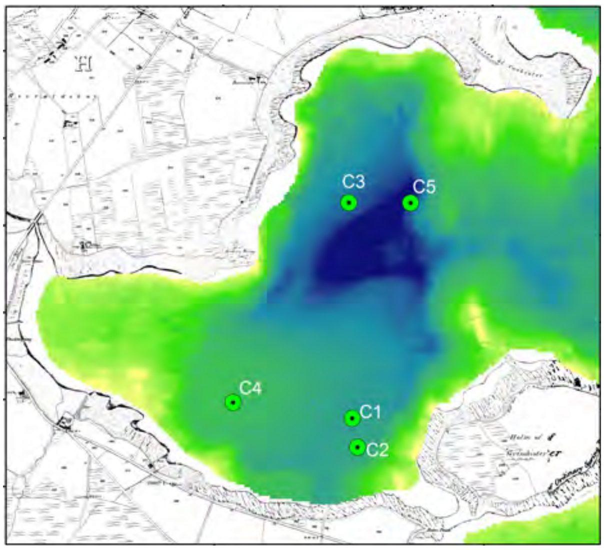
BAY OF FIRTH, ORKNEY: CORING REPORT

NOVEMBER 2013



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SUMMARY

This report describes work undertaken in the Bay of Firth, Orkney to investigate the suitability of a VibeCore-D system for the recovery of sediment samples suitable for the investigation of the palaeoenvironmental history from shallow marine situations. Previous work (Bates et al 2013) at the Bay of Firth has demonstrated that within the Finstown basin a large submerged lake existed prior to sea level rise causing its inundation. The results of the investigation demonstrated that this method of drilling is both suitable and practical even within shallow marine waters such as those of the bay. Approximately 2.8m of seabed stratigraphy was recovered and this proved internally coherent and undisturbed by the drilling process allowing sampling for microfossils and the provision of radiocarbon determinations from well-provenanced stratigraphic horizons. It was thus possible to reconstruct a well-documented and chronologically constrained record of landscape evolution and sea level change demonstrated by the combined foram, ostracod and diatom records. Furthermore initial assessment of the radiocarbon age estimates has demonstrated that coherent and consistent dates can be obtained from the contained molluscan remains. This is a significant step forward for studies of landscape evolution in shallow marine areas as the methods used were both cost effective and easily replicable.

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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 (Bates et al 2013). 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 2011a). 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 2011b).

