Relative Sea Level Changes at Clachan Harbour, Raasay, Scottish Hebrides

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Abstract

An intertidal organic deposit enclosed within estuarine clastic sediments, is described for Clachan harbour, Raasay, Scottish Inner Hebrides. The organic sediments are over and underlain by fine sands and silts containing marine microfossils. Macrofossil analyses (pollen and diatoms) indicate a regression and subsequent transgression at the site during the early Holocene. The altitude at which early Holocene marine regression and transgression is recorded is less than at sites located on the Scottish mainland at Arisaig. This reflects the geographical position of Raasay, located on the periphery of the glacio-isostatic uplift centre, under the influence of differential isostatic uplift across the Inner Hebrides. The possible implications for Mesolithic archaeology are explored.

Introduction

Intertidal organic deposits are rarely described for western Scotland with the exception of the Isle of Coll, where early Holocene intertidal peats are described for Traigh Eileraig (Dawson et al. 2001). Other intertidal deposits are described for SW Scotland, the Orkney Islands and many from the Outer Hebrides. These latter examples are located at sites which lie around the periphery of the Scottish glacio-isostatic uplift centre. This paper examines a site on the Isle of Raasay, Inner Hebrides where intertidal peats and wood outcrop at the harbour surface in Clachan, South West Raasay. The results of lithostratigraphic and geomophological survey combined with pollen and diatom analyses are used to determine the origins of the deposit together with the raised suite of shingle ridges and terraces in the vicinity of Clachan harbour. These results are compared with recent research on Holocene relative sea level changes in North West Scotland.

Isle of Raasay, Clachan Harbour

The area of Clachan harbour is sheltered and lies to the south of Raasay House facing the Raasay Sound overlooking the Isle of Skye (Figures 1 and 2). An investigation into sediment sequences exposed on the harbour floor led to the discovery of extensive wood and pest deposits covering the western area. Woody peat and organic rich sands and silts occur in the intertidal zone at Clachan harbour, Isle of Raasay (Figure 3). The intertidal area making up the harbour lies in a sheltered bay within the larger Churchton Bay shielded from high winds and storm waves by stone piers which extend out into the bay and thus affording some shelter which has probably led to the continuing preservation of the buried wood and peat.

Methodology and Techniques

Morphological survey was undertaken in the vicinity of Clachan harbour of all terraces and former shoreline features below an altitude of 50m OD. This survey determined the areas of further investigation as well as providing the relative sea level context of the detailed work undertaken in the harbour. Stratigraphical investigation involved hand coring over the harbour sub-surface to determine the general pattern of estuarine and freshwater sedimentation, which was followed by detailed stratigraphical study of the sediments and the microfossils contained within the sediments. Microfossil analyses were undertaken on two monoliths from the harbour floor sediments which encompassed the greatest extent of the buried peat and underlying clastic sediments. This was to ensure that continuity of sedimentation from the clastic to the organic sequences as well as giving an understanding of the possible environment of deposition of the sediment sequences studied.

Morphological Mapping

The surfaces immediately upslope of the harbour were mapped at a scale of 1:10,000 using standard geomorphological techniques (Firth, 1984). This was followed by measuring the altitudes of all terraces including the present day sand and mudflats along their lengths using a Sokisha total station and Zeiss autoset level. All boreholes and the monolith locations were levelled to Ordnance Datum (O.D.) Newlyn. Tidal data was taken from Portree, Skye and levels related in the discussion to High Water Mark of Ordinary Spring Tides (H.W.M.O.S.T.) refer to the position in the tidal cycle that the transition from estuarine to terrestrial sedimentation occurs.

Stratigraphical analyses

Sites were selected for detailed analyses and monolith sampling after initial examination of the harbour area using a hand operated gouge sampler. Boreholes selected for detailed study were undertaken using a 50cm length, 25cm wide monolith tin, which was pushed into the sediment face after widening a pit in the surface sands.

Microfossil analyses

Microfossil analyses follow standard preparation techniques and included preparation for diatoms, pollen, foraminifera and Ostracoda. The study of the microfossil content of sediments allow determination of general changes in the environment of deposition of the clastic and terrestrial sediments studied as well as determining the presence or absence of hiatus in sedimentation, to enable the changes in relative sea level to be assessed.

