Lateglacial and Holocene Relative Sea Level Change in Applecross, Raasay and eastern Skye

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Abstract

The paper provides an account of the changes in relative sea level that accompanied the history of settlement in Applecross (Sand), Raasay and eastern Skye (An Corran) that, together, form the basis of the "Scotland's First Settlers" research project. The changes in relative sea level that are described are also discussed within the context of changes in climate that accompanied the melting of the last (Late Devensian) ice sheet in Scotland. Relative sea level changes are thus also described for the Holocene with particular emphasis given to changes that took place during the period of Mesolithic occupation. The report also considers relationships between past patterns of relative sea level across the Scottish Inner Hebrides and archaeological history given recent advances in our understanding of Holocene sea level changes research.

Introduction

The origins of the rock shelters at Sand and An Corran investigated in 'Scotland's First Settlers' are intimately related to past changes in relative sea level change that took place at the close of the last (Late Devensian) glaciation in Scotland. The relative sea level changes that took place across the NW Highlands at this time resulted from the complex interplay of glacio-isostatic rebound consequent upon regional ice melting (deglaciation) and the influence of glacio-eustatic changes in global ocean volume linked to the melting of ice sheets worldwide. This account describes the interaction of these two key processes and describes how the raised shoreline features of Applecross, Raasay and eastern Skye were mostly formed when sea level was lower (and *not* higher) than present. In the following pages for the purpose of simplicity, dates are expressed in conventional radiocarbon years BP.

Background

Glacial isostasy and eustasy

The last ice sheet in Scotland is generally believed to have reached its maximum extent ca. 20,000 yr ago when it was sufficiently thick to have covered nearly all of the highest mountains and wide enough to have extended westwards across the (now submerged) continental shelf (Sutherland 1984, Ballantyne et al. 1998). Widespread glaciation at this time was also associated with the growth of large ice sheets in North America (the Laurentide ice sheet), Scandinavia (the Fennoscandian ice sheet) and across large areas of Russia (the Eurasian ice sheet). Together with ice that accumulated in ice sheets elsewhere, the expansion of existing ice sheets in Greenland and Antarctica, and the growth of mountain glaciers, the accumulation of ice on land was sufficient to lower the average sea level worldwide by ca. -150m. This glacio-eustatic lowering of sea level in turn, had an effect on the underlying ocean crust. The decreased ocean volume resulted in less mass being exerted on the ocean floor and consequently there was a hydro-isostatic unloading of oceanic crust that resulted in an observed fall in sea level of ca. –120 m. In ocean areas located far from the last great ice sheet it is extremely rare to find submerged coral terraces lower than –120 m below present sea level. Thus, one might imagine that in western Scotland, the position of sea level (as seen from space) was at this approximate level during the last glacial maximum.

At this time nearly all of the present land area of the NW Highlands was covered by ice. Thus, if there was a palaeo-coastline, it was located west of the ice sheet somewhere on the (now submerged) continental shelf. The mass of ice resulted in the depression of the underlying crust (lithosphere). This process, known as glacio-isostatic deformation is enormously complex since the lithosphere is able to deform only because the zone of molten rock (magma) beneath the lithosphere has a viscosity capable of deforming as the lithosphere presses down upon it. This zone of low viscosity magma, known as the asthenosphere, is thus capable of deforming if a load is placed upon it. Thus the last ice sheet that covered the NW Highlands led to the deformation of the underlying lithosphere and uplift of the lithosphere across large areas beyond the former ice sheet margin.

Relative sea level changes

The pattern of relative sea level changes that took place following the melting of the last (Late Devensian) ice sheet in NW Scotland and during the subsequent Holocene is a result of the complex interplay between vertical (glacio-isostatic) land movements and changes in the volume of the world's ocean (Table 1). Together, these two factors resulted in changes in *relative* sea level (RSL) that, in the Skye – Applecross area are represented in the landscape by a rich and varied assemblage of raised shoreline features. In some areas, emerged shore platforms and ancient sea stacks testify to the former occurrence of higher (relative) sea levels. Elesewhere, raised shorelines are indicated by vegetated gravel terraces and shingle ridges.