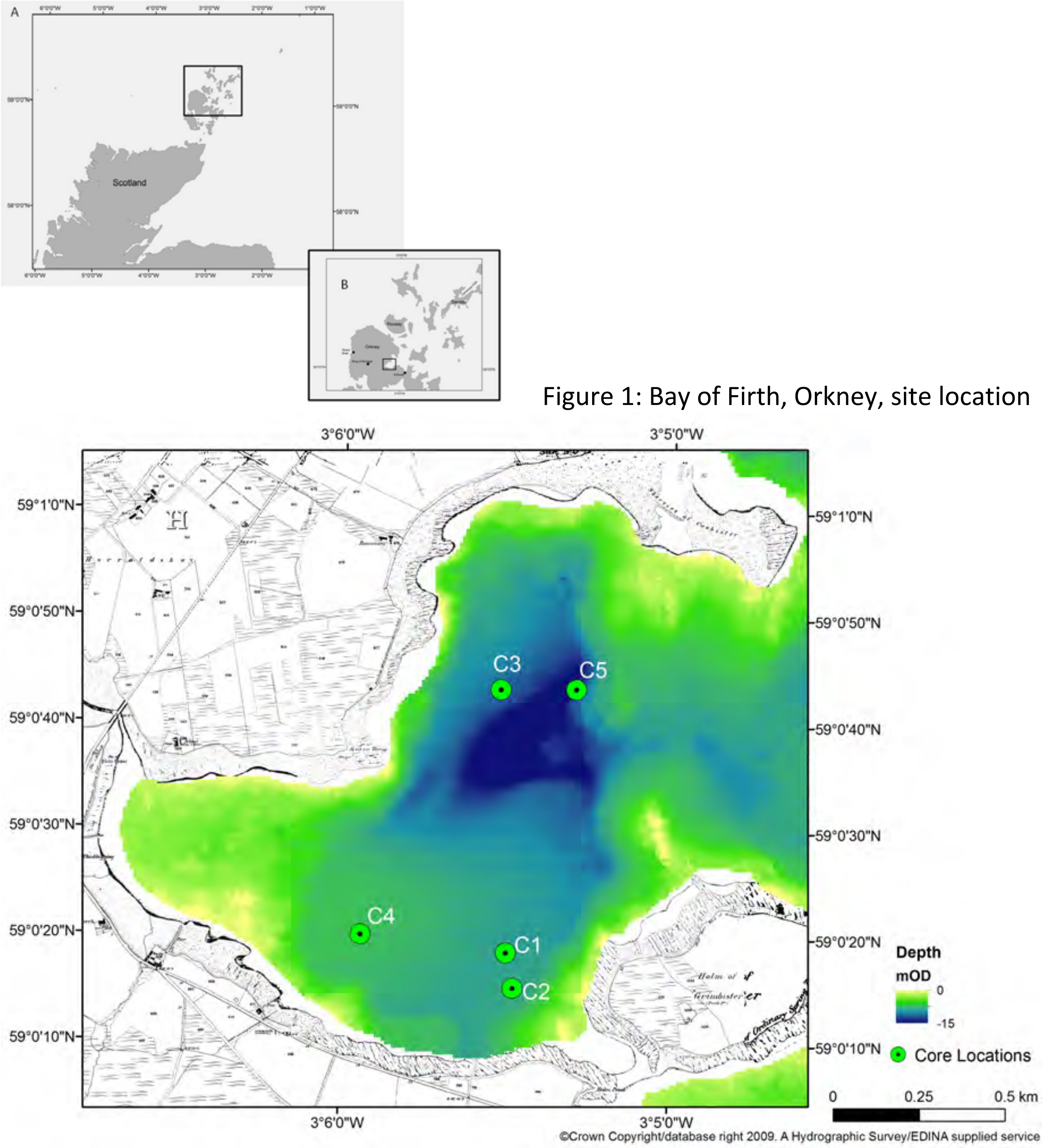

Figure 1: Bay of Firth, Orkney, site location

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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 in 2012 with a Livingstone Corer (Bates et al 2012). This was followed by a trial with a SDI VibeCore-D corer.

This report describes this most recent phase of work to demonstrate the ability to core the identified sediment bodies using the VibeCore-D system and assess their contained palaeoenvironmental record and ages.

2. Methods

2.1.1. Drilling

Fieldwork was undertaken in September 2012. Fieldwork was conducted using a small survey vessel and a VIbeCore-D (Figure 2). Previous attempts to core the seabed had been made with a gouge auger and Livingstone auger (Bates et al 2013).

Positioning of the borehole was undertaken using Hypack, dGPS and echosounder to core in water depths to 8m. Once the boat was positioned it was secured using three large sea anchors and drilling commenced with the corer lowered over the side of the vessel using a small derrick arm. 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 (Figure 2). 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 and also in extracting the core barrel once fully deployed.

The recovered core was wrapped in cling film once back on the boat deck 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 (Figure 3).

Figure 2. The VibeCore-D coring Unit

Figure 3. The Core.

2.1.2 Sample processing

Forams/ostracods

A total of 21 samples from Core 5 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 (see Table 2, uppermost table) on a presence/absence basis. Abundance of foraminiferal and ostracod species, on the other hand, was estimated by eye and by experience, semi-quantitatively (Table 2).

Diatoms

Preparation of diatoms for analysis followed well established and routine techniques as outlined in Barber & Haworth (1981). A total of 100 diatoms were counted from each sample and the identification of individual species was based on standard European diatom floras (Van Der Werff & Huls, 1974) as well as reference to online databases (WoRMS, Algaebase). The classic qualitative approach to conducting a diatom based biostratigraphical analysis involves an assessment of taxa distribution at each layer within the stratigraphy. Following this, depositional environments can be determined based on the autecology of identified species. This study used the tried and tested classic approach for diatom analysis on the basis that the ability to differentiate between marine and freshwater sediments is adequate enough without generating absolute figures for salinity etc. Core 5 from the Bay of Firth was subsampled over a depth of 68cm to 94cm using a systematic sampling strategy whereby samples were taken over the range of the diffuse lithological boundary while more detailed sampling was focused in areas where a change in depositional conditions might be observed.

