BAY OF FIRTH, ORKNEY: CORING REPORT

MARCH 2014

SUMMARY

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EXECUTIVE SUMMARY

As part of the HS sponsored Rising Tides Project, Orkney, a purpose built raft was designed and used as a platform for the acquisition of sediment cores in the Bay of Firth and Loch of Stenness using a VibeCore-D. Cores were successfully obtained in water depths to 8m with continuous sediment sampled down to sub-seafloor depths of 3m. The system proved extremely effective at obtaining quality core material for palaeo-environmental analysis and should also provide samples for C14 dating. The combined use of the adaptable, portable coring platform and the low impact coring device offers the possibility of obtaining key core information not only in the shallow waters surrounding Orkney but in many other near shore coastal and shallow loch sites of interest to palaeo-landscape reconstructions in Scotland and further should considerably aid the wider goals of establishing robust sea-level curve records.

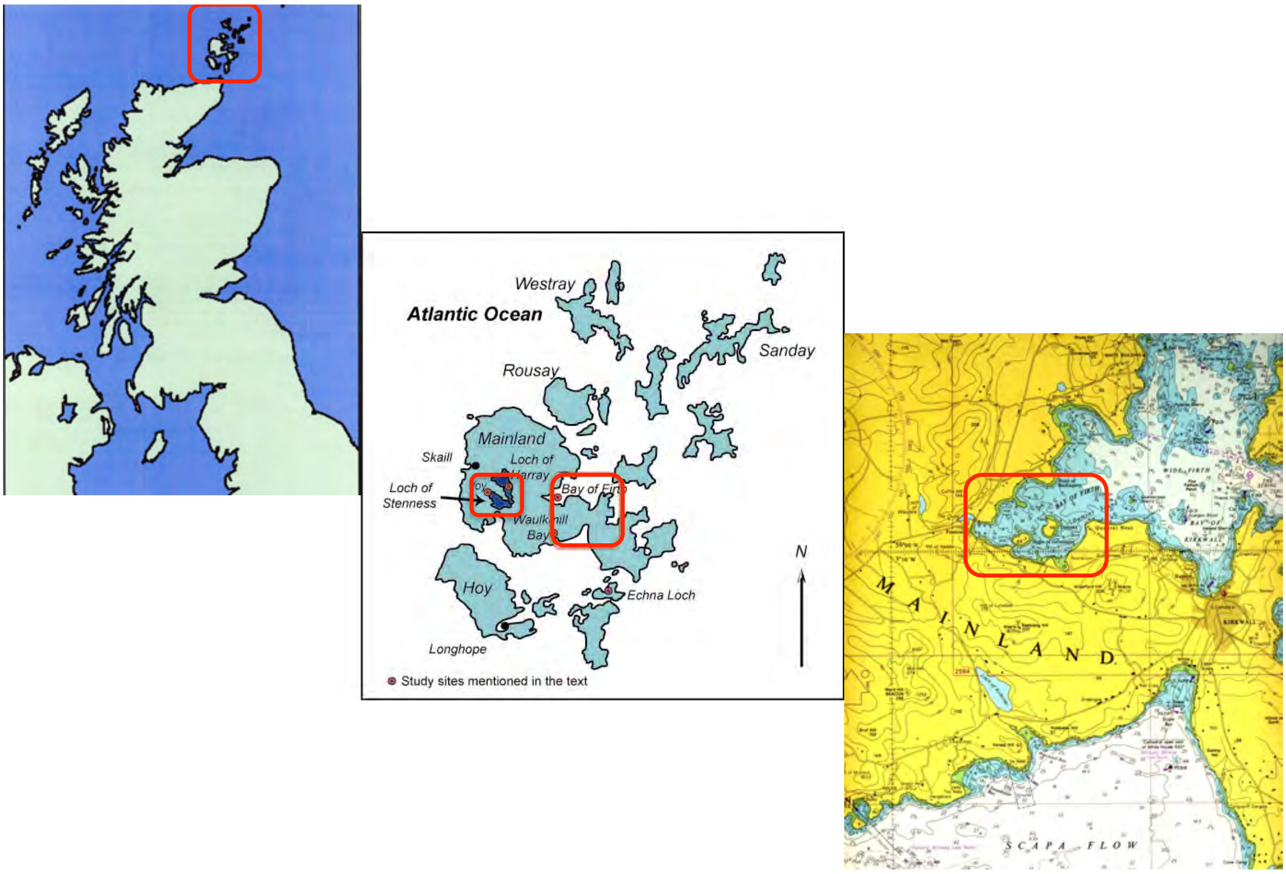

Figure 1. Orkney, location of the Research Areas in the Loch of Stenness and the Bay of Firth

1. Introduction

The Rising Tides investigation in Orkney began in 2006 with an investigation of past sea-level change through the analysis of sediment cores (Wickham-Jones et al 2008, 2009, 2010, 2011, 2012) and expanded into the Bay of Firth (Figure 1; Figure 2) where a multi-disciplinary team has been studying the submerged landscapes of the area since 2009 (Bates et al 2013a). The project has developed in a phased way commencing with bathymetric survey of the seabed of the Bay of Firth coupled with survey of the intertidal zone for remnants of the archaeology of the bay from the Mesolithic period to the present day (ibid). 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 (Bates et al 2011). The integration of these information sources enabled a model of rockhead topography to be produced and the distribution of sediment bodies pertinent to the history of infilling of the Bay of Firth to be mapped (Bates et al 2013a).