In Skye and Applecross the highest emerged shoreline features that are visible are raised shore platform fragments and associated backing cliffs that occur up to ca. 25-30 m OD (Ordnance Datum). The platforms are typically ca. 100 m in width but locally, as near Lonbain, western Applecross may be as wide as ca. 500 m (Robinson 1977). Emerged coastal rock platform on Skye were also described by Richards (1969, 1971) as occurring in a wide variety of igneous and metamorphic rock types and often being best-developed on west-facing coastlines. In western Applecross, these high rock platform features are especially well developed and are almost continuously developed along the coastline of western Applecross. Some sections of the platform surface are ice-moulded and exhibit glacial striae and thus demonstrate that the features were produced prior to the last general glaciation of the area. Other platform fragments show no evidence of having been overridden by glacier ice and are likely to have been formed during or shortly after the melting of the last (Late Devensian) ice sheet. Thus the rock shelters at An Corran and Sand are in fact the floors of abandoned sea caves formed during regional ice sheet melting. The features form part of a raised shoreline that has been affected by differential glacio-isostatic uplift. Thus the abandoned sea caves at Sand (+27.7m OD) and at An Corran (ca. +20m OD) form part of a sequence of early Lateglacial raised shorelines subject to regional glacio-isostatic tilting.

It is thus argued below that the rock shelter at Sand represents part of a raised shoreline at ca. +28 m OD that formed during the melting of the last (Late Devensian) ice sheet in the NW Highlands. The simple view that sea cave must have formed when sea level was +28 m higher than present is mistaken. At the time the sea cave was produced, global ocean volume was considerably less than present due to large volumes of ice having been locked up in the great ice sheets that formed during the last ice age. In fact, sea level (as viewed from space) was ca. –70 m below its present level at this time. The reason that the shoreline feature is now raised above sea level is because +98 m of land uplift has taken place since the feature was formed. Thus the +28 m shoreline was not produced when sea level was +28 m higher than present, it was formed when sea level was –70 m lower than present!

Relative sea level changes in Applecross, Raasay and eastern Skye

1. The initial high level and the subsequent fall

The Lateglacial marine limit (the highest level reached by the Lateglacial sea) is defined at Sand by the altitude of the rock shelter that represents the lower part of an abandoned sea cave. The overhang above the rock shelter represents the roof of the same sea cave. The altitude of the sea cave is at +27.7 m OD and is the highest level reached by the Lateglacial sea as ice melted from the area at the close of the last (Late Devensian) glaciation. The sea cave is part of a raised shoreline that can be traced northwards along the west coast of Applecross at this approximate elevation (Robinson 1977) and declines in altitude to the NW towards northeastern Skye (Figure 2). With the exception of local areas this raised shoreline has never been mapped in detail nor have regional variations in its elevation been measured in detail. Thus the altitude of this shoreline may differ markedly between Applecross, Raasay and eastern Skye. Sissons and Dawson (1979) measured a similar raised shoreline in Wester Ross and concluded that the feature has a regional slope of ca. 0.35m/km. This shoreline, known as the Main Wester Ross Shoreline, is generally considered to have been produced at approximately the same time as the Wester Ross Readvance, a period of renewed ice growth in the NW Highlands that interrupted the decay of the Late Devensian ice sheet (Figure 1, Table 1). If this correlation is broadly correct, one may imagine that the sea cave (and hence the rock shelter) was produced ca. 13-15,000 yr BP.

In Raasay, the Lateglacial marine limit is represented, for example, by a broad terrace and vegetated bank of shingle at Raasay House. The House is built on the inner (landward) edge of the Lateglacial marine sediments that here occurs at ca. +27m OD. Here, as at Sand, the regional melting of the Late Devensian ice sheet resulted in glacio-isostatic rebound of the land surface that outpaced the rate of eustatic sea level rise and resulted in a RSL fall. Several thousand years later, during the cold climate of the Younger Dryas (ca. 10-11,000 yr BP), relative sea level had fallen at Raasay House to near its approximate present level (Figure 1, Table 1).