The data generated by the above described technique was then used to populate an excel spreadsheet (Table 3). Counted diatoms were then standardised into percentages and sorted into classifications according to species habitat following the information presented in Van Der Werff & Huls (1974). A series of bar charts that show changes in species distribution with depth were then developed using the "C2" software package (Juggins, 2010). Finally, the sum of all diatoms within each habitat classification at each depth through the profile was determined and charted as bar charts using the C2 software.

Radiocarbon

The dating medium selected for processing was shell material sieved from small sub-samples of sediment at a sampling interval commensurate with sampling intervals for microfossil and diatom assessment. Samples were sieved in cold water through 0.5mm mesh and the residues caught and dried. Residues were sorted and selected for analysis using only whole shell samples. Information is provided in Table 4.

3. Results

3.1.1 Sediment core

Detailed lithological descriptions of the core are summarised in table 1.

3.2.1 Foraminifera and ostracods

These results are shown in Table 2 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-

Depth below top of core (cm)	Colour	Lithology
0-15 diffuse boundary	10YR 3/1	very dark grey very fine silt. Very soft and unconsolidated
15-50 diffuse boundary	2.5Y 3/2	very dark greyish brown very fine silt. Very finely laminated with laminations 2-4mm, sub-parallel. Becomes 5Y 2.5/2 black with depth. Basal 5cm rich in detrital shell fragments
50-69 diffuse boundary	2.5Y 3/2	very dark greyish brown very fine silt. Very soft and unconsolidated. Basal 2-3cm rich in shells
69-71 sharp boundary		shell fragments
71-81 diffuse boundary	5Y 5/1	grey very fine silt. Slightly firm texture. Molluscs present
81-86 diffuse boundary	5Y 4/1	dark grey silt with some organic fragments
86-95 diffuse boundary	5Y 5/1	grey silt
95-120 diffuse boundary	5Y 6/1	grey very fine carbonate silt. Slightly firm and possibly bedded with rare freshwater molluscs also present
120-130 diffuse boundary	5Y 6/1	grey carbonate silt with shells (fragments and complete shells). Very soft and pliable
130-145 diffuse boundary	5Y 6/2	light olive grey carbonate silt with shells (fragments and complete shells). Very soft and pliable
145-155 diffuse boundary	5Y 5/2	olive grey carbonate silt with shells (fragments and complete shells). Very soft and pliable
155-173 diffuse boundary	2.5Y 6/2	light brownish grey carbonate silt with shells (fragments and complete shells). Very soft and pliable
173-200 diffuse boundary	5Y 6/2	light olive grey carbonate silt with shells (fragments and complete shells). Very soft and pliable
200-218 diffuse boundary	2.5Y 6/2	light brownish grey very fine carbonate silt. Soft and unconsolidated. Very common freshwater shells fragments
218- base of core	2.5Y 7/2	light grey very fine slightly sandy carbonate silt. Occasional freshwater molluscs. Very soft, structureless and pliable

Table 1: Core 5, Detailed Lithology.

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 Table 2, 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.

Table 2 summarises the changing ecology of Core 5 through time. Initial conditions from the base of the drilled sequence at 250-252cm (sample 16) up to 96-98cm (sample *20*) (1.56m) represent undoubted freshwater deposition. Apart from a few rare specimens of two other species in the lowest three samples (Table 2, bottom table) the ostracod fauna is characterised by the same four species of freshwater ostracod throughout, and these often very abundantly. There are also common molluscs - "pond snails" and bivalves mainly. The ostracods – *Candona candida, Limnocythere inopinata. Cyclocypris ovum* and *Pseudocandona rostrata* – all live (according to Meisch, 2000) in a wide range of habitats, but usually they prefer permanent bodies of water (in the littoral zone of small and large lakes). They occur throughout Europe, but *C. candida* and *P. rostrata* are rare in the south. In fact *C. candida,* although living throughout Britain today, is particularly adapted to "northern" climatic conditions and often occurs with other cold/cool indicators in Pleistocene cold-climate deposits; this has most notably been shown in the Devensian of the South Coast of England (Bates *et al*., 2009) and the London area. All four species, it is true, can also tolerate slightly salty waters in coastal areas. Whether this might imply that the lower part of the sequence in Core 5 represented in this loch was always quite near the then coastline is presently not known. However by 93-95cm in the core (sample 8) (see Table 2) there is firm evidence that the coastal barrier to the loch was indeed very close to the transgressing sea and then was finally breached. In this important sample we have the first foraminifera, albeit just one brackish species: *Elphidium williamsoni*, but as foraminifera do not live in freshwater, tidal access had now been undeniably achieved.