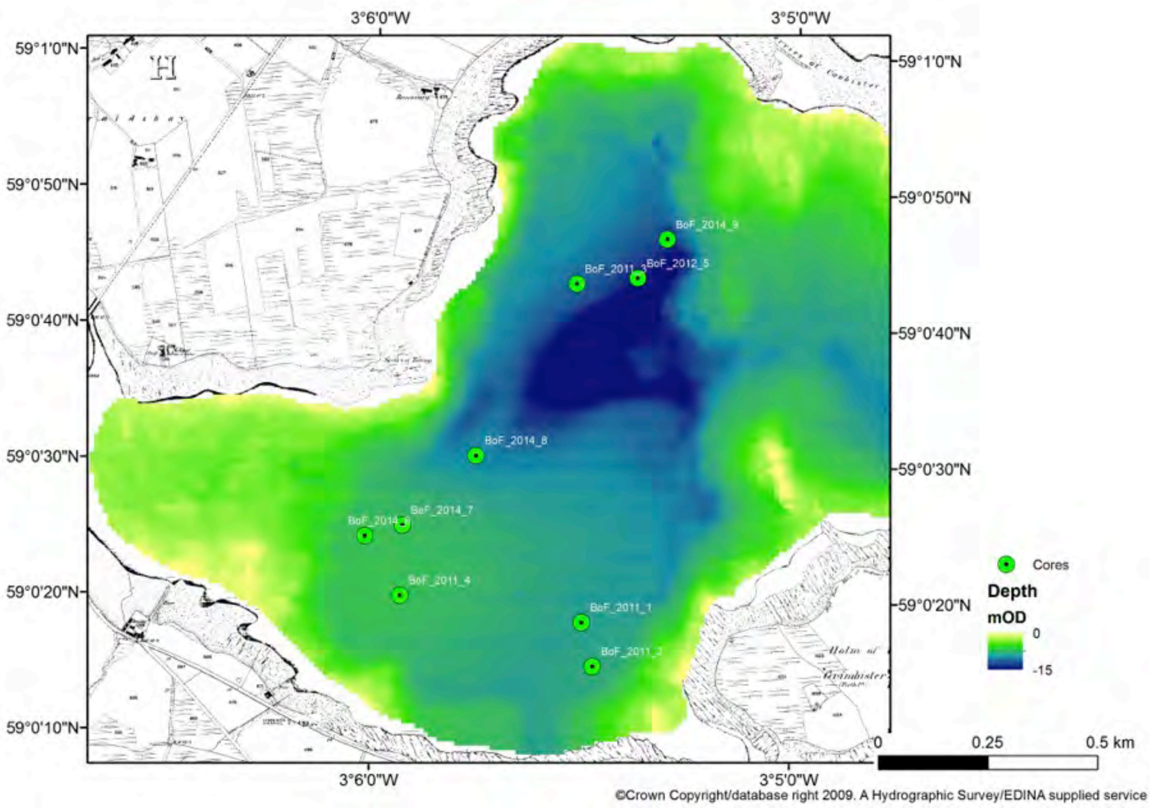

Figure 2. Bathymetric map of inner Bay of Firth showing location of cores 1-9.

While the bathymetric survey and boomer investigation of the structure and geology of the bay provided 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 deposits and begin the search for archaeological remains within the sequences. As a consequence two separate phases of the project have followed. One involved diver ground truthing of seabed features and a second involving coring to provide samples for investigation. Initial coring was undertaken in 2012 with a Livingstone Corer (Bates et al 2012). This was followed by a trial with a SDI VibeCore-D corer (Bates et al., 2013b). These projects have also expanded work from the Bay of Firth into the Loch of Stenness.

The current report describes the wider testing of a SDI Vibe-Core-D system across both the Bay of Firth and Loch of Stenness. Application of this new coring method, utilising a purpose build raft for coring in both the Bay of Firth and the Loch of Stenness, has demonstrated the ability to core the identified sediment bodies using the VibeCore-D system in a variety of settings and water depths. This has implications for the widespread application of this approach to shallow marine settings across Scotland.

2. Methods

2.1. Coring

Fieldwork was undertaken in January 2014 in both Bay of Firth and Loch of Stenness. Fieldwork was conducted using a small rib and a VIbeCore-D deployed from a purpose built raft (Figure 3).

A **B**

Figure 3. A: Close-up view of raft. **B:** raft under tow.

The location of the cores had been determined through the study of the bathymetric and sub-bottom seismic data previously collected from the study areas (Figures 2 and 5). Positions for coring were located in order to ground truth the geophysics and to return samples to the laboratory for analysis as well as to trial coring in varying water depths and conditions. Positioning of the boreholes was undertaken using dGPS and echosounder to core in water depths to 8m. The raft was towed to selected locations by a small rib and once the raft was positioned it was secured using three large sea anchors and drilling commenced with the corer lowered through the moon pool of the raft via a tripod mechanism (Figure 3). The corer vibration mechanism is powered by 24V batteries that activate the vibratory mechanism once the assembly is on the seafloor in a vertical orientation. While vibrating the core is lowered steadily to achieve complete penetration with the full core barrel that is then hauled back to the surface for recovery. The drilling method presented some challenges in ensuring the unsupported drill was vertical on the seabed prior to drilling however, with practice a methodology was worked out to ensure adequate penetration of the seabed. Issues regarding extracting the core barrel once fully deployed in the seabed that had previously been encountered when the drill was deployed off the side of a vessel were eased by use of the derrick above the moon pool.

Figure 4. **A:** Drill corer being attached to core barrel.

B: recovery of full core barrel from sea bed

A

B

Once recovered the cores (Figure 4B) were wrapped in cling film once back on the raft in order to prevent desiccation and contamination. No attempt was made to extrude or cut the core in the field, rather, all sub-sampling and analysis of the core was achieved back in the laboratory. Descriptions for the cores are given in Tables 1-4.

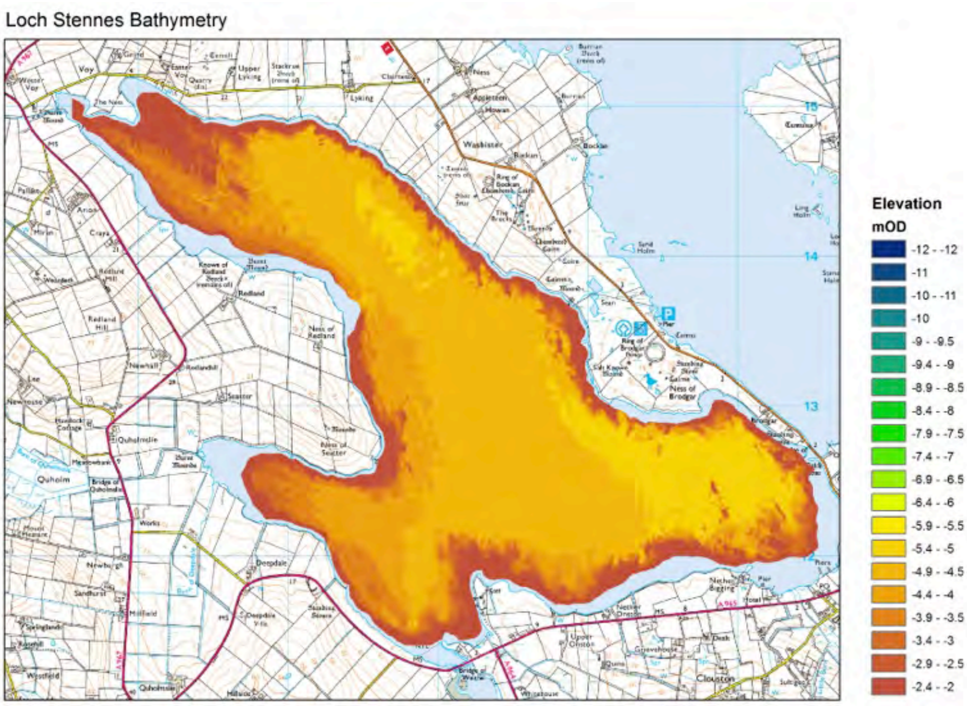

Figure 5. Combined bathymetric map of Loch of Stenness using data from SwathPlus, Tritech sonar and single beam echosounder.

2.2 Sample processing

Forams/ostracods

A total of 5 samples from Core 7 (Table 5), 25 samples from Core 8 (Table 6) and 13 samples from core 9 (Table 7) from the Bay of Firth were examined and 15 samples from Stenness, Core 1 (Table 8) were subjected to palaeoenvironmental analysis using the microfauna (foraminifera and ostracods).

Each sample was weighed and put in a ceramic bowl, broken up by hand into smaller pieces, and 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 hand-hot water and the resulting residue decanted back into the bowl for drying back in the oven. The samples generally broke down quite 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 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 5-8).