The pattern of relative sea level change in Applecross following the formation of the Sand rock shelter was characterised by a progressive fall in relative sea level as glacio-isostatic uplift outpaced the rise in eustatic sea level caused by the melting of ice worldwide. We do not know with much precision the rate at which relative sea level fell and for how long. We do know, however, that sea level continued to fall in Applecross, Raasay and Skye until the Younger Dryas period of cold climate when relative sea level was similar to present. If it is assumed that this period of relative sea level fall (ie. from +27.7 m OD to present) lasted between 2000 yr (minimum) and 4000 yr (maximum), the *average* rate of relative sea level fall during the Lateglacial was between ca. 0.7 – 1.4 cm/yr. Similar estimates for the rate of RSL fall are applicable also to Raasay and eastern Skye.

2. The Younger Dryas – relative sea level close to present

The climate in the Scotland during the period of relative sea level fall described above was generally benign. Climate amelioration, after all, was responsible for the melting of the last ice sheet and mild conditions prevailed until the cold climate of the Younger Dryas. Not surprisingly, the onset of the Younger Dryas was associated with a change in conditions at the coast as the formely mild temperatures were replaced by severe cold. It has been estimated that during this period of cold climate, mean July air temperature may have been no higher that ca. 7ºC while January temperatures at sea level may have descended to ca. –20ºC. During this period of cold climate, a small ice cap developed over southern Skye (Ballantyne 1989). In eastern Skye, opposite Raasay, an outlet glacier from this ice cap advanced to the mouth of Loch Sligachan (ibid). No other glacier reached the sea at this time in eastern Skye, Applecross or Raasay although large areas of glacier ice occupied the interior areas of Applecross as well as outlet glaciers having reached sea level in Loch Torridon and Loch Carron (Robinson 1977, Sissons 1977).

During this period, a well developed shore platform and cliff was produced throughout the western Highlands as a result of cold climate shore processes. The platform occurs up to 10-11 m in the Oban area, is typically 50-150m wide and is backed by a 10-20m high cliff (Dawson 1988, 1989, Stone et al. 1996) (Figure 2). In Applecross as a result of differential glacio-isostatic uplift, this shoreline occurs slightly above high tide level at Sand where it is represented by a narrow platform and low cliff on the headland immediately south of the dunes. The platform and cliff, known as the Main Lateglacial Shoreline (Main Rock Platform), can also be traced intermittently northwards along the Applecross coast. Within the Sand dune complex it may also form the rock basement seaward of the cliff and beneath the sand accumulations. In many areas, the occurrence of inclined Torridonian sandstone strata render identification of the platform and cliff difficult.

Throughout the western Highlands the platform and cliff of presumed Younger Dryas age is associated with the widespread development of sea caves. The floors of the sea caves occur at different elevations in different places as a result of differential glacio-isostatic uplift. Thus sea caves of this age occur between 4 – 6 m OD along the west coast of Jura, at 10-11 m OD in the Oban area, between 2-4 m OD along the Sleat peninsula in Skye (Figure 2). In Applecross, Raasay and eastern Skye the sea cave floors occur within and slightly above the intertidal zone. The caves floors everywhere are mantled by younger Holocene marine gravels. However, there is convincing evidence to indicate that the periods cave formation during the Younger Dryas and marine gravel deposition during the Holocene were separated by an episode of low RSL and terrestrial sedimentation within the caves (see below).

It has long been recognised that there a striking regional differences in the clarity and development of the Main Lateglacial Shoreline, particularly between the SW and NW Highlands. Bailey et al. (1924) first observed the comparitive obscurity of the feature throughout Ardnamurchan, Moidart and Syke and suggested that the SW Highlands had "…enjoyed a more prlonged period of constant sea-level during the Post Glacial submergence than the country farther northwest”. Thus the Main Lateglacial Shoreline (Main Rock Platform), although visible locally, is not a striking feature of the Applecross, Raasay and eastern Skye coastlines.