As the transgression continued, there followed an interesting transitional phase. There is permanent tidal access, but there is still a rather restricted environment containing a mixture of estuarine/brackish and freshwater species, although the freshwater component is diminishing, completely disappearing at 70-72cm (sample 4) in the core. This is the only part of the sequence that contains ostracods of brackish estuarine mudflats and creeks and apart from the usual species of this realm, is notable for a small loxoconchid (David Horn (pers. comm.) suggests it has been reported in the literature from the Baltic but a name and a suitable reference for it is, for the moment, lacking). Of other interest is the fact that this initial tidal phase appears to be completely lacking in saltmarsh development (i.e. there are none of the specialised agglutinating foraminifera so prevalent in early tidal phases of sites on the South Coast of England and on the Medway, for instance).

By sample *17* (at 60-62cm) all the freshwater species have disappeared. Perhaps previously the site was but the eastern extremity of a much larger sea loch, fed by a small river from the west, that still provided freshwater input into the system (it cannot all be reworking), until it was completely engulfed by sea-level rise. The marine/outer estuarine foraminifera and ostracods that had first appeared at 89-91cm (sample *19*) now become more common and diverse, and like the sediments represented throughout in cores 1 and 4, previously studied to the west (Whittaker, 2012) indicate a shallow embayment with marine or near-marine salinities and abundant marine-algae and sea-grass, just as I suspect occurs today. The turn-over from the small simple *Ammonia* species in the brackish part of the sequence to the large, ornate marine *Ammonia batavus* at 70-72cm (sample 4) is particularly impressive ecologically.

BAY OF FIRTH, ORKNEY (2012)

Core 5 microfossil distributions.

8093±47 BP ▼ (sample 4, 70-72cm)
8138±29 BP ▼ (sample 6, 80-82cm)
8459±29 BP ▼ (between samples 19 and 8)
8991±26 BP ▼
Onset of tidal access ▼ (between samples 8 and 20)

ORGANIC REMAINS

SAMPLE NO.	1	2	3	*17*	4	5	*18*	6	7	*19*	8	*20*	*21*	9	10	11	12	13	14
DEPTH IN CORE	10-12cm	30-32cm	50-52cm	*60-62cm*	70-72cm	73-75cm	*77-79cm*	80-82cm	85-87cm	*89-91cm*	93-95cm	*96-98cm*	*98-100cm*	110-112cm	130-132cm	150-152cm	170-172cm	190-192cm	210-212cm
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									
brackish/marine molluscs	x	x	x	x	x	x	x	x	x	x									
plant debris + seeds + megaspores	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
fish remains	x	x	x		x	x			x										
brackish foraminifera	x	x	x	x	x	x	x	x	x	x	x								
insect remains		x	x			x	x	x	x	x	x	x	x	x	x	x	x	x	x
brackish ostracods					x	x	x	x	x	x									
freshwater ostracods					x	x	x	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	x
cladocera (valves + ephippia)							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

Ecology	*Further sea-level rise; now a shallow embayment with marine/near marine salinities*	*Permanent tidal access, but still a rather restricted environment. Estuarine and brackish, however freshwater influence diminishing*	*Coastal barrier to loch breaches with sea-level rise*	*Shallow freshwater coastal loch*

OUTER ESTUARINE/MARINE FORAMINIFERA

SAMPLE NO.	1	2	3	*17*	4	5	*18*	6	7	*19*	8	*20*	*21*	9	10	11	12	13	14
DEPTH IN CORE	10-12cm	30-32cm	50-52cm	*60-62cm*	70-72cm	73-75cm	*77-79cm*	80-82cm	85-87cm	*89-91cm*	93-95cm	*96-98cm*	*98-100cm*	110-112cm	130-132cm	150-152cm	170-172cm	190-192cm	210-212cm
Elphidium macellum	xx	xx	xxx	xx	x			o	x										
Ammon ia batavus (large & ornate)	x	o	x	x	o														
Elphidium excavatum	x	x	x	xx	x	x	x	x	x	x									
Eggerelloides scaber	x			o			o												
lagenids	x																		
Cibicides lobatulus	x								o	o									
Nonion depressulus	o			x	x														
miliolids				x															