3.Results

3.1. Sediment cores

Detailed lithological descriptions of the cores are summarised in Tables 1-4. A maximum depth of 2.62m of core was achieved in core 8 from Bay of Firth (Table 2). Cores recovered from the Bay of Firth (Tables 1-3) are plotted in Figure 6 (including lithologies from the previous investigations). In all cases sediments recovered from the Bay of Firth are similar to those previously encountered in core 5 (Bates et al., 2012; 2013b) where minerogenic silts/sands (upper parts of cores) of presumed brackish/marine derivation overlay carbonate rich silts (similar to those previously described at the base of core 5 and in the Loch of Brockan) containing freshwater shells from a carbonate rich lake. The single sediment core from the Loch of Stenness (Table 4) produced similar minerogenic silts/sand overlying carbonate rich sediments but where these carbonate rich silts appeared to contain significant quantities of organic material.

As in the previous trial (Bates et al., 2013b) core recovery was good with those units penetrated well preserved in the core. There was little evidence of deformation when cleaned cores were examined.

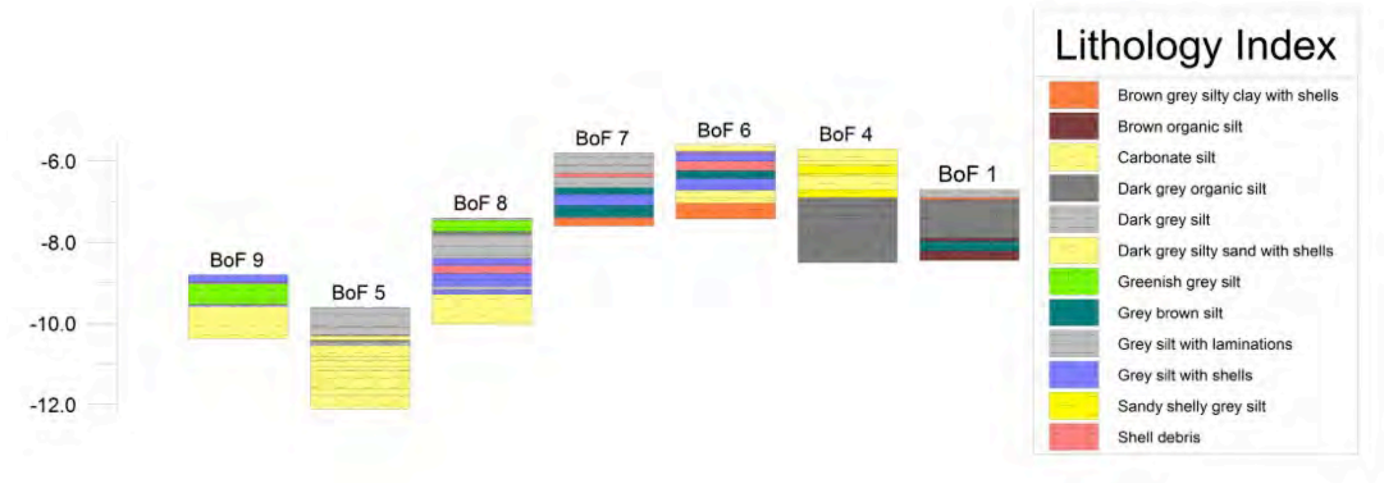

Figure 6. Core lithology from selected cores in the Bay of Firth.

0 - 20	Dark grey shelly very fine silt. Soft and unconsolidated
	---sharp contact---
20 - 22	Shell debris – no matrix
	---sharp contact---
22 - 72	Greenish grey to greyish green very fine silt. Soft but cohesive. Occasional shell fragments throughout.
	---sharp contact---
72 - 77	Greyish green silt with shell fragments. Occasional patches of grey carbonate silt (eroded from below). Soft and structureless.
	---sharp contact---
77 - 157	Very pale grey silt – rich in carbonate. Common freshwater shell fragments and complete shells. Massive and structureless.
	---base of borehole 157---

Table 1. Bay of Firth, core 7 Lithology

0 - 7	Dark grey silt with stone fragments. ---abrupt contact---
7 - 33	Greenish grey very fine silt. Soft and structureless. Occasional small shell fragments. ---diffuse contact---
33 - 41	Mid grey silt with flecks of brown organic material. Soft and structureless. Very rare shell fragments. ---abrupt contact---
41 - 100	Mid grey laminated silts with brown organic laminae (2-3mm thick) wavy and inclined across core. ---abrupt contact---
100 - 117	grey shelly silt. Structurelss and massive. Occasional large shell fragments ---abrupt contact---
117 - 136	Laminated grey silt with dipping laminae, laminae 2-4mm thick and consisting of organic material. Occasional fragments of comminuted shell. ---diffuse contact---
136 - 152	grey silt with shell fragments. Soft and structureless ---diffuse contact---
152 - 168	Greyish brown to brownish grey silt with common shell fragments ---diffuse contact---
168 - 178	Grey silt. Very few shell fragments ---abrupt contact---
178 - 188	Grey silt with common freshwater and marine shell fragments. Possibly some thin root filaments. Loose and unconsolidated. ---eroded/undulating/sharp contact---
188 - 262	Pale grey carbonate rich silt with shell fragments. ---base of borehole 262---

Table 2. Bay of Firth, Core 8 Lithology

0 - 20	Dark grey shelly very fine silt. Soft and unconsolidated ---sharp contact---
20 - 22	Shell debris – no matrix ---sharp contact---
22 - 72	Greenish grey to greyish green very fine silt. Soft but cohesive. Occasional shell fragments throughout. ---sharp contact---
72 - 77	Greyish green silt with shell fragments. Occasional patches of grey carbonate silt (eroded from below). Soft and structureless. ---sharp contact---
77 - 157	Very pale grey silt – rich in carbonate. Common freshwater shell fragments and complete shells. Massive and structureless. ---base of borehole 157---

Table 3. Bay of Firth, Core 9 Lithology

0 - 55	Dark grey soft silt with occasional shell fragments. Unconsolidated.	
	---diffuse contact---	
55 - 62	As above but slightly firmer.	
	---abrupt contact---	
62 - 72	As above but very fine partings with organic material. Partings are sub horizontal and 2-3mm thick. Soft and pliable.	
	---abrupt contact---	
72 - 78	Mid grey very fine silt.	
	---abrupt contact---	
78 - 81.5	Dark grey silt. Soft and pliable.	
	---sharp contact---	
81.5 - 88	Pale grey to yellowish grey silt with freshwater shells.	
	---abrupt contact---	
88 - 141	Pale grey silt. Occasional shell fragments. Structureless and massive.	
	---sharp contact---	
141 - 147	Brown to greyish brown organic silt. Possibly bedded with discontinuous laminae of grey silt. Occasional shell fragments.	
	---sharp contact---	
147 - 150	Pale grey silt	
	---sharp contact---	
150 - 152	Brown silt with pale grey patches. Organic content.	
	---abrupt contact---	
152 - 159	Dark brown organic silt with occasional fragments of shell	
	---diffuse contact---	
159 - 173	Grey brown silt slightly organic silt. Occasional shell fragments.	
	---sharp contact---	
173 - 173.5	Brown organic silt.	
	---sharp contact---	
173.5 - 179	Grey brown organic silt with patches of brown silt. Shells present.	
	---sharp contact---	
179 - 183	Brown organic silt	
	---diffuse contact---	
183 - 194	Grey silt with shells	
	---diffuse contact---	
194 - 200	Brown organic silt	
	---diffuse contact---	
200 - 210	Grey silt with shells	
	---base of boreholes 210---	