A minimum of 300 microfossils were counted at every level sampled. Eighteen levels were prepared for diatoms using standard techniques (Barber and

Haworth 1981). The sediment was subsampled from small tins taken at the site from two trenches (1 and 2). Approximately 1gm wet weight of sediment was placed into a beaker and 20mls of Hydrogen peroxide (H_2O_2) added. The beaker was heated gently on a hotplate for 1-3 hours until all organic matter was oxidized. The material was then transferred to centrifuge tubes and topped up with distilled water. The centrifuge was set at 1200 rpm for 5 minutes. The supernatant was then decanted carefully, topped with distilled water and re centrifuged. This process was repeated 5 times to reduce the amount of clays and fine silts.

Diatom slides were made up by allowing the suspension to settle out on a cover slip overnight. The resultant cover slips were mounted in Naphrax and heated for a few minutes in a fume cupboard to evaporate the Toluene within the Naphrax. The slides were then left to cool in the fume cupboard until required for counting.

The diatoms were identified with reference to Hendey (1964) and Van der Werff and Huls (1958-66). Diatom nomenclature follows Hartley (1986) and salinity and lifeform classification is based on Vos and de Wolf (1993) and Denys (1991/2). Polyhalobian and mesohalobian classes broadly reflect marine and brackish conditions and oligohalobian and Halophilics reflect freshwater environments.

Geomorphology

Following morphological mapping of the area below 25 m O.D., terraces representing former sea level changes were identified around Raasay House, immediately NE of the harbour (Figure 4). The uppermost level of vegetation in the intertidal area occurs at 3.66 m O.D which lies approximately 0.70 m above the tidal level at M.H.W.S.T. A suite of vegetated shingle ridges occur immediately to the NE of the intertidal area, down slope of Raasay House. The lowest ridge occurs at 7.57 m O.D., a second (less well defined) occurs at 8.89 m O.D. and the highest ridge occurs at 14.55 m O.D. Raasay house itself sits on the surface of a well defined terrace at c.24 m O.D. It is likely that the highest shingle ridge and the terrace that the house stands on are related to Late Glacial relative sea level changes (see report by A.G. Dawson, this volume) when sea levels were lower and have been subsequently uplifted to their present altitudes.

The terrace at c.7.5 m O.D is comparable to terraces identified in Skye and Applecross as being a product of the highest level attained by the mid Holocene rise in sea level known as the Main Postglacial Transgression. The higher surface at c. 8.90 m O.D. is probably a Holocene terrace formed from exceptional storm wave activity in which storm waves can overtop the main level at c.7.5m O.D. by 2-3 m.

Lithostratigraphy

The harbour floor at Clachan is characterised by a thin (>5cm) veneer of coarse shelly sand overlying a highly compacted peat with wood, which in turn overlies a suite of sands and silty and clays which compose the intertidal sediments. Underlying the surface sand is a highly compacted rich brown peat with large pieces of wood (pine) up to 35 cm (long axis) and woody fragments sometimes accounting for up to 80% of the organic deposit. The peat is variable in terms of the presence within the harbour floor area. A greater extent of exposed peat and wood was noted by a Scotland's First Settlers reconnaissance trip prior to the sampling trip to excavate the monolith for analysis. The peat and wood are easily eroded from the harbour floor by natural processes as well as being excavated for local fuel use.

A monolith of excavated sediment encompassing the main stratigraphic units (Table 1) was obtained from the northern part of the harbour towards to back of the present day beach ridge at an altitude of 0.22 m O.D. and the main units are shown in Figure 5 with the sand veneer clear towards the top of the monolith and the organic deposit below underlain by the silts and clay deposits. The organic deposit exhibits a variable thickness across the area, being up to 0.25 m thick in places. In monolith 1 the organic unit is 0.06 m thick. The largest stratigraphic unit is composed of sands, silts and clays which make up the intertidal sediments. In the sampled monolith these sediments are c. 0.40 m in thickness. The silty clay unit extends to greater depths in excess of several metres and only the sediments around the lithostratigraphic boundaries were collected or further analysis.

