

7.1 Late-glacial and Holocene Relative Sea-Level Change in Applecross, Raasay and eastern Skye | Alastair Dawson

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7.1.1 Introduction

The origins of the rockshelters at Sand and An Corran are intimately related to past changes in relative sea-level that took place at the close of the last (Late Devensian) glaciation in Scotland. The relative sea-level changes that took place across the North West 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, in line with the geosciences, ages are expressed in conventional, years BP alone (that is years before present, taken at 1950). Most of the dates refer to the general age ranges of natural periods, but where radiocarbon dates have been used they have not been calibrated because there are various radiocarbon plateaux which affect dates of this age thus making calibration uncertain.

7.1.2 Background

7.1.2.1 Glacial isostasy and eustasy

The last ice sheet in Scotland is generally believed to have reached its maximum extent *c*20,000 years 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 *c*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 *c*120m. In ocean areas located far from the last great ice sheet it is extremely rare to find submerged coral terraces lower than 120m 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 North West Highlands was covered

by ice. Thus, if there was a palaeocoastline, 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 capable of deforming if a load is placed upon it. Thus the last ice sheet that covered the North West Highlands led to the deformation of the underlying lithosphere with both depression, below the ice, and uplift, beyond the former ice sheet margin, across large areas.

7.1.2.2 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 North West 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 (see [Table 180](#), below). 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. Elsewhere, raised shorelines are indicated by vegetated gravel terraces and shingle ridges.

Table 180			
Stage	Substage	Stadial/Interstadial	Boundary (¹⁴ Cyr BP)
Flandrian Interglacial			
Pleistocene/Holocene Boundary			10,000
Devensian	Late Devensian	Loch Lomond Stadial (Younger Dryas)	11,000
		Windermere Interstadial (Wester Ross ice advance)	13,000
		Dimlington Stadial	26,000

Table 180: Quaternary stratigraphic nomenclature (after [Ballantyne & Harris 1994](#))

In Skye and Applecross the highest emerged shoreline features visible are raised shore platform fragments and associated backing cliffs that occur up to c25–30m OD (Ordnance Datum). The platforms are typically c100m in width but locally, as near Lonbain, in western Applecross they may be as wide as c500m ([Robinson 1977](#)). The emerged coastal rock platforms 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 rockshelters at An Corran and Sand are in fact the floors of 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 sea caves at Sand (27.7m OD) and at An Corran (c10m OD) form part of a sequence of early Late-glacial raised shorelines subject to regional glacio-isostatic tilting.

It is argued below that the rockshelter at Sand represents part of a raised shoreline at c28m OD that formed during

the melting of the last (Late Devensian) ice sheet in the NW Highlands (see [Illustration 325](#), right). The simple view that the sea cave must have formed when sea-level was 28m 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 c70m below its present level at this time. The reason that the shoreline feature is now raised above sea-level is because 98m of land uplift has taken place since the feature was formed. Thus the 28m shoreline was not produced when sea-level was 28m higher than present, it was formed when sea-level was 70m lower than present!



Illus 325: The rockshelter at Sand

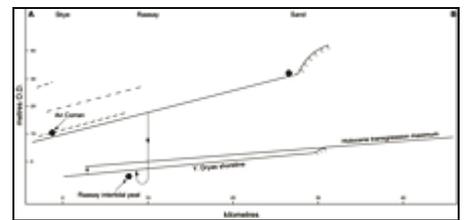
7.1.3 Relative sea-level changes in Applecross, Raasay and Eastern Skye

7.1.3.1 The initial high level and the subsequent fall



Illus 537: Location map for the raised shoreline of which the Sand rockshelter is part

The Late-glacial marine limit (the highest level reached by the Late-glacial sea) is defined at Sand by the altitude of the rockshelter that represents the lower part of an old sea cave. The overhang above the rockshelter represents the roof of the same sea cave. The altitude of the sea cave is at 27.7m OD and is the highest level reached by the Late-glacial sea as ice melted from the area at the close of the last (Late Devensian) glaciation.



Illus 538: Generalised shoreline height-distance diagram for Applecross, Raasay and eastern Skye

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 North West towards north eastern Skye (see [Illustrations 537](#), left & [538](#), right). 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 & Dawson \(1981\)](#) measured a similar raised shoreline in Wester Ross and concluded that the feature has a regional slope of c0.35m/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 North West Highlands that interrupted the decay of the Late Devensian ice sheet (see [Illustrations 537](#), left; [538](#), right & [Table 180](#), above). If this correlation is broadly correct, one may imagine that the sea cave at Sand (and hence the rockshelter) was produced c13–15,000 years BP.