Table 4. Loch of Stenness, Core 1. Lithology

3.2 Foraminifera and ostracods

These results are shown in Tables 5-8 and are colour-coded to facilitate the ecological interpretation (based on extensive data contained in Murray (2006) for the foraminifera, Athersuch *et al.* (1989) for the marine/brackish ostracods, and Meisch (2000) for the freshwater ostracods). Outer estuarine/marine foraminifera are colour-coded bright blue - these are species of shallow near-marine embayments, living on sediment or clinging to marine algae and sea-grass. Outer estuarine/marine ostracods are colour-coded a lighter blue - these are essentially marine species but are also able to penetrate outer estuaries, often living on marine-algae. Species labelled as brackish foraminifera (and colour-coded light grey) occur in estuaries and shallow embayments; they can survive a wide range of salinities from near-marine right down to low brackish (but never freshwater) and live on mud and sandflats. Brackish ostracods (colour-coded lime-green) are denizens of estuarine tidal flats and creeks. Finally freshwater ostracods are colour-coded light sky-blue.

In addition to the detailed analysis of the foraminifera and ostracods there are listed (in Tables 5-8, uppermost table) various “organic remains” including molluscs - brackish/marine and freshwater forms are differentiated, plant remains/seeds/megaspores, insect remains, cladocera (water-fleas) including their ephippia (eggs cases), and charophyte (stonewort) oogonia (often extremely common although they are invariably decalcified, the outer calcareous cortex being missing and only the organic inner lining surviving). They are, finally, a few fish remains, but they are invariably rare.

Bay of Firth

Core 7. The evidence from this core suggests that from 140-162cm core depth (-7.20 to -7.42m O.D.) marine/near-marine microfaunas exist but a display a rather restricted microfauna. Below, 170-178cm (below -7.50m O.D.) the sediments appear decalcified, but remnants suggest it was near-marine.

Core 8.

0 - 7	Dark grey silt with stone fragments.
	---abrupt contact---
Jul-33	Greenish grey very fine silt. Soft and structureless. Occasional small shell fragments.
	---diffuse contact---
33 - 41	Mid grey silt with flecks of brown organic material. Soft and structureless. Very rare shell fragments.
	---abrupt contact---
41 - 100	Mid grey laminated silts with brown organic laminae (2-3mm thick) wavy and inclined across core.
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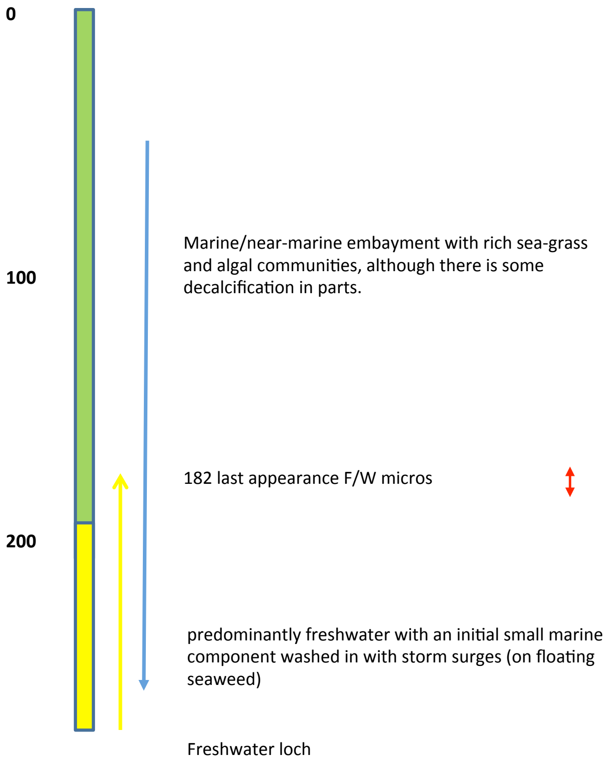


Figure 7. Bay of Firth, Core 8 stratigraphy Green: dark grey silts, yellow carbonate rich silts. Yellow arrow – distribution of freshwater ostracods, blue arrow – distribution of brackish/marine forams/ostracods. Red arrow – distribution of ?reworked sand in core.

The evidence from this core suggests that from 20-202cm (-7.66 to -9.42m O.D.) marine/near-marine embayment existed with a rich sea-grass and algal community (Figure 7). There is some decalcification however in parts of this sequence. The freshwater component is present below 182cm (c.-9.20m O.D.). Between 184-190cm (-9.22 to -9.30m O.D.) many black rock fragments are present in the same, possibly indicative of a high energy event perhaps associated with erosion or storm surge. From 220-258cm (-9.60 to -9.98m O.D.) there is a transitional phase with a strong freshwater competent but with an initial small marine component washed in with storm surges (on floating seaweed) as sea-level rises. This appears to be possibly associated with a phase in which the coastal barrier may be breaking down. Below 260cm (-10m O.D.) a freshwater loch is evident with no marine or brackish influences.

Core 9 The evidence from this core suggests that from 30-86cm (-9.10m to -9.66m O.D.) marine/near marine assemblages are present. A freshwater component exists below 72cm (c. 9.50m O.D.). Between 88-94 (-9.68 to -9.75m O.D.) freshwater environments exist with a limited brackish component suggesting a transitional phase. . Below 96 (-9.76m O.D.) freshwater loch conditions exist.

Loch of Stenness

Core 1 By contrast with the cores from the Bay of Firth, the single core from Stenness (Figure 8.) is peculiar. Below 102cm freshwater conditions dominate. Above this (between 82 and 102cm) is a phase of transition (similar to that observed in Bay of Firth) in which initially very low brackish conditions (with ostracods only) prevailed. Above 82cm a very restricted foraminiferal fauna exists dominated by *Miliammina fusca*. This represents a curious brackish sedimentary environment that exhibits traces of decalcification.

