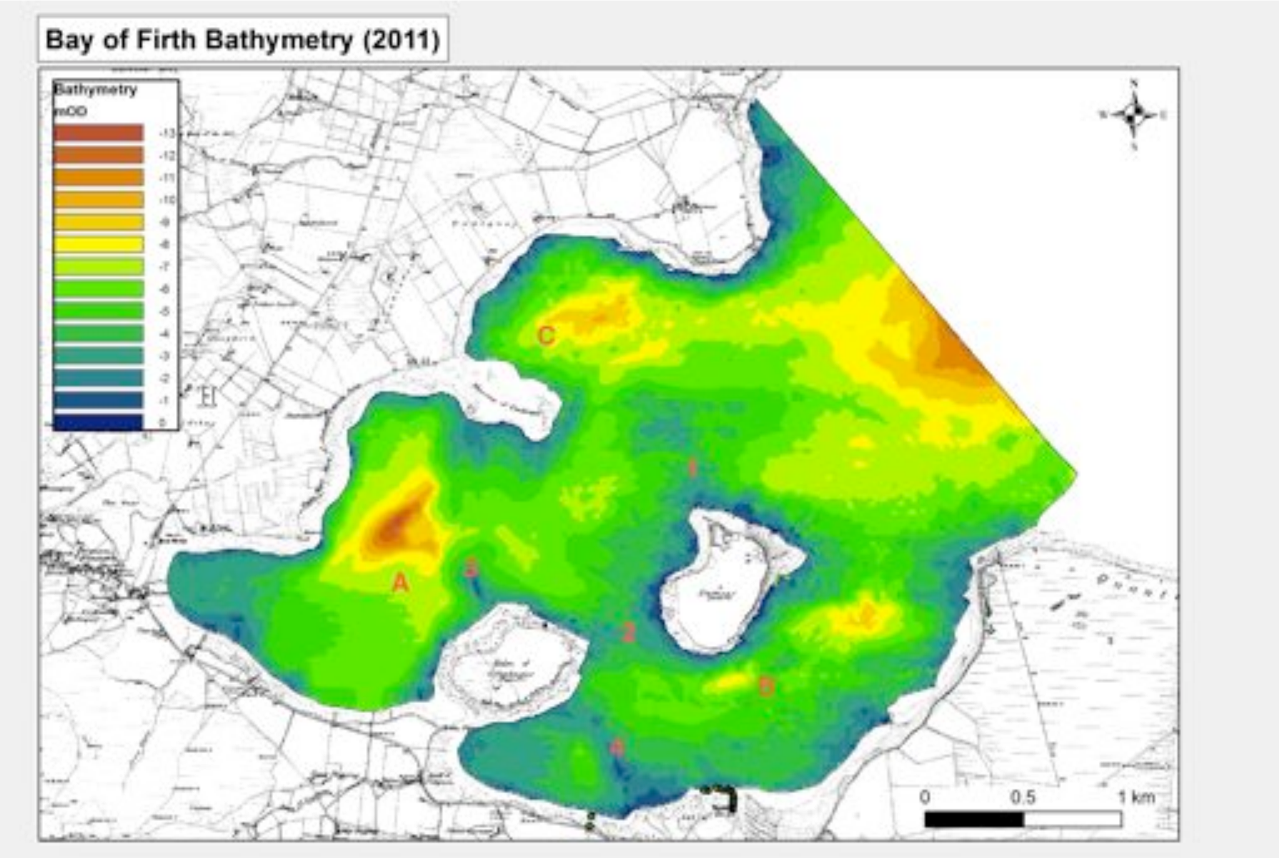

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Figure 2. Bathymetric map of the seabed in the Bay of Firth.

The features noted of significance within the bay were:

1. Area A. Large, deep basin like feature in the inner part of the bay. This feature was surrounded by a sea bed with a texture unlike that over much of the bay (i.e. the sea floor appeared relatively smooth around the basin but comparision with a rougher surface texture of much of the seafloor elsewhere in the bay). Additionally the eastern edge of the basin contained a series of geomorphological features that appeared to indicate erosion and deposition from the east into the basin.

2. Area B. A small elongated basin south east of Damsay with a prominent rock ledge running NW to SE along its eastern margin.

3. Area C. A small basin feature east of Coubister.

In addition two rock ridges have been identified either side of Damsay (1 and 2, Figure 2). Other rock ridges are found east of Area A (3) and south of Grimbister (4).

1.2 Sub-bottom profiling

In June 2011 a IKB Seistec boomer system was used to acquire data within the bay in those locations (Areas A-C, Figure 2) identified in the bathymetric survey as likely to contain sediment bodies suitable for sampling in order to elucidate the bay's environmental history. The distribution of lines are shown in Figure 3. The three basin-like areas identified as of high potential were surveyed but only in Area A (Finstown Bay) were extensive suites of sediments located. Small volumes of sediment were located in Areas B (east of Damsay) and C (east of Coubister). Areas B and C are not discussed further although remain important for future investigaiton.