OUTER ESTUARINE/MARINE OSTRACODS

SAMPLE NO.	1	2	3	*17*	4	5	*18*	6	7	*19*	8	*20*	*21*	9	10	11	12	13	14
DEPTH IN CORE	10-12cm	30-32cm	50-52cm	*60-62cm*	70-72cm	73-75cm	*77-79cm*	80-82cm	85-87cm	*89-91cm*	93-95cm	*96-98cm*	*98-100cm*	110-112cm	130-132cm	150-152cm	170-172cm	190-192cm	210-212cm
Pontocythere mytiloides	xx	x	x	x	x														
Cythere lutea	xx	xx	x	x	x	o		o	x	o									
Hirschmannia viridis	xx	xx	xx	x	x	x	x	x	x	x									
Hemicythere villosa	x	x	x	x	xx	x	o		x	x									
Semicytherura nigrescens	x	xx	xx	xx	xx	x	x		x	x									
Xestoleberis depressa	o																		
Aurila convexa			o																
Leptocythere pellucida				o	x														
Calistocythere badia					x				o										

BRACKISH FORAMINIFERA

SAMPLE NO.	1	2	3	*17*	4	5	*18*	6	7	*19*	8	*20*	*21*	9	10	11	12	13	14
DEPTH IN CORE	10-12cm	30-32cm	50-52cm	*60-62cm*	70-72cm	73-75cm	*77-79cm*	80-82cm	85-87cm	*89-91cm*	93-95cm	*96-98cm*	*98-100cm*	110-112cm	130-132cm	150-152cm	170-172cm	190-192cm	210-212cm
Elphidium williamsoni	x	xxx	xxx	xx	xxx	xxx	xx	xx	xxx	xxx	x								
Haynesina germanica	x	xx	xx	xx	xxx	xx	x	x		xx									
Miliammina fusca	x				o														
Ammonia sp. (brackish)					x	xx	x	x	xx	xx									
Elphidium waddense									x	x									

BRACKISH OSTRACODS

SAMPLE NO.	1	2	3	*17*	4	5	*18*	6	7	*19*	8	*20*	*21*	9	10	11	12	13	14
DEPTH IN CORE	10-12cm	30-32cm	50-52cm	*60-62cm*	70-72cm	73-75cm	*77-79cm*	80-82cm	85-87cm	*89-91cm*	93-95cm	*96-98cm*	*98-100cm*	110-112cm	130-132cm	150-152cm	170-172cm	190-192cm	210-212cm
loxoconchid indet.					x		o	x	x	o									
Cyprideis torosa					o	x	x		xx	x									
Leptocythere castanea						x	x	x		x									
Leptocythere lacertosa						o	x		x										
Cytherura gibba										x									
Elofsonia baltica							o			o									

FRESHWATER OSTRACODS

SAMPLE NO.	1	2	3	*17*	4	5	*18*	6	7	*19*	8	*20*	*21*	9	10	11	12	13	14
DEPTH IN CORE	10-12cm	30-32cm	50-52cm	*60-62cm*	70-72cm	73-75cm	*77-79cm*	80-82cm	85-87cm	*89-91cm*	93-95cm	*96-98cm*	*98-100cm*	110-112cm	130-132cm	150-152cm	170-172cm	190-192cm	210-212cm
Candona candida					x	x	xx	x	xxx	xx	xxx	xx	xx	xx	xx	xx	xx	xx	xxx
Limnocythere inopinata					x	x	x	x	xx	x	xx	x	x	x	x	x	x	x	
Cyclocypris ovum (RV>LV)						x	x	x	x	x	xxx	xx	x	xx	x	x	x	x	xx
Pseudocandona rostrata						x	x			x	xx	xx	xx	xx	xxx	xxx	o	x	
Candona sp. (juveniles)																			x
Potamocypris sp.																			o