Biostratigraphical analyses – diatoms and pollen

The diatom assemblage for Clachan Harbour is shown in Figure 6. At the base of the sequence the clastic sediments composed of silts and sands have increasing numbers of Mesohalobous (brackish) species. High frequencies of *Diploneis interrupta* and *Navicula peregrina* are indicative of saltings in the supratidal zone. Low numbers of marine and marine-brackish species, including *Diploneis* didyma, *Achnanthes delicatula* and *Navicula digito-radiata* occur in the sands suggesting deposition on mud or sandflats (Vos and de Wolf, 1993). As the contact with the overlying organic sediments is approached, the diatom assemblage returns to Mesohalobous dominated, with *Diploneis interrupta* and *Diploneis ovalis* prominent. The organic unit is characterised by increasing values of oligohalobian (Freshwater) species, with *Fragilaria* sp. and *Navicula pusilla* in greatest numbers. This assemblage is characteristic of a reduction in marine influence. The silty sands providing a thin veneer over the organic sediments across the harbour floor surface are characterised by polyhalobous and mesohalobous species including *Paralia sulcata, Cocconeis scutellum, Navicula peregrine, Nitzschia punctata* and *Diploneis didyma*. The presence of these brackish species together with the aeophile *Diploneis interrupta* indicates deposition within the intertidal area.

The overall assemblage provides evidence for a fall and then a subsequent rise in the marine influence at the site in the early to middle Holocene.

Contemporary diatom assemblages

An examination of contemporary diatom assemblages across the vegetated upper intertidal zone and the harbours surface sand flats was undertaken to try and establish the altitudinal relationships between the representative diatom assemblages within the monolith examined and the present day tidal levels. This is undertaken to ensure that the interpretation of the fossil sequences is based upon an understanding of the natural succession of coastal sedimentary sequences in the immediate vicinity of the study site. It is therefore imperative to establish contemporary relationships between the diatom assemblages, water levels, sedimentary facies and the coastal vegetation communities to determine the indicative meanings of the relative sea level changes deduced.

The contemporary samples cover Mean High Water Neap Tides (M.H.W.N.T.), across the sandflats to the landward edge of the beach and the start of vegetation communities at around Mean High Water Spring Tides (M.H.W.S.T.). The altitudes of these environments are related to tidal levels interpolated from the Admiralty Tide Tables for Portree (the nearest Secondary port) and Ullapool (the nearest Main tidal port). The predicted levels for Clachan harbour are summarised in Table 2.

Holocene sea level changes are reliant upon the identification of distinctive diatom boundaries. These include where the assemblage displays a marked change from polyhalobous (marine) species (indicative of intertidal mud and sandflats) to the dominance of mesohalobous (brackish) species (indicative of a developing saltmarsh) and occurs at c. 0.20 m above the predictive level of MHWST. The second boundary occurs where a change from mesohalobous species to the dominance of oligohalobous (fresh) taxa is evident. Finally, the third boundary of significance concerns the transition to more freshwater and salt intolerant species around HAT.

Many of the characteristic diatoms observed in the contemporary sediments are also characteristic of particular diatom zones within the Holocene sequence at Clachan harbour. The diatom assemblages are similar to those contemporary samples determined for the Kentra Moss area, Arisaig (Shennan *et al*., 1995).

Pollen assemblages

Pollen analysis was undertaken on the organic sediments from Clachan harbour (see paper and figure by Green *et al.* this volume). In brief, pollen grains identified at the base of the organic deposit are characterised by *Betula* with low percentages of *Pinus* and *Salix* and high frequencies of Cyperaceae (>50%), some *Artemisia* and minimal counts of *Rumex*. Sedge, willow and birch continue to rise throughout the organic unit with *Atemisia* peaking at 25% before falling to c.10%. Towards to top of the organic deposit rising *Corylus-Avellana-type* indicate the continued presence of Hazel scrub in the vicinity of the site. The continuous curve for *Betula* plus the commencement and development of *Corylus-Avellana-type* at Clachan harbour suggest that a birch-hazel woodland was established in the area and indicate an early Holocene, c. 9300 BP date for the expansion of this throughout the Hebrides (Birks, 1989).