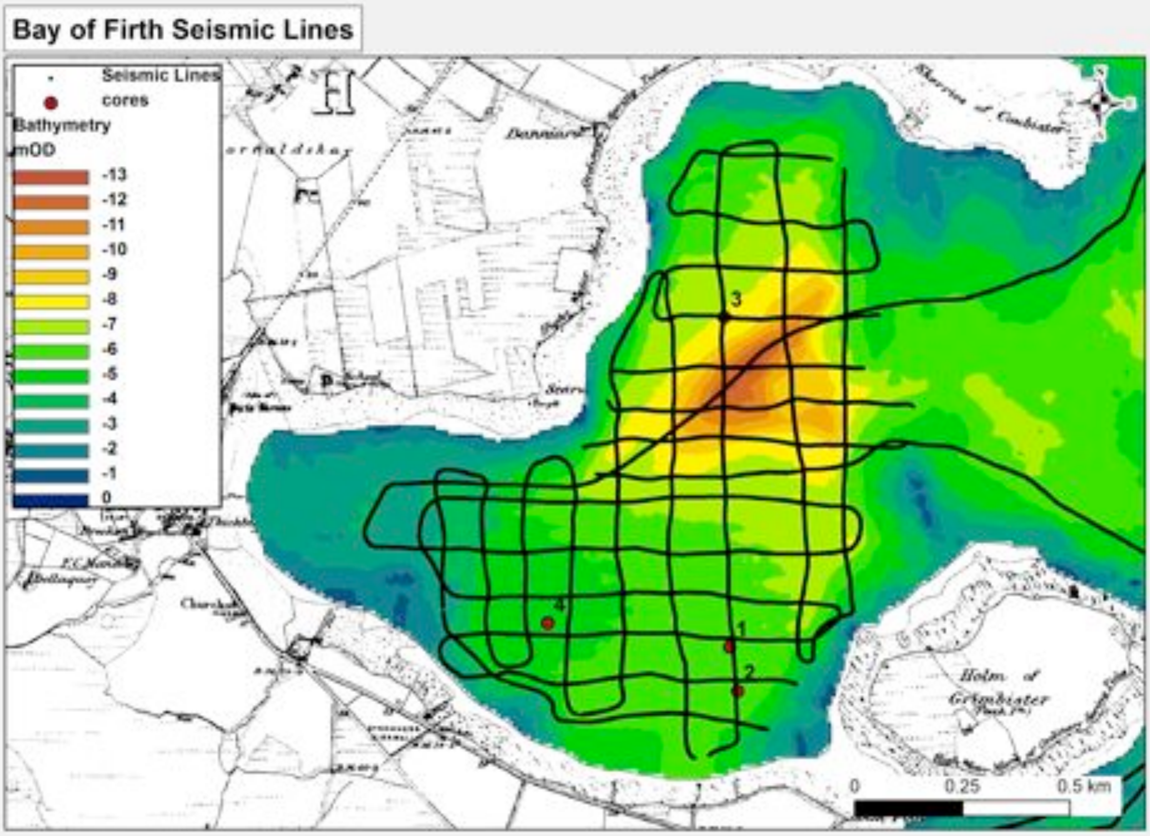

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Figure 3. Boomer survey transect lines.

Within the Finstown Bay area (Area A) a significant body of sediment (Figure 4A/B) was discovered to be infilling the basin like feature (Figure 5) with a long axis running north to south. Comparison between the bathymetry and rockhead topography modelled from the boomer data indicate that the basin like feature on the seabed today (Area A, Figure 2) appears to be an erosive feature cut into the sediments infilling the basin (Figure 4A) and the extent of the basin is significantly larger than that previously inferred from the bathymetry alone. The distribution of sediments filling this basin largely conforms to the distribution of smoothed seabed surface noted in 1.1 above.

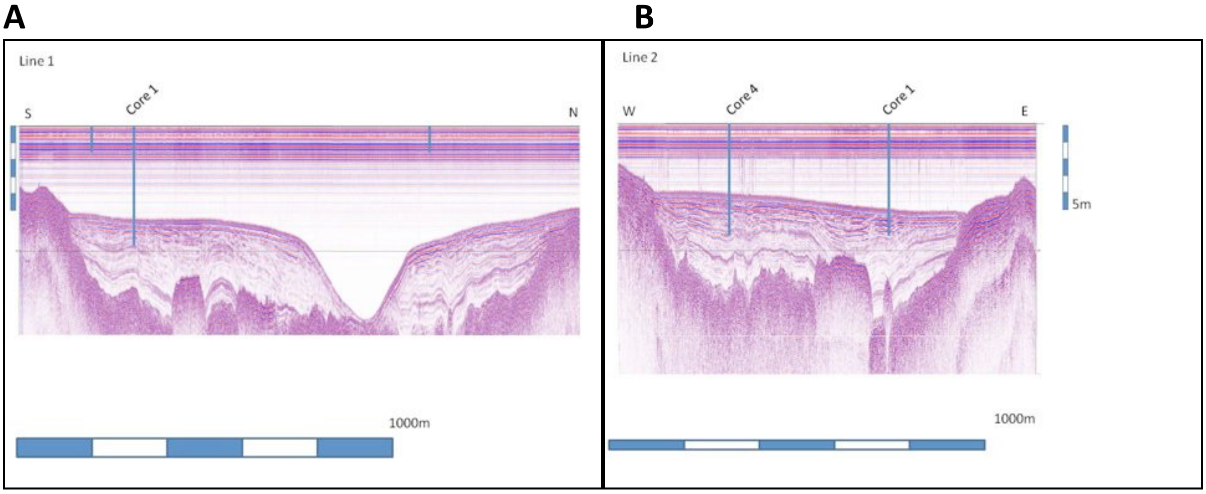

Figure 4. A: Sub-bottom profile and core 1. **4.B:** Sub-bottom profile and cores 1 and 4.