Foraminifera of shallow near-marine embayments, on sediment or clinging to algae
Essentially marine ostracod species, but able to penetrate outer estuaries (most phytal on algae)

Foraminifera of estuaries and shallow embayments (brackish to near-marine, mud and sandflats)
Brackish ostracods of tidal flats and creeks
Non-marine ostracods, but able to tolerate low salinities

1-16 original samples submitted
17-21 “extra” samples submitte

Organic remains are listed on a presence (x)/absence basis
Foraminifera and ostracods are listed: o - one specimen; x - several specimens; xx - common; xxx - abundant/superabundant

Table 2

10817± BP
▼

15	16
230-232cm	250-252cm
x	x
x	x
x	x
x	x
x	x

15	16
230-232cm	250-252cm

15	16
230-232cm	250-252cm

15	16
230-232cm	250-252cm

15	16
230-232cm	250-252cm

15	16
230-232cm	250-252cm
xx	xx
x	x
x	x
x	x
o	o

d 12/9/2012
d 6/10/2012

3.3.1. Diatoms

The results from the above described analysis are discussed below. A total of 1100 diatoms representing 37 different species were observed in the profile and are presented in Table 3. The results of diatom analysis are discussed in terms of variations through the profile from the base upwards rather than a conventional surface down description. This allows for a better demonstration of the change in environmental conditions from the early site history to the contemporary setting.

The distribution of diatom accumulations according to species habitat clearly varies with depth (Table 3). The percentage of marine species gradually increases from the base of the profile towards the surface whereas the percentage of total freshwater species shows a broadly asymmetrical pattern, gradually decreasing from the base upwards. The distribution of brackish species through the profile gradually increases from the base upwards towards a depth of ~80cm before declining progressively towards the surface of the profile. Habitat marginal species such as brackish/freshwater or marine/brackish species do not occur in sufficiently high accumulations through the profile to allow for a meaningful description of their trends.

Several key species are identified through the profile that allow for a detailed description of the change from predominantly freshwater conditions at the base of the profile to a predominantly marine environment at the surface. Freshwater species such as *Fragilaria brevistriata* and *Amphora ovalis* are most present at the base of the profile with percentages of 26% and 22% respectively. *Fragilaria brevistriata* declines as depth decreases and is found to be absent from a depth of 82cm upwards. Likewise, *Amphora ovalis* gradually declines upwards through the profile and is entirely absent above a depth of 80cm. The brackish species *Navicula cincta* is found to gradually increase from 9% at 86cm to 29% at 79cm and thereafter decreases gradually to 7% at the surface of the profile. *Navicula cincta* is found to dominate the profile between 84cm and 79cm. The marine species *Gramatophona oceanica* is dominant towards the surface of the profile but is largely absent below a depth of ~82cm. The species increases dramatically from 3% at a depth of 84cm to 29% in the next sample at 82cm, above which it dominates and peaks at 45% towards the surface at 72cm depth.

The above description of changes in diatom distribution through the profile permits a discussion relating to the change in relative sea level over time at the site. Early in the site history the relative sea level must have been low enough to allow freshwater species such as *Fragilaria brevistriata* and *Amphora ovalis* to thrive. While marine and brackish species are found to be present during this time, they do not appear in sufficient quantities to suggest that they developed in a saline depositional environment. Their presence can be readily explained through landward aeolian transportation of diatoms and deposition through sea spray or during storm surges. During this early period of the site history the depositional environment was likely a freshwater coastal lake. As time progressed, RSL appears to have risen and created a brackish depositional environment whereby marine, brackish and freshwater species all appear in potentially significant quantities. Rather than a dramatic and sudden change in depositional environment, associated with the crossing of a local threshold, the change appears more diffuse, concurrent with the gradual rise in RSL observed in many Scottish coastal sites during the early- to mid-Holocene. The more recent site history suggests a thoroughly marine depositional environment, reflecting the contemporary sea level and shallow marine conditions at the site.

The absolute depth at which the depositional environment ceased to reflect freshwater conditions is therefore difficult to interpret, given the gradual change discussed above. However, given that the marine species *Gramatophona oceanic*a appears to dominate the more recent marine conditions, its sudden increase between 84/82cm serves as a best estimate for when the depositional environment began to reflect the contemporary site setting.