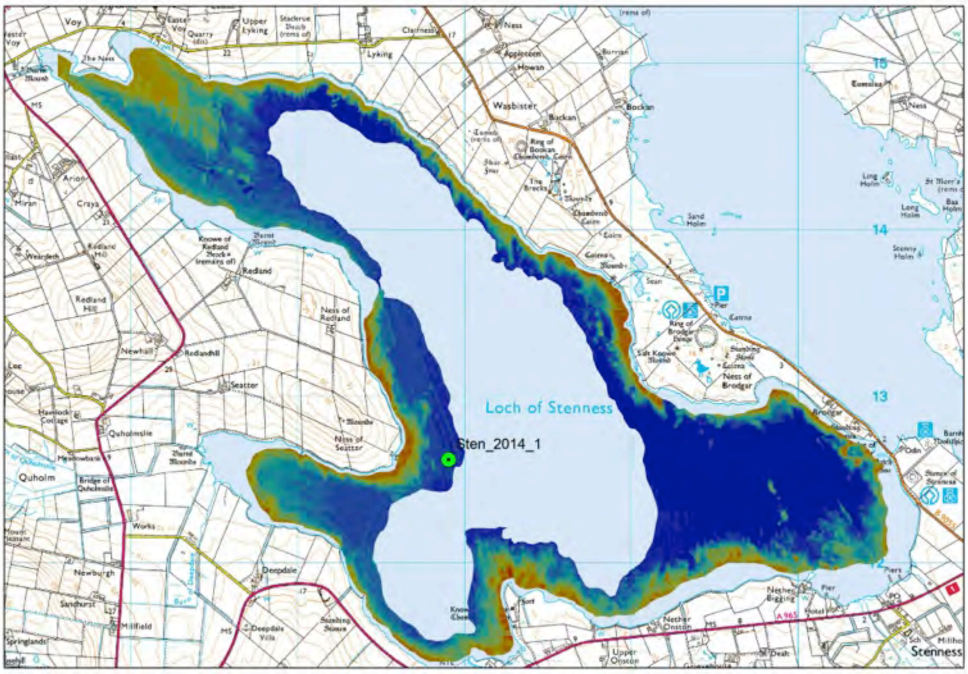
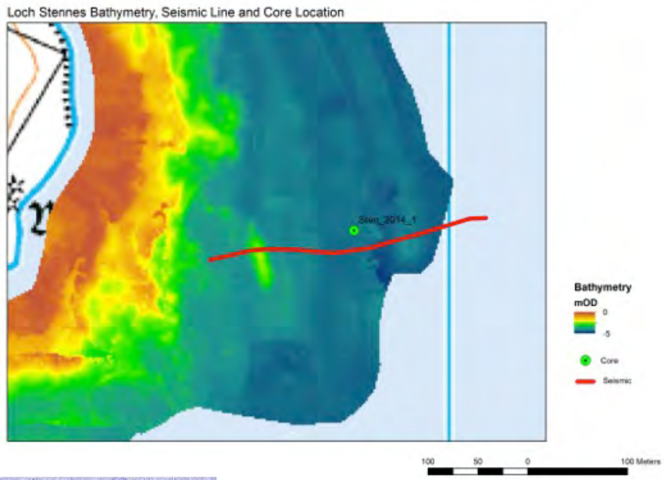


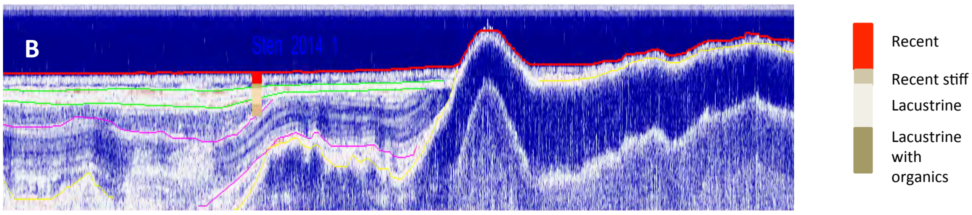
Figure 8. Bathymetric map (SwathPlus) of Loch of Stenness showing location of core 1.

This core is currently under analysis as part of a more detailed investigation of the mound-like feature that appears on both sonar and seismic surveys of the loch taken during earlier phases of the project (Figure 9.).

Figure 9.
A: Bathymetry and position of seismic profile and borehole relative to 'mound-like feature'.

B: Seismic profile through lake fill sediments and ground truth core (Sten 2014 1).





4. Discussion
This work underlines the suitability of the cores for producing material for detailed palaeo-enivronmental reconstructions.

In the Bay of Firth the differences between the findings in the three boreholes (in terms of ecological successions) and with borehole 5 (previously investigated) indicate that spatial variability in sequence records is common (a point worth considering for the future when formulating plans for site investigation and determining the number and location of cores to be selected for drilling). Additionally it is clear that although lithological changes are apparent in the cores (i.e. the transition from basal carbonate rich silts to minerogenic silts) changes in the associated microfaunas do not respect these boundaries. This has implications for the picking of seismic profiles for boundaries that are meaningful in terms of regional environmental change.

In the Loch of Stenness it is hoped that further coring, possibly combined with diver survey, will help to shed light on the nature of the long mound-like feature. This is of particular interest given its position close to the monuments of the Heart of Neolithic Orkney and the dynamic change that is being revealed in the landscape here.

5. Summary

The results of the investigation have demonstrated that the method of drilling applied is a suitable and practical means of recovering drill core samples from shallow marine waters for low costs. Some minor problems were encountered in positioning the coring device vertically above the sea bed but with practice this was overcome.

The cores recovered some high quality samples that proved internally coherent and undisturbed by the drilling process. The high quality of the core enabled sampling for microfossils and dating from well provenanced stratigraphic horizons. The platform built was stable and core recovery good. Mechanisms for core recovery from the seabed worked well. The only limitation currently to be addressed regards the depth of core recovery possible. During the investigation a maximum of 2.62m of core was drilled. This was insufficient to sample all seismo-stratigraphic units identified and consequently this needs to be addressed. It is possible that in consolidated sediments, such as those drilled here, the core catcher used to retain soft, unconsolidated sediments in the core barrel is not needed and its removal may facilitate deeper drilling in the future.

Finally, the project has demonstrated the significance of core data for palaeo-enivronmental reconstruction and this has implications for long-term conservation. Detailed work has resulted in a degree of spatial variability even within the relatively small geographical area of the Bay of Firth and this is an important consideration for similar analysis and management anywhere. In this way the work trialled in Orkney is of demonstrable value in the wider sphere: around Scotland and in shallow, but economically significant, waters elsewhere

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BAY OF FIRTH, ORKNEY

CORE 7

ORGANIC REMAINS

DEPTH IN CORE	140-142cm	150-152cm	160-162cm	170-172cm	176-178cm
Depth O.D.	7.20-7.22m	7.30-7.32m	7.40-7.42m	7.50-7.52m	7.56-7.58m
outer estuarine/marine foraminifera	x	x	x		
outer estuarine/marine ostracods	x	x	x	x	x
brackish foraminifera	x	x	x		
estuarine/marine molluscs	x	x	f		
fish remains	x		x		
insect remains			x		

Ecology	*Marine/near-marine but a rather restricted microfauna*	*Decalcified, but remnants suggest it was near-marine*

OUTER ESTUARINE/MARINE FORAMINIFERA

DEPTH IN CORE	140-142cm	150-152cm	160-162cm	170-172cm	176-178cm
Depth O.D.	7.20-7.22m	7.30-7.32m	7.40-7.42m	7.50-7.52m	7.56-7.58m
Elphidium macellum	xxx	xxx	xx		
Ammonia batavus (large & ornate)	xx	x	xx		
Elphidium excavatum	xx	x	xx		
Nonion depressulus	x				
Eggerelloides scaber	o	x	x		
Cibicides lobatulus	o				