The age and origin of the abandoned sea caves associated with the Main Lateglacial Shoreline is of fundamental importance to mesolithic archaeology. For example, the ‘Obanian’ culture of Lacaille (1954) was partly based on the notion that the caves and associated sediment infill represent the product of postglacial (Holocene) marine processes. Since the postglacial relative marine transgression culminated during the mid-Holocene, the cave archaeology had to post-date this marine transgression. The modern interpretation is that whereas the marine sediments within the caves were deposited during the culmination of this relative marine transgression, the caves themselves were not. Given that RSL fell during the Early Holocene after the caves were formed and later rose during the Holocene (postglacial) transgression, the caves were therefore available for human occupation during the intervening period prior to marine inundation.

3. The post- Younger Dryas low stand in relative sea level

The melting of the last ice sheet across Scotland was associated with a pattern of glacio-isostatic rebound that decreased exponentially with time. Most of the crustal rebound took place during the Lateglacial period and relatively little during the

Holocene. For the Younger Dryas period, the nature of crustal deformation across the NW Highlands is unclear given that there was widespread development of glacier ice in Skye and Applecross. It is not known if the renewed growth and expansion of ice during this period resulted in the re-depression of the lithosphere (crust) or if the growth of ice in Skye, Applecross and elsewhere had no effect on the pattern of decreased crustal rebound. At the start of the Holocene, therefore, crustal rebound was still continuing. The key change influencing patterns of RSL change across the NW Highlands was the (glacio-eustatic) effect of melting ice sheets worldwide that resulted in a progressive increase in global ocean volume. The rate at which ocean volume increased over time in response to melting ice sheets is not known. It is known, however, that in the NW Highlands, the rate of ocean volume increase began to result in a sea level rise that soon began to outpace the rate of land uplift. It would appear that this change took place between ca. 8000 –9000 14C yrs BP. Thus the first ca. 1000-1500 years of the Holocene interglacial were associated with a low RSL and it is most likely that it was during this time interval that the Raasay intertidal peat deposit began to accumulate (Figure 1).

4. The rising Holocene sea level

During the Early Holocene period, climate amelioration resulted in the widespread melting of ice sheets. The largest of those to disappear entirely were the Laurentide ice sheet in North America and ice sheets in Scandinavia and Eurasia. The last vestiges of ice in Scandinavia and Eurasia had mostly disappeared by ca. 9000 14C years ago. The Laurentide ice sheet took a little longer to melt – its final disintegration is generally considered to have taken place between 7500 –8000 yr BP. Thus the Early Holocene is characterised by a dramatic rise in sea level worldwide and it would appear that this rise culminated between ca. 7000 – 7500 yr BP. It is because of this huge influx of meltwater into the world's oceans that in the NW Highlands, the rate of eustatic sea level rise during the Early Holocene very quickly outpaced the rate of crustal (glacio-isostatic uplift). Thus the period of intertidal peat accumulation was soon ended by this dramatic rise in sea level. This RSL rise drowned all the previously abandoned sea caves produced during the Younger Dryas. During this relative marine trangression, all sea caves of Younger Dryas age were subject to wave action and the previously dry floors (possibly containing occupation horizons ?) were mantled with marine gravels. In sheltered estuarine environments, this rise in RSL resulted in the deposition of (now raised) mudflats. Along more exposed stretches of coastline, banks and ridges of shingle were deposited. Examples of such vegetated shingle deposits can been seen at Sand immediately adjacent to the unvegetated dunes (Figure 3). Similarly a raised vegetated marine terrace and shingle ridge occur landward of the harbour area at Raasay House. Here, the Holocene raised marine deposits are succeeded upslope by a degraded cliffline that represents the seawards edge of the (higher) Lateglacial marine terrace into which the Holocene shoreline features were cut.