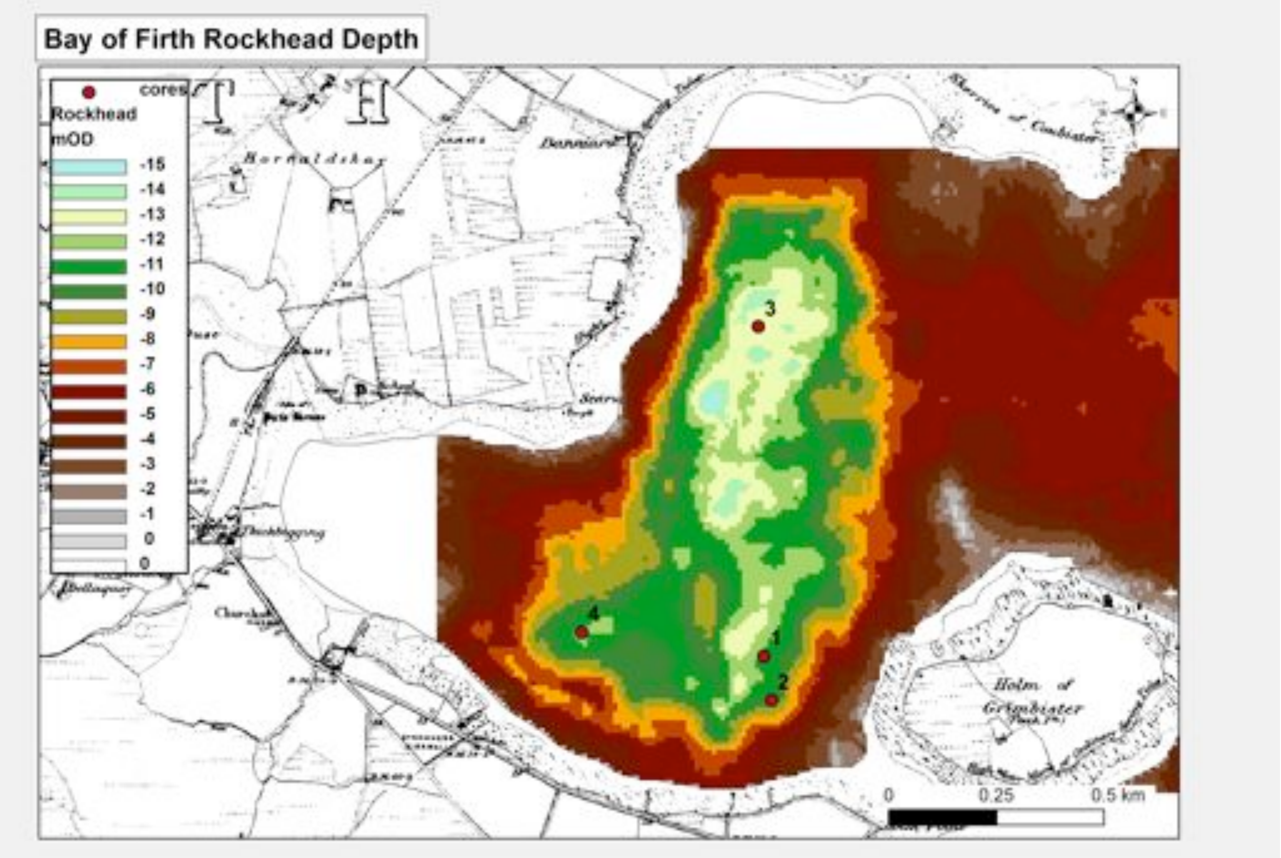

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Figure 5. Mapped extent of 'lake' basin and position of the coring sites.

A number of discrete seismic units were identified within the basin that suggests a complex history to basin formation and filling and that sedimentary packages relating to the pre-inundation history of the basin as well as the post inundation history are probably present. These sequences appear to be up to 8 meters in thickness and from the shape of the basin there is a strong possibility that prior to inundation by the sea following sealevel rise that lacustrine conditions prevailed in the earlier Holocene period.

1.3 The evolution of submerged features of the Bay of Firth

The combined evidence from the swath bathymetric survey and the boomer survey indicates that landscape history within the bay has passed through a number of phases of development that can be summarised as:

1. Erosion of the bay and excavation of the rock cut basins (A-C) (Event 1). This probably occurred most recently during the last glacial maximum (although probably exploiting a pre-existing topography).

2. Infilling of the eroded surface through filling of topographic hollows by pockets of sediment (Unit A). The seismic characteristics of this unit include strong coherent reflectors that are probably associated with well defined internal bedding. Infilling of the topographic hollows may be associated with deglaciation within the catchment.

3. Temporary stabilisation associated with Event 2. This may be of late Pleistocene or early Holocene date.

4. Deposition of basal widespread unit (Unit B). Seismically this unit exhibits weak, laterally continuous uniform reflectors. Units clearly onlap the basal reflector at the basin margins signifying infilling of a basin. The presence of the rock ridge feature 3 (see above and Figure 2) indicates that drainage to the east was likely to have been impeded and consequently standing water would have accumulated in the basin until it overtopped the easterly ridge. This might imply that Unit B may be lacustrine in origin.

5. Strong reflector of Event 3. This may suggest the infilling of the lake had occurred and that the reflector represents a terrestrialisation of the sequence perhaps through the development of peaty facies and their subsequent compaction through weathering and later compaction as a result of loading by later sedimentary units.

6. Deposition of Unit C with a seismic characteristic of parallel, planar reflectors and towards the top the unit is marked by a series of strong/high amplitude events between which discontinuous reflectors onlap the major amplitude events.

7. In place Unit C grades upwards into Unit D which exhibits a signature of strong, parallel to seabed reflectors. Unit C also shows some angular truncation on an eroded surface with downlap by Unit D. Unit C likely represents a mixed sequence of marine sedimentation showing intervals of deposition and erosion. Unit D grades uniformly into recent seafloor sediments. The main erosion event seen between C and D is most clear near to the rock barrier (3) to the east. Here the erosion has cut through C into unit B to remove over 5m of sediment. The deep cutting suggests a major change in erosive power..