Foraminifera of shallow near-marine embayments, on sediment or clinging to algae

OUTER ESTUARINE/MARINE OSTRACODS

DEPTH IN CORE	140-142cm	150-152cm	160-162cm	170-172cm	176-178cm
Depth O.D.	7.20-7.22m	7.30-7.32m	7.40-7.42m	7.50-7.52m	7.56-7.58m
Pontocypris mytiloides	xxx	xxx	xx	xx	x
Cythere lutea	xx	x	xx		
Hirschmannia viridis	x	x	x		
Hemicythere villosa	x	xx	x		
Callistocythere badia	x	x	x		
Semicytherura nigrescens	o				
Callistocythere littoralis	o				
Leptocythere pellucida		x			

Essentially marine ostracod species, but able to penetrate outer estuaries (most phytal on algae)

BRACKISH FORAMINIFERA

DEPTH IN CORE	140-142cm	150-152cm	160-162cm	170-172cm	176-178cm
Depth O.D.	7.20-7.22m	7.30-7.32m	7.40-7.42m	7.50-7.52m	7.56-7.58m
Haynesina germanica	xxx	xxx	xxx		
Elphidium williamsoni	xx	xx	xx		
Miliammina fusca	x	x	x		

Foraminifera of estuaries and shallow embayments (brackish to near-marine, mud and sandflats)

Organic remains are recorded on a presence (x)/absence basis only; f – fragments only
Foraminifera and ostracods are recorded: x - several specimens; xx - common; xxx - abundant/superabundant

BAY OF FIRTH, ORKNEY

CORE 8

Many black rock fragments – major erosion event/storm surge? (► 182-184cm to 188-190cm ◄)

ORGANIC REMAINS

DEPTH IN CORE	20-22cm	36-38cm	50-52cm	70-72cm	90-92cm	110-112cm	130-132cm	150-152cm	170-172cm	182-184cm	186-188cm	188-190cm	190-192cm	200-202cm	220-222cm	226-228cm	230-232cm	234-236cm	240-242cm	244-246cm	248-250cm	252-254cm	254-256cm
Depth O.D.	7.60-7.62m	7.76-7.78m	7.90-7.92m	8.10-8.12m	8.30-8.32m	8.50-8.52m	8.70-8.72m	8.90-8.92m	9.10-9.12m	9.22-9.24m	9.26-9.28m	9.28-9.30m	9.30-9.32m	9.40-9.42m	9.60-9.62m	9.66-9.68m	9.70-9.72m	9.74-9.76m	9.80-9.82m	9.84-9.86m	9.88-9.90m	9.92-9.94m	9.94-9.96m
outer estuarine/marine foraminifera	x	x	x	x	x	x	x	x	x	x	x	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	x	x	x	x		x			x			
brackish foraminifera	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x		x	x	x
estuarine/marine molluscs	x	x		x	x	x	x	x	x	x	x	f	x				f						
fish remains	x	x						x		x													
insect remains						x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
charophyte oogonia									x	x	x	x	x	x									
freshwater ostracods										x	x	x	x	x	x	x	x	x	x	x	x	x	x
freshwater molluscs										x	x	x	x	x	x	x	x	x	x	x	x	x	x
cladocera										x	x		x	x	x	x	x	x	x	x	x	x	x
brackish ostracods											x												
Ecology	*Marine/near-marine embayment now established with rich sea-grass and algal communities, although there is some decalcification in parts. Freshwater component finally disappears at c.9.20m O.D.*														*Transitional phase. Coastal barrier breaking down. Still predominantly freshwater with an initial small marine component wa: storm surges (on floating seaweed) as sea-level rises*								

OUTER ESTUARINE/MARINE FORAMINIFERA

DEPTH IN CORE	20-22cm	36-38cm	50-52cm	70-72cm	90-92cm	110-112cm	130-132cm	150-152cm	170-172cm	182-184cm	186-188cm	188-190cm	190-192cm	200-202cm	220-222cm	226-228cm	230-232cm	234-236cm	240-242cm	244-246cm	248-250cm	252-254cm	254-256cm
Depth O.D.	7.60-7.62m	7.76-7.78m	7.90-7.92m	8.10-8.12m	8.30-8.32m	8.50-8.52m	8.70-8.72m	8.90-8.92m	9.10-9.12m	9.22-9.24m	9.26-9.28m	9.28-9.30m	9.30-9.32m	9.40-9.42m	9.60-9.62m	9.66-9.68m	9.70-9.72m	9.74-9.76m	9.80-9.82m	9.84-9.86m	9.88-9.90m	9.92-9.94m	9.94-9.96m
Ammonia batavus (large & ornate)	xxx	xx	x	xx	xx	xx	xx	xx	xx	xx	xx	xx	x	x	x	x		o	o	o	x	o	
Elphidium macellum	xxx	xx	o	xx	xx	xx	xx	xx	xx	x	x	xx	x	x	o	o	x	x	o	x	x		o
Nonion depressulus	xx	x		o		x	x	x	x	x	x	x		o									
Elphidium excavatum	xx	x	x	x	x	x	x	x	x	xx	xx	x	x	o									
Eggerelloides scaber	x	x	x	x	x	xx	xx	x	x		x	xx	x	x	o					o			o
Bulimina marginata	x	x																					
lagenids	x			o	o									o									
miliolids				o	x	x	xxx		xxx		o		o										
Nonion orbicularis						x				x	x												
Cibicides lobatulus						o																	

Foraminifera of shallow near-marine embayments, on sediment or clinging to algae

OUTER ESTUARINE/MARINE OSTRACODS

DEPTH IN CORE	20-22cm	36-38cm	50-52cm	70-72cm	90-92cm	110-112cm	130-132cm	150-152cm	170-172cm	182-184cm	186-188cm	188-190cm	190-192cm	200-202cm	220-222cm	226-228cm	230-232cm	234-236cm	240-242cm	244-246cm	248-250cm	252-254cm	254-256cm
Depth O.D.	7.60-7.62m	7.76-7.78m	7.90-7.92m	8.10-8.12m	8.30-8.32m	8.50-8.52m	8.70-8.72m	8.90-8.92m	9.10-9.12m	9.22-9.24m	9.26-9.28m	9.28-9.30m	9.30-9.32m	9.40-9.42m	9.60-9.62m	9.66-9.68m	9.70-9.72m	9.74-9.76m	9.80-9.82m	9.84-9.86m	9.88-9.90m	9.92-9.94m	9.94-9.96m
Pontocypris mytiloides	xxx	xx	xx	xx	xx	x	x	x	x	x	o	x		o			o						
Cythere lutea	xx	x		xx	xx	xx	xx	xxx	xx	x	x			x	o								
Hirschmannia viridis	xx	x		xx	xx	xx	xx	x	x	x	x	x	o										
Hemicythere villosa	xx	x		x		x	x	x	x	x	x	o	x	x						o			
Callistocythere badia	x				o		o																
Robertsonites tuberculatus	x	x		x	x			o		o	x	o	o										
Semicytherura nigrescens	x			o	x	x	xx	x	x	x		x											
Loxoconcha rhomboidea		o		xx	x								x										
Semicytherura undata				o		o	o																
Callistocythere littoralis				o																			
Xestoleberis depressa					x		xx		x														
Leptocythere pellucida						o	x		xx	xx		x	x	x	o								
Finmarchinella logani						o	o																
Aurila convexa						o																	
Semicytherura cornuta							x	o															