The Clachan harbour pollen assemblages can be compared with other sites in western Scotland to provide an assessment of the timing of deposition of the intertidal organic sediments. The pollen record from Gruinart, Isle of Islay (Dawson *et al.* 1998) exhibits a similar sequence at the base of the organic deposit which are characterised by *Betula, Juniperus, Salix* and occasional *Pinus*. Betula is replaced up core by Corylus-Avellana-type. A similar sequence is also observed for Arisaig within uplifted coastal isolation basins. The pollen assemblages described are typical of early Holocene vegetation development with an open tundra landscape being replaced by the development of birch and hazel woodland as a consequence of climatic amelioration (Walker *et al.* 1992). The pollen sequences described for an intertidal organic deposit on the Isle of Coll are dated at 8000 radiocarbon years BP (Dawson *et al.* 2001). The low percentages of arboreal taxa, typical of the Younger Dryas, suggest an early

Holocene age but later than that suggested by the Islay and Arisaig pollen evidence.

Relative sea level changes

The pattern of relative sea level changes in Raasay during the early to middle Holocene are characterised by a fall in sea level, when the rate of glacio-isostatic uplift outpaced the glacio-eustatic increase in the volume of ocean water due to widespread ice melt throughout the globe. This was followed by a rise, when decreasing glacio-isostatic rebound was overtaken by the rate of rise in sea level caused by increased melting. The rate of rebound is variable across the inner Hebrides from the mainland due to the variability of the ice thickness across the area.

Relative sea level changes: Isle of Skye

Relatively little is known about the chronology of relative sea level change on the Isle of Skye and Raasay, although many raised marine terraces have been identified no systematic study of the raised shorelines in the area has taken place. Terraces have been identified at c. 30 m OD which represent Late Glacial sea level changes (see report by Dawson A.G., this volume). Raised shorelines formed during or following the culmination of the Main Postglacial Transgression are widespread in Skye and reach up to 7 m O.D. in eastern Skye at Sconser, the Braes and Peinchorran (Benn, 1991). Raised shingle ridges occur at higher altitudes (up to 10m O.D.) in more exposed locations. The nearest site to Raasay is a raised tombolo (connecting a former island to the mainland) of vegetated beach gravels at c. 7m O.D. at the Braes, on the mainland opposite Raasay.

Recent work by Selby *et al*., (2000) has examined the late Devensian and Holocene sea level record from selected isolation basins throughout Skye and shows evidence for marine inundation and sand and silt deposition (in quiet water conditions compared to the high energy raised terraces composed of gravel and shingle around the coastline of Skye), to at least 5 m O.D.

Relative sea level changes: Isle of Raasay

The sediments analysed from the floor of the harbour in SW Raasay, together with the information from the raised shingle terraces surrounding the harbour area, can be used to determine the pattern of relative sea level changes for Raasay during the Holocene. A graph of relative sea level change for the Inner Hebrides is shown in Figure 7 based upon data from the Isle of Coll and the Isle of Raasay. The earliest part of the Holocene was characterised by low relative sea levels at c. 0 m O.D. or slightly lower. This is in accord with other areas around the Inner Hebrides. The contact between the silts and clays and the overlying intertidal organic unit at 0.15 m O.D. marks a change from marine sedimentation, typical of an intertidal environment, to terrestrial sedimentation above the influence of marine activity. This boundary marks a relative marine regression at the site in the earliest part of the Holocene. Relative sea level remained low, sufficiently long enough to allow the growth of woodland at the site, although it was probably at these levels for between 500 and 1000 years. There then ensued a rise in relative sea level which commenced at c. 8800 radiocarbon years BP on the Isle of Skye (Selby *et al*. 2000). Pollen evidence from Clachan harbour suggests that the transgression may be earlier than the Skye and Coll data and be closer to the timing of the transgression on the Isle of Islay around c.9500 radiocarbon years B.P. (Dawson et al. 1998). The raised shorelines around the harbour provide morphological expression of this transgression with shingle ridges located at c. 7.5 m O.D. and c. 9 m O.D. The stratigraphic evidence for this transgression is present in the thin veneer of sediments overlying the organic unit across the harbour, although much erosion of the sand unit has undoubtedly taken place due to its situation within the present-day intertidal area. The ridges at c. 7 m O.D. are comparable to terraces located around the Isle of Skye and mark the culmination of the Main Postglacial Shoreline. An isobase map for this Shoreline is shown in Figure 8.