2.1 Methods

Fieldwork was undertaken in September 2011. Fieldwork was conducted using two small survey vessels and a Livingstone corer (Figures 6 and 7) was selected for coring. Previous attempts to core the seabed had been made with a gouge auger with limited success.

Figure 6. Livingstone corer used to take samples

Figure 7. Coring taking place in Finstown Bay.

Positioning of the boreholes was undertaken using DGPS (Digital Geographical Positioning System) mounted on the coring vessel. Once the boats were positioned they were held in place with three sea anchors and drilling commenced. Coring was undertaken in water depths of up to 8m and this presented some challenges in ensuring program as unsupported drill rods bent in the moving water column (Figure 8). Four drill sites were selected for investigation and core recovery of up to 2.75m was achieved at one of the locations (core 4).

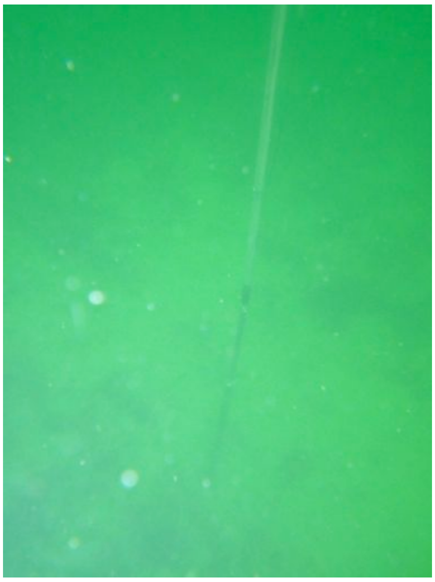

Figure 8. View of coring rods emplaced on seabed and resulting warping of rods hindering coring.

Recovered cores (Figure 9) were briefly logged and then wrapped in cling film to prevent dessication and contamination (Figure 10). Cores were returned to the laboratory and sub-sampled for assessment.

Figure 9. Core samples of marine sands and silts From core 1.

Figure 10. Core preparation of transportation and storage.

2.1a Sample processing for ostracods and foraminifera

21 samples from two of the cores were selected for foraminifera and ostracods. From core 1 (10 samples) the sampled interval was between 0-175cm. From core 4 (11 samples) the sampled interval covered 25-275cm. Each sample was weighed and put in a ceramic bowl and, first, thoroughly dried in the oven. Boiling water was then poured on the sample and a little sodium carbonate added to help remove the clay fraction on washing. It was then left to soak. Next, it was washed through a 75 micron sieve with hot water and the resulting residue decanted back into the bowl for drying back in the oven. The samples broke down readily and when dry, they were stored in labelled plastic bags. Picking was undertaken under a binocular microscope. First the residue was put through a nest of dry sieves (>500, >250 and >150 microns) and representatives of the foraminiferal and ostracod faunas were picked out with a fine camel-haired brush from a tray, a fraction at a time. They are stored on 3x1" faunal slides for record purposes. Other interesting "organic remains" were also noted (see Tables 2 and 3 - upper) on a presence/absence basis. Abundance of foraminiferal and ostracod species, on the other hand, was estimated by eye and by experience, semi-quantitatively (Tables 2 and 3 - mid and lower).

The results are colour-coding to help explain the ecological preferences of the various species. It must be stated, however, that very little is known of the distribution of these organisms in Orkney at the present day and to this end it would seem highly desirable, if not essential, to undertake a survey of the modern foraminiferal and ostracod faunas for comparative purposes.

2.1b. Sample processing for diatoms

Twenty-one selected samples were subject to preparation for diatom analysis. The samples were taken from a two sediment cores (cores 1 and 4) extracted from the Bay of Firth, Orkney following a series of remote sensing techniques to illustrate areas of the bay conducive to the preservation of fine grained, and potentially organic, sediments. From core 1 (10 samples) the sampled interval was between 0-175cm. From core 4 (11 samples) the sampled interval covered 25-275cm. The aim of the analysis was to determine the provenance of the sediments recovered and to date possible changes in the coastal configuration of the bay with varying salinity regimes as the sea level changed through the Holocene. The analysis also allows the environmental context of the sediments in relation to their environment of deposition to be determined.

The sediment samples were prepared according to standard laboratory techniques (Barber and Haworth, 1981) involving distillation on a hotplate with Hydrogen peroxide to remove any organic matter and then a series of washes with distilled water to concentrate the diatoms and reduce the amount of clay and silt particulate matter.

Diatom species were identified with reference to Hendey (1964) and Van der Werf and Huls, 1957-74). Diatom nomenclature follows Hartley (1986) and salinity and lifeform classification is based upon Vos and de Wolf (1993) and Denys (1991/2). In general, polyhalobous and mesohalobous diatom classes broadly reflect marine and brackish conditions whilst oligohalobous and halophilics classes reflect freshwater and terrestrial environments.

2.1c. Samples for dating

Samples for radiocarbon dating were selected following detailed biostratigraphical analyses. In the absence of clear organic horizons suggesting a terrestrial or lacustrine environment, it was decided to date the base of both cores. This would allow an assessment of the sedimentation rates as well as providing an independent check on the ages provided. Two methods have been followed. Firstly, selected 1cm^3 of material was sliced and packaged for standard AMS dating from Core 1 at 175cm depth and from Core 4 at 275cm depth. Secondly, a 5cm slice of the whole core was selected for foraminifera dating. This was sliced at 170-175cm (Core 1) and 265-270cm (Core 4). Careful picking of all the individuals within the slice allows a radiocarbon date to be obtained should the samples sent using conventional dating prove insufficient in the amount of carbon they may contain. In addition, the two sets of dates will allow a check for dating accuracy as they should provide a similar age profile.