The date of the culmination of the rise in Holocene sea level is unclear. Some consider that the culmination may have occurred ca. 6500 yr BP but more recent research by Selby (1997) at the Braes, eastern Skye, appears to indicate that the sea may have reached its highest level as late as ca. 4000 yr BP. The latter view, if correct, would appear to indicate most of the Y Dryas sea caves remained flooded until the Neolithic. The altitude reached by the relative marine transgression is difficult to determine with precision, given a tidal range in the NW Highlands of ca. 3.5 m. Whereas in northern Applecross, Shennan et al. (2000) describe the maximum altitude of quiet water sedimentation was no higher than +5.7m OD, the altitudes of gravel terraces and shingle ridges (e.g. at the head of Loch Torridon) deposited at this time are considerably higher (up to 7.1 m OD)(Robinson 1977). From an archaeological perspective, the latter value (ca. +7 mOD) provides a reasonable estimate for the upper limit of the high water mark of spring tides during the Holocene in Applecross, Raasay and eastern Skye.

Since ca. 4000 yr BP, the rise in eustatic sea level has been so limited that it has been outpaced by residual glacio-isostatic uplift. Indeed , there may have been periods of time during the last ca. 4000 yr when eustatic sea level may have fallen (ie. reduced ocean volume) due to the renewed growth of glaciers and ice sheets.

5. Aeolian sedimentation and increased storminess

During recent centuries there has been a marked increase in storminess across the N Atlantic region (cf. Meeker and Mayewski 2002). Whereas the Medieval Warm period was relatively quiescent, the cold climate of the Little Ice Age was extremely stormy. The change from benign to stormy conditions appears to have taken place soon after AD 1400 and it is during this period that wind-blown sand accumulated at the coast. At Sand, this is demonstrated by the presence of considerable thicknesses of blown-sand on top of Medieval metal workings. However, coastal dune formation may also have taken place during earlier times during the Holocene. For example at Sand, the presence also of considerable thicknesses of sand beneath the metal workings points to episodes of dune construction earlier during the Holocene. At Sand, the lower dune deposits locally rest upon Holocene marine gravels, therefore implying that the majority of the dune accumulation in this area took place during the latter part of the Holocene.

Summary

The pattern of Lateglacial and Holocene RSL changes that took place in the NW Highlands is complex and represents the interaction of glacio-isostatic rebound following the melting of the Late Devensian ice sheet and the progressive increase in global ocean volume following the melting of ice sheets worldwide. The pattern of differential glacio-isostatic rebound that took place has resulted in individual raised shoreline features of the same age occurring at different altitudes in different places. In a restricted area such as Applecross , Raasay and Skye, the pattern of RSL changes is almost certainly likely to differ between An Corran, Raasay Harbour and Sand. However, the pattern of Lateglacial and Holocene RSL change at each location is likely to have been very similar.

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Figures

1. Location map. The black lines (both continous and stippled) show the uplift isobases of the Main Lateglacial Shoreline (Main Rock Platform) expressed in metres above Ordnance Datum (OD). Shown also for comparison are the

uplift isobases for prominent Lateglacial shorelines in SW and SE Scotland. Profile line A-B shows the location of the shoreline height-distance diagram shown in Figure 2.

2. Generalised shoreline height-distance diagram for Applecross, Raasay and eastern Skye. Each sloping line represents a prominent raised shoreline. The tilted shoreline that rises in altitude from Skye to Sand terminates at the margin of the decaying Late Devensian ice sheet (the ice margin is shown as a curved hatched line). Other older tilted Lateglacial raised shorelines are shown schematically as dashed lines. A vertical arrowed line shows the trend of RSL changes as sea level fell to its low level during the Younger Dryas and early Holocene. The location and altitude of the Raasay Harbour intertidal peat accumulation is also shown.

Table

1. Quaternary stratigraphic nomenclature (after Ballantyne and Harris 1994).

Table 1

Stage	Substage	Stadial/Interstadial	Boundary (^{14}Cyr BP)
Flandrian Interglacial			
------ *Pleistocene/Holocene Boundary* ------			10,000
		Loch Lomond Stadial (Younger Dryas)	11.000
		Windermere Interstadial	
Devensian	Late Devensian		13,000

(Wester Ross ice advance)

Dimlington Stadial

----------26,000 ----

(after Ballantyne and Harris 1994)