Summary

The pattern of relative sea level change in western Scotland during the Holocene is the product of the combined effects of glacio-isostatic deformation and glacio-eustatic changes. As a consequence, the pattern of Holocene relative sea level change is regionally variable. Intertidal woody peat in south west Raasay began to accumulate during the early Holocene around c. 9500 - 8500 ^{14}C years BP at which time relative sea level fell close to 0 m OD or slightly lower. Terrestrial organic sedimentation and the development of woodland accumulated at or close to sea level until c. 8500 ^{14}C years BP when they were submerged by a rise in sea level which reached an altitude of at least c. 7.6 m OD, the highest Holocene terrace immediately NE of the intertidal zone in the grounds of Raasay House.

Storm waves, deposited shingle ridges at even higher altitudes. In the area immediately surrounding Clachan harbour, the occurrence of raised storm ridges with crest altitudes up to c. 10 m O.D. imply that storm waves may have occasionally reached and exceeded this altitude. The age of this relative transgression maximum is dependant upon radiocarbon dating. Analysis by Selby *et al*. (2000) for relative sea level changes in SW Skye suggest that this transgression maximum may have culminated as recently as c. 3000 radiocarbon years BP.

The stratigraphic position and altitude of the intertidal sediments is consistent with the results of relative sea level investigations undertaken on sediments of a similar age in Islay (Gruinart flats) and NE Coll. Relative sea level data for this transgression from Kentra Moss (Loch Shiel) and Arisaig, Moidart are at higher altitudes due to the variability in the uplift history between the two areas.

The presence of the sediments in the surf zone leads them to be susceptible to erosion by storm wave activity and removal as well as disturbance by human excavation at the present day.

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List of Figures

Table 1.

Depth cm	Altitude m O.D	Stratigraphic description
0-1.0	0.21	coarse grey shelly sand
1.0-7.0	0.15	brown peat with wood fragments
7.0-7.5	0.14.5	fine grey sand
7.5-9.0	0.13	grey-brown organic sand
9.0-10.0	0.12	grey silty sand
10.0-16.0	0.06	clayey silt with sand grains evident
16.0-18.0	0.03	highly organic sand
18.0-50.0	-0.28	grey silty clay

Table 2.

	Chart datum	**L.A.T.**	**M.L.W.S.T**	**M.L.W.N.T**	**M.S.L**	**M.H.W.N.T**	**M.H.W.S.T**	**H.A.T**
Ullapool Main Port		0.0	0.7	2.1	3.0	3.9	5.2	5.8
(Broadford)		(0.0)	(-0.1)	(0.1)	(3.0)	(0.2)	(0.3)	(6.1)
Broadford	**-2.85**	**-2.85**	**-2.25**	**0.60**	**0.15**	**1.25**	**2.95**	**3.25**
Contemporary Samples	**Characteristic diatom species**						**Tidal equivalent**	
1 -0.00 m OD	*Paralia sulcata, Rhabdonema minutum, Diploneis smithii Achnanthes brevipes*						**MSL ± 0.15**	
2 0.22 m O D	*Paralia sulcata, Cocconeis scutellum, Rhabdonema minutum*						**MSL**	
3 0.17 m O D	*Paralia sulcata, Navicual peregrina, Diploneis didyma*						**MSL**	
4 1.52 m O D	*Diploneis interrupta, Paralia sulcata, Cocconeis scutellum*						**MHWNT**	
5 2.32 m O D	*Diploneis interrupta, Navicula peregrine, Navicula digito-radiata*						**MHWST ± 0.50**	