3. Results

3.1 Sediment cores

Sediments were recovered from four core sites (Figures 3 & 5) and the longest cores were selected for further study (cores 1 and 4). Core stratigraphies are shown in Table 4. The two cores studied are remarkable uniform in composition (Figure 9) and are dominated by grey organic silts. Core 1 is composed of grey-brown organic silts with shelly horizons at 20-25cm depth. Core 4 has a matrix of grey brown organic silts but much greater concentrations of shells at 30-40cm, 60-65cm, 100-120cm and 200-205cm.

The fine grained nature of the silts and clays reflects sedimentation in a sheltered environment, with limited wave action and therefore the cores lack coarser sands and gravels associated with more exposed coastal environments. Whilst the sediments within the cores analysed do not display any fully organic units, which would indicate lacustrine (lake) or terrestrial sedimentation, there is a suggestion at the base of core 4 that the sediments are becoming slightly more organic. It is unfortunate that the coring set up used was not able to penetrate deeper in to the sediments and confirmation of the presence of such organic units must await a future coring mission with a more heavy duty coring rig to provide the necessary stability and control in such water depths.

3.2 Foraminifera and ostracods

Core 1

The results from the 1.75m sequence of Core 1 are shown in Table 2. Foraminifera and ostracods were found in all of the ten samples examined. Molluscs and plant remains were found in eight samples. Fish remains were found in five, insect remains in two and charophyte oogonia in one. The microfauana are characterised as "shallow near-marine/outer estuarine communities associated with algae" throughout (Table 2). The foraminiferal assemblages are very similar all through the sequence (except for 40-45cm which is almost barren). The colour coding used indicates grey for species of estuaries and lagoons (mud and sandflats) and blue for marine inner shelf and estuary mouth species (on sediment or clinging to algae). The environment would appear to have been rather protected and shallow with quite warm water temperatures. The species associated with algae (especially *Ammonia batavus* and *Elphidium macellum*) are large and the former named species very ornate.

The ostracods, are divided similarly into those indicative of the marine inner-shelf/estuary mouths (on substrate and/or algae) (colour-coded blue) and shallow marine/lagoonal forms, littoral/sublittoral in habit (living on algae) (colour-coded green). By comparison with the foraminifera the ostracod distribution is much more patchy, their diversity being quite low, sometimes only of one species, whereas in the sample from 20-25cm some 16 species were found, many of them very common! This must reflect something about the nature of the sediment which appears to be decalcifying the ostracods to some extent. It is widely recognised that at many Pleistocene and Holocene sites ostracod valves are more prone to decalcification than the generally heavily butressed foraminiferal tests.

Elements of the ostracod fauna are indicative of cold/cool "northern" indicators (from what we know of the present distribution of modern ostracods in the British Isles); these are shown in blue typeface (Tables 2 and 3). These include *Pontocypris mytiloides* that has been recorded from numerous, mainly northerly, British localities, at depths down to 80 metres on a variety of coarse substrates and *Xestoleberis depressa* that is recorded almost exclusively from water of 20-60 metres depth, associated with coarse substrates and algae and is frequently found around the coasts of Britain, especially in the north, and Scandinavia (Athersuch *et al.,* 1989). On the other hand, there are two other ostracod species (in red typeface) which are generally considered warm "southern" indicators. The significance of these speices is difficult to address due to our poor understanding of modern Orcadian faunas however, if the sediments were from an interglacial or even the Early Holocene such occurrences would not be surprising as these "non-analogue" ostracod faunas appear to be common; their presence in sediments of more recent age remains to be ascertained.

Core 4

The results from the 2.50m sequences between 25-275cm are shown in Table 3. Ostracods and plant remains were found in all of the samples, foraminifera in ten, molluscs in nine, fish remain in seven and insect remains in five. In this particular core both the foraminifera and the ostracods have a patchy distribution, the lower half of the core (below 125cm) being generally low to very low in diversity. The upper sequence (25-105cm) is therefore characterised as "near-marine shallow protected sea-grass and algal communities" (Table 3). Both the foraminifera and ostracods are diverse (up to 13 species being recorded in each case) and common to abundant. It is notable that this part of the sequence contains huge numbers of the marine agglutinating foraminifer *Eggerelloides scaber* in this interval, and to some extent lower down the core. By comparison its presence was quite limited in Core 1 (Table 2). *Eggerelloides scaber* occurs in high abundance in the seasonal layer, in shallow water areas (*c.* 10-20m) with slightly less than normal marine salinity (commonly less than 33‰) in the Oslofjord (Elisabeth Alve (University of Oslo) pers. comm.). It has also been recorded in the Fleet lagoon in Dorset in tens of thousands in the shallow *Zostera* sea-grass beds, in salinities slightly less than fully marine.

The remainder of core 4, from 125-275cm, is characterised as "near-marine microfaunas developing slowly as area floods; patchy with some decalcification" (Table 3). Even in the lowermost part of the core there is no real difference to these near-marine faunas although their occurrence is less, but certainly no suggestion of brackish-water, saltmarsh and the like occurring, and no reworked freshwater ostracods to suggest pre-flooding conditions may lay very near the base of the core.