3.4.1. Radiocarbon dating

Individual C14 reporting documents are presented in Appendix 1 and summarised in Table 4. The five radiocarbon determinations are consistent with the relative stratigraphic positions of the dated shells, providing further confirmation that the coring procedure has successfully recovered an undisturbed sequence of sediments. Preliminary calibration of the radiocarbon determinations has been undertaken using Oxcal 4.2 (Bronk Ramsey, 2009) and calibration curves IntCal09 for the freshwater gastropods and Marine 09 (Reimer *et al*., 2009) for the marine bivalves (see Table 4). Marine reservoir correction has been made in line with procedures employed on dates from Viking burials in Orkney where marine diet was seen as a complicating factor (Barrett *et al.,* 2000). In due course, more sophisticated dating models should be possible making full use of the Bayesian statistical modelling of stratigraphic sequences, and utilising the very recently released IntCal13 and Marine13 calibration curves.

Table 4: Radiocarbon Dating

Lab code	**BoF code**	**Depth (cm)**	**Material**	**Δ^{13}C**	**Radiocarbon age BP**	**Calibrated date range (95.4%, IntCal 09)**	**Calibrated date range (95.4%, Marine 09)**
SUERC-44051	BoF H5-4	70-72	Marine bivalve	-0.4°/₀₀	8093±47	-	6747-6468calBC
SUERC-44049	BoF H5-3a	80-82	Marine bivalve	-4.3°/₀₀	8138±29	-	6779-6566calBC
SUERC-44044	BoF H5-2a	89-91	Freshwater gastropod	-4.0°/₀₀	8459±29	7579-7495calBC	-
SUERC-44043	BoF H5-1b	96-98	Freshwater gastropod	-7.0°/₀₀	8991±26	8283-8025calBC	-
SUERC-44042	BoF H5-1a	250-252	Freshwater gastropod	-6.6°/₀₀	10817±28	10889-10639calBC	-

4. 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 in future either the use of a diver in water to guide drilling on the fitting of a remote video camera to the vibration mechanism should allow these minor issues to be overcome.

The core recovered some 2.8m of seabed stratigraphy 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. This has, for the first time, provided in sub-tidal open Orkney waters a well-documented and chronologically constrained record of landscape evolution and sea level change demonstrated by the combined foram, ostracod and diatom record. Furthermore initial assessment of the radiocarbon age estimates has demonstrated that coherent and consistent dates can be obtained from the contained molluscan remains.

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Appendix 1. SUERC radiocarbon dating certificates

Scottish Universities Environmental Research Centre

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RADIOCARBON DATING CERTIFICATE

29 January 2013

Laboratory Code	SUERC-44042 (GU29215)
Submitter	Richard Bates Earth Sciences University of St Andrews Irvine Building St Andrews KY16 9AL
Site Reference	Bay Of Firth
Context Reference	BoF_H5_1a
Sample Reference	BoF_H5_1a
Material	Shell
δ^{13}C relative to VPDB	-6.6 ‰
Radiocarbon Age BP	10817 ± 28

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standards, background standards and the random machine error.

The calibrated age ranges are determined using the University of Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.1 (Bronk Ramsey 2009). Terrestrial samples are calibrated using the IntCal09 curve while marine samples are calibrated using the Marine09 curve.

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Conventional age and calibration age ranges calculated by :-   Date :-

Checked and signed off by :-   Date :-

Calibration Plot

Scottish Universities Environmental Research Centre
Director: Professor R M Ellam
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East Kilbride, Glasgow G75 0QF, Scotland, UK
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RADIOCARBON DATING CERTIFICATE

29 January 2013

Laboratory Code	SUERC-44043 (GU29216)
Submitter	Richard Bates Earth Sciences University of St Andrews Irvine Building St Andrews KY16 9AL
Site Reference	Bay Of Firth
Context Reference	BoF_H5_1b
Sample Reference	BoF_H5_1b
Material	Shell
δ^{13}C relative to VPDB	-7.0 ‰
Radiocarbon Age BP	8991 ± 26

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standards, background standards and the random machine error.

The calibrated age ranges are determined using the University of Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.1 (Bronk Ramsey 2009). Terrestrial samples are calibrated using the IntCal09 curve while marine samples are calibrated using the Marine09 curve.