Essentially marine ostracod species, but able to penetrate outer estuaries (most phytal on algae)

BRACKISH FORAMINIFERA

DEPTH IN CORE	20-22cm	36-38cm	50-52cm	70-72cm	90-92cm	110-112cm	130-132cm	150-152cm	170-172cm	182-184cm	186-188cm	188-190cm	190-192cm	200-202cm	220-222cm	226-228cm	230-232cm	234-236cm	240-242cm	244-246cm	248-250cm	252-254cm	254-256cm
Depth O.D.	7.60-7.62m	7.76-7.78m	7.90-7.92m	8.10-8.12m	8.30-8.32m	8.50-8.52m	8.70-8.72m	8.90-8.92m	9.10-9.12m	9.22-9.24m	9.26-9.28m	9.28-9.30m	9.30-9.32m	9.40-9.42m	9.60-9.62m	9.66-9.68m	9.70-9.72m	9.74-9.76m	9.80-9.82m	9.84-9.86m	9.88-9.90m	9.92-9.94m	9.94-9.96m
Haynesina germanica	xxx	xxx	xx		x	xx	x	x	xx	xxx	xx	xxx	x	x			o				o		
Elphidium williamsoni	xx	xx	x	x	xx	x	x	x	xx	xxx	xxx	xxx	xx	x	x		x	o	x		o	x	o
Miliammina fusca						x			x														
Ammonia sp.										x	x												

Foraminifera of estuaries and shallow embayments (brackish to near-marine, mud and sandflats)

BRACKISH OSTRACODS

DEPTH IN CORE	20-22cm	36-38cm	50-52cm	70-72cm	90-92cm	110-112cm	130-132cm	150-152cm	170-172cm	182-184cm	186-188cm	188-190cm	190-192cm	200-202cm	220-222cm	226-228cm	230-232cm	234-236cm	240-242cm	244-246cm	248-250cm	252-254cm	254-256cm
Depth O.D.	7.60-7.62m	7.76-7.78m	7.90-7.92m	8.10-8.12m	8.30-8.32m	8.50-8.52m	8.70-8.72m	8.90-8.92m	9.10-9.12m	9.22-9.24m	9.26-9.28m	9.28-9.30m	9.30-9.32m	9.40-9.42m	9.60-9.62m	9.66-9.68m	9.70-9.72m	9.74-9.76m	9.80-9.82m	9.84-9.86m	9.88-9.90m	9.92-9.94m	9.94-9.96m
Cyprideis torosa											o												

Brackish ostracods of tidal flats and creeks

FRESHWATER OSTRACODS

DEPTH IN CORE	20-22cm	36-38cm	50-52cm	70-72cm	90-92cm	110-112cm	130-132cm	150-152cm	170-172cm	182-184cm	186-188cm	188-190cm	190-192cm	200-202cm	220-222cm	226-228cm	230-232cm	234-236cm	240-242cm	244-246cm	248-250cm	252-254cm	254-256cm
Depth O.D.	7.60-7.62m	7.76-7.78m	7.90-7.92m	8.10-8.12m	8.30-8.32m	8.50-8.52m	8.70-8.72m	8.90-8.92m	9.10-9.12m	9.22-9.24m	9.26-9.28m	9.28-9.30m	9.30-9.32m	9.40-9.42m	9.60-9.62m	9.66-9.68m	9.70-9.72m	9.74-9.76m	9.80-9.82m	9.84-9.86m	9.88-9.90m	9.92-9.94m	9.94-9.96m
Candona candida										x	xx	xx	xx	xx	x	xx	xx	xx	x	xx	xx	xx	xx
Cyclocypris ovum (RV>LV)											x	xx	xx	x	x	x	x	xx	x	xx	xx	xx	xx
Pseudocandona rostrata										x	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Limnocythere inopinata										x	x	x	xx	xx	x	x	x	x	o	x	x	x	x
Cypria ophtalmica																					x	x	x

Organic remains are recorded on a presence (x)/absence basis only; f – fragments only

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

256-258cm	260-262cm
9.96-9.98m	10.00-10.02m
x	
x	x
x	x
x	x
x	x

shed in with	*Freshwater loch*

256-258cm	260-262cm
9.96-9.98m	10.00-10.02m
x	
o	

0

256-258cm	260-262cm
9.96-9.98m	10.00-10.02m

256-258cm	260-262cm
9.96-9.98m	10.00-10.02m

256-258cm	260-262cm
9.96-9.98m	10.00-10.02m

256-258cm	260-262cm
9.96-9.98m	10.00-10.02m
xx	xx
x	x
xx	xx
x	o
x	

BAY OF FIRTH, ORKNEY

CORE 9

initial marine access ▼ (between 92-94cm and 96-98cm)

ORGANIC REMAINS

DEPTH IN CORE	30-32cm	50-52cm	70-72cm	74-76cm	78-80cm	80-82cm	84-86cm	88-90cm	90-92cm	92-94cm	96-98cm	100-102cm	120-122cm
Depth O.D.	9.10-9.12m	9.30-9.32m	9.50-9.52m	9.24-9.26m	9.58-9.60m	9.60-9.62m	9.64-9.66m	9.68-9.70m	9.70-9.72m	9.73-9.75m	9.76-9.78m	9.80-9.82m	10.00-10.02m
outer estuarine/marine foraminifera	x	x	x	x	x	x	x						
outer estuarine/marine ostracods	x	x	x	x	x	x							
brackish foraminifera	x	x	x	x	x	x	x	x		x			
brackish/marine molluscs	x	x	x	x	x	x	f	f	f				
fish remains	x	x			x								
brackish ostracods			x	x	x			x					
freshwater ostracods			x	x	x	x	x	x	x	x	x	x	x
insect remains			x	x	x	x	x	x	x	x	x	x	x
charophyte oogonia			x	x	x				x				
cladocera			x	x			x	x	x	x	x	x	x
freshwater molluscs					x	x	x	x	x	x	x	x	x

Ecology	With added sea-level rise, marine/near marine assemblages gradually become established. Freshwater component finally disappears at c. 9.40m O.D.	Coastal barrier breaches, but still with very limited brackish component	Coastal freshwater loch

OUTER ESTUARINE/MARINE FORAMINIFERA

DEPTH IN CORE	30-32cm	50-52cm	70-72cm	74-76cm	78-80cm	80-82cm	84-86cm	88-90cm	90-92cm	92-94cm	96-98cm	100-102cm	120-122cm
Depth O.D.	9.10-9.12m	9.30-9.32m	9.50-9.52m	9.24-9.26m	9.58-9.60m	9.60-9.62m	9.64-9.66m	9.68-9.70m	9.70-9.72m	9.73-9.75m	9.76-9.78m	9.80-9.82m	10.00-10.02m
Ammonia batavus (large & ornate)	xx	xx	xx	xx	x	x	x						
Elphidium macellum	xx	xx	x	x	o								
Elphidium excavatum	x	x	xx	xx									
Nonion depressulus	x	x	xx	x									
Elphidium gerthi	x	x	x										
Cibicides lobatulus	x												
lagenids	x												
Bulimina marginata	x												
miliolids	o	x		o									
Eggerelloides scaber		o		x									
Nonion orbicularis				o									