3.3 Diatoms

Core 1

The key diatom species from the 1.75m sequences of Core 1 are shown in Table 5. Diatoms were found in all samples analysed (same depths as the foraminifera and ostracoda). The diatom assemblage for Core 1 exhibits, at the base of the sequence, the clastic sediments composed of silts and sands have increasing numbers of Polyhalobous-Mesohalobous (marine-brackish) diatom taxa. Increasing numbers of marine and marine-brackish species, including *Diploneis didyma*, *Achnanthes delicatula* and *Navicula digito-radiata* occur in the silts suggesting deposition on mud or sandflats (Vos and de Wolf 1993). The organic silt unit towards the base of the core is characterized by polyhalobous and mesohalobous species including *Paralia sulcata,* Cocconeis scutellum*, Rhaphoneis surirella* and *Rhaphoneis amphiceros.* The presence of these brackish species together with the aeophile *Diploneis interrupta* indicates deposition within an inter-tidal environment. The results from the diatom analysis complement results from foraminifera and ostracod analysis (section 3.2) in suggesting that the species inhabit shallow estuarine or lagoonal conditions.

Core 4

The results from the 1.75m sequences of Core 1 are shown in Figure 11. All samples had abundant species and allow a diatom assemblage diagram to be produced. The core is predominantly comprised of assemblages typically found within an estuarine environment. Species diversity indicate predominantly shallow water conditions with fully marine, deep water species largely absent. The assemblage is dominated by *Paralia sulcata*, a typical species that inhabits a wide range of intertidal habitats and together with *Coconeis scutellum, Rhaphoneis surirella* suggest species that are adapted to living attached to silt and sand flats. The Poly-mesohalobous species *Diploneis didyma* and Nitzschia concur in this interpretation of a relatively sheltered marine embayment with lowered salinity preference. A core depth of 100-200cm exhibits species with a clearer marine, estuarine preference. As the base of the core is approached there is some indication of slightly shallower conditions and reducing salinity. However, there is no evidence of saltmarsh conditions within the core sequence analysed.

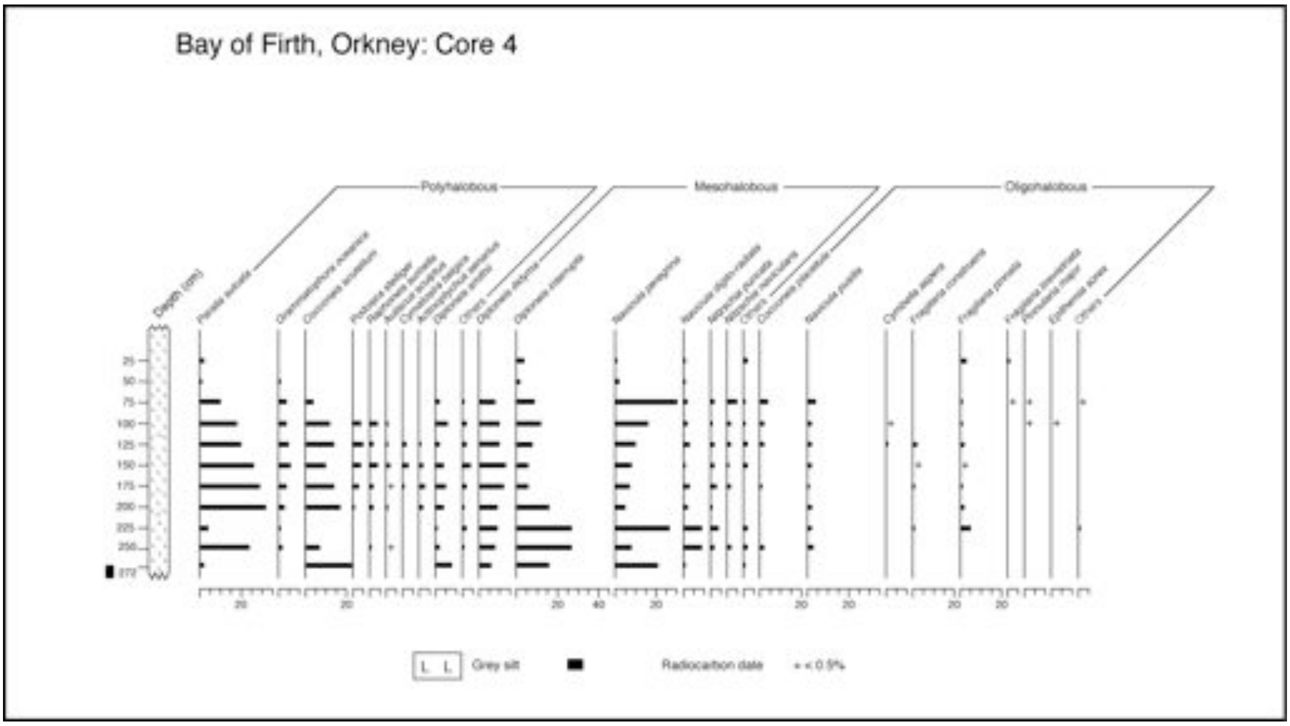

Figure 11. Diatom assemblages from Core 4.

3.4 Radiocarbon dating

Four samples for radiocarbon dating have been submitted to Beta Analytic as detailed in section 2.1c and results should be returned by May 2012. An addendum to the report will be provided once the dates have been received.

4. Discussion

Results from the survey (as outlined in section 1) are complemented by the program of sediment sampling, collection and analysis. Critical areas highlighted from the bathymetric survey and the subsequent sub-bottom profiling allowed targeted coring to be undertaken within the bay. The deepest areas were not cored due to limitations with the coring equipment used, nevertheless, areas samples showed continuity in sedimentation as evidenced by the microfossil analysis. The analyses of the cores in terms of lithostratigraphy and biostratigraphy allow an assessment of the possible mode of deposition of the sediments to be determined in Area A of the inner Bay of Firth, Orkney.