In Raasay, the Late-glacial marine limit is represented at Raasay House by a broad terrace and vegetated bank of shingle. The house is built on the inner (landward) edge of the Late-glacial marine sediments that here occur at c27m OD (see [Illustration 539](#), right). 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 (c10–11,000 years BP, relative sea-level had fallen at Raasay House to near its approximate present level (see [Illustrations 537](#), [538](#) & [Table 180](#), all above).



Illus 539: Holocene and Late-Glacial shingle bank, south-

The pattern of relative sea-level change in Applecross following the formation of the Sand rockshelter 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 (that is from +27.7m OD to present levels) lasted between 2000 years (minimum) and 4000 years (maximum), the average rate of relative sea-level fall during the Late-glacial was between $c0.7$ – 1.4 cm per year. Similar estimates for the rate of RSL fall are applicable also to Raasay and eastern Skye.

7.1.3.2 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 formerly 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 than $c7^{\circ}\text{C}$ while January temperatures at sea-level may have descended to $c-20^{\circ}\text{C}$. 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 though 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 10–11m 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) (see Illustration 538, above). 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 Late-glacial 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 occurrences 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 4–6m OD along the west coast of Jura, at 10–11m OD in the Oban area, between 2–4m OD along the Sleat peninsula in Skye (see Illustration 538, above). In Applecross, Raasay and eastern Skye the sea cave floors occur within and slightly above the intertidal zone. The cave floors everywhere are mantled by younger Holocene marine gravels. However, there is convincing evidence to indicate that the period of cave formation during the Younger Dryas was separated from the marine gravel deposition during the Holocene by an episode of low RSL and terrestrial sedimentation within the caves (see below).

It has long been recognised that there are striking regional differences in the clarity and development of the Main Late-glacial Shoreline, particularly between the South West and North West Highlands. Bailey *et al* (1924) first observed the comparative obscurity of the feature throughout Ardnamurchan, Moidart and Syke and suggested that the SW Highlands had "...enjoyed a more prolonged period of constant sea-level during the Post Glacial submergence than the country farther northwest". Thus the Main Late-glacial 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 sea caves associated with the Main Late-glacial Shoreline is of fundamental importance to Mesolithic archaeology. For example, the 'Obanian' culture of [Lacaille \(1954:345\)](#) 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 (post-glacial) transgression, the caves were clearly available for human occupation during the intervening period prior to marine inundation.

7.1.3.3 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 Late-glacial period and relatively little during the Holocene. For the Younger Dryas period, the nature of crustal deformation across the North West 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 North West 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 North West 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 c8,000–9,000 14C years BP. Thus the first c1000–1500 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 (see [Section 7.2](#)).

7.1.3.4 The rising Holocene sea-level

During the Early Holocene, climatic 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 the ice sheets of Scandinavia and Eurasia. The last vestiges of ice in Scandinavia and Eurasia had mostly disappeared by c9,000 14C years ago. The Laurentide ice sheet took a little longer to melt – its final disintegration is generally considered to have taken place between 7,500–8,000 years BP. Thus the Early Holocene is characterised by a dramatic rise in sea-level worldwide and it would appear that this rise culminated between c7,000–7,500 years BP. It is because of this huge influx of meltwater into the world's oceans that in the North West 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 sea caves produced during the Younger Dryas. During this relative marine transgression, 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 be seen at Sand immediately adjacent to the unvegetated dunes. 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) Late-glacial 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 *c*6,500 years 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 *c*4,000 years BP. The latter view, if correct, would appear to indicate that most of the Younger 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 North West Highlands of *c*3.5m. Whereas in northern Applecross, [Shennan *et al* \(2000\)](#) describe the maximum altitude of quiet water sedimentation as no higher than 5.7m OD, the altitudes of gravel terraces and shingle ridges (for example at the head of Loch Torridon) deposited at this time are considerably higher (up to 7.1m OD) ([Robinson 1977](#)). From an archaeological perspective, the latter value (*c*7m OD) 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 *c*4,000 years 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 *c*4,000 years when eustatic sea-level may have fallen (that is reduced ocean volume) due to the renewed growth of glaciers and ice sheets.

7.1.3.5 Aeolian sedimentation and increased storminess

During recent centuries there has been a marked increase in storminess across the north Atlantic region ([Meeker & 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 AD1,400 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 in the Holocene. For example at Sand, the presence of considerable thicknesses of sand beneath the metal workings points to episodes of dune construction earlier in 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 after the drop in RSL.

7.1.4 Summary

The pattern of Late-glacial and Holocene RSL changes that took place in the North West 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. Thus, even in a restricted area such as Applecross, Raasay and Skye, the details of RSL changes are likely to differ between An Corran, Raasay Harbour and Sand. However, the pattern of Late-glacial and Holocene RSL change within each location is likely to have been very similar.

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