Foraminifera of shallow near-marine embayments, on sediment or clinging to algae

OUTER ESTUARINE/MARINE OSTRACODS

DEPTH IN CORE	30-32cm	50-52cm	70-72cm	74-76cm	78-80cm	80-82cm	84-86cm	88-90cm	90-92cm	92-94cm	96-98cm	100-102cm	120-122cm
Depth O.D.	9.10-9.12m	9.30-9.32m	9.50-9.52m	9.24-9.26m	9.58-9.60m	9.60-9.62m	9.64-9.66m	9.68-9.70m	9.70-9.72m	9.73-9.75m	9.76-9.78m	9.80-9.82m	10.00-10.02m
Pontocypris mytiloides	xxx	xxx	xx	o									
Leptocythere pellucida	xx	xx	xx	xx	o	o							
Cythere lutea	xx	xx	x	x	x	o							
Loxoconcha rhomboidea	xx	xx	xx	o									
Hirschmannia viridis	xx	x	x	x	o								
Hemicythere villosa	x	xx	x	x	o	o	o						
Callistocythere badia	x	xx		o									
Semicytherura nigrescens	x	x	xx	x		o							
Xestoleberis depressa	x	x	x	x									
Robertsonites tuberculatus	x	o											
Semicytherura cornuta		x											

Essentially marine ostracod species, but able to penetrate outer estuaries (most phytal on algae)

BRACKISH FORAMINIFERA

DEPTH IN CORE	30-32cm	50-52cm	70-72cm	74-76cm	78-80cm	80-82cm	84-86cm	88-90cm	90-92cm	92-94cm	96-98cm	100-102cm	120-122cm
Depth O.D.	9.10-9.12m	9.30-9.32m	9.50-9.52m	9.24-9.26m	9.58-9.60m	9.60-9.62m	9.64-9.66m	9.68-9.70m	9.70-9.72m	9.73-9.75m	9.76-9.78m	9.80-9.82m	10.00-10.02m
Elphidium williamsoni	x	x	xxx	xxx	xx	xx	xx	x		o			
Haynesina germanica	x	x	xxx	xxx	x	x	x	x					
Miliammina fusca	x												
Ammonia sp. (brackish)				o				o					

Foraminifera of estuaries and shallow embayments (brackish to near-marine, mud and sandflats)

BRACKISH OSTRACODS

DEPTH IN CORE	30-32cm	50-52cm	70-72cm	74-76cm	78-80cm	80-82cm	84-86cm	88-90cm	90-92cm	92-94cm	96-98cm	100-102cm	120-122cm
Depth O.D.	9.10-9.12m	9.30-9.32m	9.50-9.52m	9.24-9.26m	9.58-9.60m	9.60-9.62m	9.64-9.66m	9.68-9.70m	9.70-9.72m	9.73-9.75m	9.76-9.78m	9.80-9.82m	10.00-10.02m
Leptocythere castanea			x	x									
Cyprideis torosa				o	o			o					

Brackish ostracods of tidal flats and creeks

FRESHWATER OSTRACODS

DEPTH IN CORE	30-32cm	50-52cm	70-72cm	74-76cm	78-80cm	80-82cm	84-86cm	88-90cm	90-92cm	92-94cm	96-98cm	100-102cm	120-122cm
Depth O.D.	9.10-9.12m	9.30-9.32m	9.50-9.52m	9.24-9.26m	9.58-9.60m	9.60-9.62m	9.64-9.66m	9.68-9.70m	9.70-9.72m	9.73-9.75m	9.76-9.78m	9.80-9.82m	10.00-10.02m
Candona candida			x	x	x	x	xx	xx	xx	xx	xx	xx	xx
Cyclocypris ovum (RV>LV)			x	x	x	x	x	x	xx	x	x	x	x
Cyclocypris laevis (LV>RV)			x	x			x	x	x	x	x		
Pseudocandona rostrata			x	x	x	xx	xx	xx	xx	xx	xx	x	x
Limnocythere inopinata			x	x	x	o	xx	xx	x	x	xx	x	x

Organic remains are recorded on a presence (x)/absence basis only; f – fragments only

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

LOCH OF STENNESS, ORKNEY

CORE 1

initial tidal access ▼ (between 100-102cm and 104-106cm)

ORGANIC REMAINS

Depth in core	20-22cm	40-42cm	60-62cm	70-72cm	78-80cm	82-84cm	84-86cm	88-90cm	94-96cm	100-102cm	104-106cm	108-110cm	114-116cm	120-122cm
brackish molluscs	x	x												
brackish foraminifera	x	x	x	x	x									
insect remains	x	x			x	x	x	x	x	x	x	x	x	x
charophyte oogonia	x	x			x	x	x	x	x	x	x	x	x	
freshwater molluscs						x	x	x	x	x	x	x	x	x
cladocera						x	x	x	x	x	x	x	x	x
brackish ostracods						x	x			x				
freshwater ostracods						x	x	x	x	x	x	x	x	x
bryozoan statoblasts							x							

Ecology	*Restricted foraminiferal fauna. Curious brackish sedimentary environment above c.80cm with decalcification*	*With onset of tidal access, initially very low brackish (with ostracods only)*	*Freshwater loch*

BRACKISH FORAMINIFERA

Depth in core	20-22cm	40-42cm	60-62cm	70-72cm	78-80cm	82-84cm	84-86cm	88-90cm	94-96cm	100-102cm	104-106cm	108-110cm	114-116cm	120-122cm
Miliammina fusca	xxx	xxx	xx	x	x									
Elphidium williamsoni			xx											
Haynesina germanica			xx											

BRACKISH OSTRACODS

Depth in core	20-22cm	40-42cm	60-62cm	70-72cm	78-80cm	82-84cm	84-86cm	88-90cm	94-96cm	100-102cm	104-106cm	108-110cm	114-116cm	120-122cm
Cyprideis torosa (noded)						x	x			x				

FRESHWATER OSTRACODS

Depth in core	20-22cm	40-42cm	60-62cm	70-72cm	78-80cm	82-84cm	84-86cm	88-90cm	94-96cm	100-102cm	104-106cm	108-110cm	114-116cm	120-122cm
Cyclocypris ovum (RV>LV)						xx	xx						x	
Candona candida						x	xx	x	xx	x	x	x	x	x
Cyclocypris laevis (LV>RV)						x	x	x	x	x	x	x	x	x
Pseudocandona rostrata						x	o	o	x		x	x		
Limnocythere inopinata							x	x	x	x	x			x
Sarscypridopsis aculeata							x							

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

Calcareous foraminifera of low-mid saltmarsh and tidal flats
Agglutinating foraminifer of marsh and shallow lagoons/estuaries; intertidal
Brackish ostracods of tidal flats and creeks

139-141cm
x
x
x
x

139-141cm

139-141cm

139-141cm
x
x