Lithostratigraphic interpretation and microfossils contained within the sediments concur in supporting a conclusion that the sediments were laid down in relatively shallow, marine waters suggestive of an estuarine, inner shelf environment. The fine-grained nature of the sediments suggest a quiet, sheltered embayment which would allow the gradual build up of sediment in natural hollows across the bay. These deeper embayments are sediment rich and allow organic silts and clays to build up. The base of the cores, especially the deepest (Core 4) has a change in sedimentation towards the base with more organic material evident. This is confirmed by the microfossil analysis which shows a reduction in salinity at a depth of 260-270cm. Coring was hindered at the site due to tension in water depths of up to 8m and thus further sediment recovery was not possible. It is hoped that a deeper recovery will be possible at the site with a suitable coring rig.

It has been highlighted that the Bay of Firth has the potential to provide a Holocene palaeoenvironmental history (to be confirmed by the dating analysis) and that the possibility of lacustrine (lake) or terrestrial sediments attesting to a time when sea levels were demonstrably lower than present are held within sediments deeper in the bay. This organic material, once recovered, will allow further investigation into the potential for prehistoric occupation within the bay linked to anomalies found as a result of previous work undertaken within the bay over the last two years.

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Core 1		**Core 4**	
Depth	**Wt**	**Depth**	**Wt**
0-5cm	30g	25-30cm	45g
20-25cm	30g	50-55cm	60g
40-45cm	30g	75-80cm	30g
60-65cm	25g	100-105cm	40g
80-85cm	30g	125-130cm	30g
100-105cm	30g	150-155cm	30g
120-125cm	30g	180-185cm	25g
140-145cm	20g	200-205cm	20g
160-165cm	30g	225-230cm	30g
179-175cm	25g	250-255cm	20g
		270-275cm	25g

Table 1. Samples processed for foraminifera and ostracods.

Core 1 depth (cm)	**Lithostratigraphy**
0 -20	Dark grey silt
20-25	Brown-grey silty clay with shells
25-120	Dark grey organic silt
120-128	Grey-brown silt, organic
128-150	Grey-brown silt
150-175	Brown organic silt
Core 4 depth (cm)	**Lithostratigraphy**
0-30	Fine sandy shelly grey silt
30-40	High shell concentration- bivalves, gastropods
40-60	Sandy, shelly grey silt
60-65	High shell concentration
65-100	Sandy, shelly grey silt
100-120	High shell concentration
120-140	Dark grey organic shell rich silt
140-160	Lighter grey organic silt
160-200	Dark grey organic silt
200-225	High shell concentration
225-250	Dark grey organic silt
250-280	Light grey organic silt

Table 4. Stratigraphy of Cores 1 and 4

Paralia sulcata	Polyhalobous (marine) Planktonic
Podosira stelliger	Polyhalobous, tychcopelagic, common in Plankton
Triceriatum favus	Polyhalobous, Planktonic southern North Sea
Cocconeis scutellum	Polyhalobous, Epiphytic (attaches to plant material/alagae)
Rhabdonema minutum	Polyhalobous
Actinoptychus scenarios	Polyhalobous, Planktonic (common littoral sp)
Actinoptychus undulatus	Polyhalobous, Planktonic
Rhaphoneis surirella	Polyhalobous, episammic (attaches to sand grains/typical of sandy tidal flats)
Rhaphoneis amphiceros	Polyhalobous, episammic (attaches to sand grains/typical of sandy tidal flats)
Cosconodiscus marginatus	Polyhalobous, Planktonic-common on North Sea coasts
Coscinodicus radiatus	Polyhalobous, Planktonic
Nitzschia punctata	Mesohalobous-polyhalobous(brackish-marine), muddy tidal flats
Nitzschia navicularis	Mesohalobous, epipelic (attaches to muds), typical on muddy tidal flats
Nitzschia panduriformis	Mesohalobous-polyhalobous, frequent along English Channel
Scoliopleura turmida	Mesohalobous (brackish), epipelic
Diploneis didyma	Meso-Polyhalobous, epipelic
Diploneis smithii	Polyhalobous, epipelic (sandflats)
Diploneis interrupta	Mesohalobous, episammic

Table 5. Key diatom species present within the Bay of Firth sediment cores 1 and 4 and lifeform information (after Hendey, 1964).

ORGANIC REMAINS										
DEPTH	0-5cm	20-25cm	40-45cm	60-65cm	80-85cm	100-105cm	120-125cm	140-145cm	160-165cm	170-175cm
outer estuarine/marine foraminifera	x	x	x	x	x	x	x	x	x	x
outer estuarine/marine ostracods	x	x	x	x	x	x	x	x	x	x
molluscs	x	x		x	x	x		x	x	x
fish remains	x			x			x		x	x
plant debris		x	x	x	x	x		x	x	x
charophyte oogonia		x								
insect remains					x					x

Ecology	*Shallow near-marine/outer estuarine communities associated with algae; faunas (especially the ostracods) quite patchy with some decalcification*

FORAMINIFERA										
DEPTH	0-5cm	20-25cm	40-45cm	60-65cm	80-85cm	100-105cm	120-125cm	140-145cm	160-165cm	170-175cm
Elphidium williamsoni	xx	xx		xx	xx	xx	xx	xx	xx	xx
Elphidium excavatum	xx	xx		xx	xx	x	x	x	xx	xx
Elphidium macellum	x	xxx		x	xx		x	x	x	xx
Ammonia batavus (large & ornate	x	xxx		xx	xxx		x	xx	x	x
Haynesina germanica	x	x		xxx	xx	x	x	xx	xx	xx
Nonion depressulus		xx		x	x	x	x	x	x	x
Bulimina marginata		x		x	x	o				
Cibicides lobatulus		x		x						
Eggerelloides scaber		x	x	x			x	x		x
Bolivina sp		x		o	x					
lagenids		x		o	o				o	o
Quinqueloculina sp.		o								