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Conventional age and calibration age ranges calculated by :- Date :-

Checked and signed off by :- Date :-

Calibration Plot

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RADIOCARBON DATING CERTIFICATE

29 January 2013

Laboratory Code	SUERC-44044 (GU29217)
Submitter	Richard Bates Earth Sciences University of St Andrews Irvine Building St Andrews KY16 9AL
Site Reference	Bay Of Firth
Context Reference	BoF_H5_2a
Sample Reference	BoF_H5_2a
Material	Shell
δ^{13}C relative to VPDB	-4.0 ‰
Radiocarbon Age BP	8459 ± 29

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standards, background standards and the random machine error.

The calibrated age ranges are determined using the University of Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.1 (Bronk Ramsey 2009). Terrestrial samples are calibrated using the IntCal09 curve while marine samples are calibrated using the Marine09 curve.

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Conventional age and calibration age ranges calculated by :- Date :-

Checked and signed off by :- Date :-

Calibration Plot

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RADIOCARBON DATING CERTIFICATE

29 January 2013

Laboratory Code	GU29218
Submitter	Richard Bates Earth Sciences University of St Andrews Irvine Building St Andrews KY16 9AL
Site Reference	Bay Of Firth
Context Reference	BoF_H5_2b
Sample Reference	BoF_H5_2b
Material	Shell
δ^{13}C relative to VPDB	-
Result	Failed on AMS.

N.B. Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Signed :-

Date :-

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RADIOCARBON DATING CERTIFICATE

29 January 2013

Laboratory Code	SUERC-44049 (GU29219)
Submitter	Richard Bates Earth Sciences University of St Andrews Irvine Building St Andrews KY16 9AL
Site Reference	Bay Of Firth
Context Reference	BoF_H5_3a
Sample Reference	BoF_H5_3a
Material	Shell
δ^{13}C relative to VPDB	-4.3 ‰
Radiocarbon Age BP	8138 ± 29

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standards, background standards and the random machine error.

The calibrated age ranges are determined using the University of Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.1 (Bronk Ramsey 2009). Terrestrial samples are calibrated using the IntCal09 curve while marine samples are calibrated using the Marine09 curve.

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Conventional age and calibration age ranges calculated by :- Date :-

Checked and signed off by :- Date :-

Calibration Plot

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RADIOCARBON DATING CERTIFICATE

29 January 2013

Laboratory Code	GU29220
Submitter	Richard Bates Earth Sciences University of St Andrews Irvine Building St Andrews KY16 9AL
Site Reference	Bay Of Firth
Context Reference	BoF_H5_3b
Sample Reference	BoF_H5_3b
Material	Shell
δ^{13}C relative to VPDB	-
Result	Failed on AMS.

N.B. Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Signed :- Date :-

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RADIOCARBON DATING CERTIFICATE

29 January 2013

Laboratory Code	SUERC-44051 (GU29221)
Submitter	Richard Bates Earth Sciences University of St Andrews Irvine Building St Andrews KY16 9AL
Site Reference	Bay Of Firth
Context Reference	BoF_H5_4
Sample Reference	BoF_H5_4
Material	Shell
δ^{13}C relative to VPDB	-0.4 ‰
Radiocarbon Age BP	8093 ± 47

N.B. The above ^{14}C age is quoted in conventional years BP (before 1950 AD). The error, which is expressed at the one sigma level of confidence, includes components from the counting statistics on the sample, modern reference standards, background standards and the random machine error.

The calibrated age ranges are determined using the University of Oxford Radiocarbon Accelerator Unit calibration program OxCal 4.1 (Bronk Ramsey 2009). Terrestrial samples are calibrated using the IntCal09 curve while marine samples are calibrated using the Marine09 curve.

Samples with a SUERC coding are measured at the Scottish Universities Environmental Research Centre AMS Facility and should be quoted as such in any reports within the scientific literature. Any questions directed to the Radiocarbon Laboratory should also quote the GU coding given in parentheses after the SUERC code. The contact details for the laboratory are email g.cook@suerc.gla.ac.uk or Telephone 01355 270136 direct line.

Conventional age and calibration age ranges calculated by :-   Date :-

Checked and signed off by :-   Date :-

Calibration Plot