▨ **estuaries and lagoons (mud and sandflats)**

🟦 **marine inner shelf/estuary mouths (on sediment or clinging t**

OSTRACODS										
DEPTH	0-5cm	20-25cm	40-45cm	60-65cm	80-85cm	100-105cm	120-125cm	140-145cm	160-165cm	170-175cm
Pontocythere mytiloides	xx	xx	x	x	x	x	x	x	xx	x
Loxoconcha rhomboidea	xx	xx		x						
Semicytherura nigrescens	x	xx		x	o			x		o
Hemicythere villosa	o	xx		o	x					
Cythere lutea	o	x		x	x			x	o	x
Leptocythere pellucida		xx		x	x					
Hirschmannia viridis		x		x	x			o	x	x
Callistocythere badia		x								o
Robertsonites tuberculatus		x		x	x					
Semicytherura cornuta		x								
Xestoleberis depressa		x								
Xestoleberis aurantia		x								
Aurila convexa		x								
Finmarchinella logani		x								
Leptocythere tenera		x								
Callistocythere littoralis		o								

🟦 **marine inner shelf/estuary mouths (on substrate and/or algae**

🟩 **shallow marine/lagoonal; littoral/sublittoral (phytal on algae)**

cold/cool “northern” indicators

warm “southern” indicators

Organic remains are recorded on a presence (x)/absence basis only

Foraminifera and ostracods are recorded: o - one specimen; x - several specimens; xx - common; xxx – abundant/superabundant

Table 2. Core 1 microfossil distributions.

ORGANIC REMAINS

DEPTH	25-30cm	50-55cm	75-80cm	100-105cm	125-130cm	150-155cm	180-185cm	200-205cm	225-230cm	250-255cm	270-275cm
outer estuarine/marine foraminifera	x	x	x	x	x	x	x	x	x		x
outer estuarine/marine ostracods	x	x	x	x	x	x	x	x	x	x	x
molluscs	x	x	x	x	x	x	x	x			x
fish remains	x	x	x	x	x					x	x
plant debris	x	x	x	x	x	x	x	x	x	x	x
insect remains	x	x	x	x					x		

Ecology	***Near-marine shallow protected sea-grass and algal communities***				***Near-marine microfaunas developing slowly as area floods; patchy with some decalcification***						

FORAMINIFERA

DEPTH	25-30cm	50-55cm	75-80cm	100-105cm	125-130cm	150-155cm	180-185cm	200-205cm	225-230cm	250-255cm	270-275cm
🟦 ***Eggerelloides scaber***	xxx	xxx	xx	xxx	x	x	xx	x			o
🟦 ***Ammonia batavus*** (large & ornate)	xx	xx	xx	xx	x	x	x	xx	x		x
🟦 ***Elphidium excavatum***	xx	xx	xx	xx		x	x	xx			
🟦 ***Elphidium magellanicum***	xx	xx	x	x			x				x
🟦 ***Nonion depressulus***	xx	x	xx	xx			o				
🟦 ***Elphidium macellum***	xx	xx	xx	xxx	x	x	x	xx	o		xx
▨ ***Miliammina fusca***	xx	xx	xx	x							o
🟦 **lagenids**	x	x	x	x				x			
▨ ***Elphidium williamsoni***	x	xx	x	x			x	x			
🟦 ***Cibicides lobatulus***	x	o	x								
🟦 ***Elphidium gerthi***	x	x	x								
▨ ***Haynesina germanica***		xx	x	x		x	x				
🟦 ***Bulimina marginata***		x		x		o		x			o
🟦 ***Buliminella elegantissima***			x	x							

▨ **estuaries and lagoons (mud and sandflats)**

🟦 **marine inner shelf/estuary mouths (on sediment or clinging to algae)**

OSTRACODS

DEPTH	25-30cm	50-55cm	75-80cm	100-105cm	125-130cm	150-155cm	180-185cm	200-205cm	225-230cm	250-255cm	270-275cm
🟦 ***Pontocythere mytiloides***	xxx	xxx	xx	xxx	x	xx	x	xx	x	x	x
🟩 ***Xestoleberis depressa***	xx	x	xx	x			x	x			
🟩 ***Hemicythere villosa***	xx	x	xx	xxx			x	x			x
🟩 ***Heterocythereis albomaculata***	x		o	o							
🟩 ***Cythere lutea***	x	x	x	x			x	x			
🟦 ***Leptocythere pellucida***	x			o							
🟩 ***Hirschmannia viridis***	x	x	x	x							
🟩 ***Semicytherura nigrescens***	x	x	x	xx							
🟩 ***Semicytherura undata***	x										
🟩 ***Callistocythere littoralis***	o		o								
🟩 ***Paradoxostoma variabile***	o										
🟦 ***Finmarchinella logani***	o										
🟦 ***Leptocythere tenera***	o										
🟦 ***Robertsonites tuberculatus***		x		o							
🟩 ***Loxoconcha rhomboidea***			xx	x							
🟦 ***Callistocythere badia***				**o**							

🟦 **marine inner shelf/estuary mouths (on substrate and/or algae)**

🟩 **shallow marine/lagoonal; littoral/sublittoral (phytal on algae)**

cold/cool "northern" indicators

warm "southern" **indicator**

Organic remains are recorded on a presence (x)/absence basis.

Foraminifera and ostracods are recorded: o – one specimen; x – present (several specimens); xx – common; xxx – abundant/superabundant

Table 3. Core 4 microfossil distributions.