North Atlantic climate change and Late Holocene windstorm activity in the Outer Hebrides, Scotland

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Scottish Archaeological Internet Report 48, 2011
www.sair.org.uk

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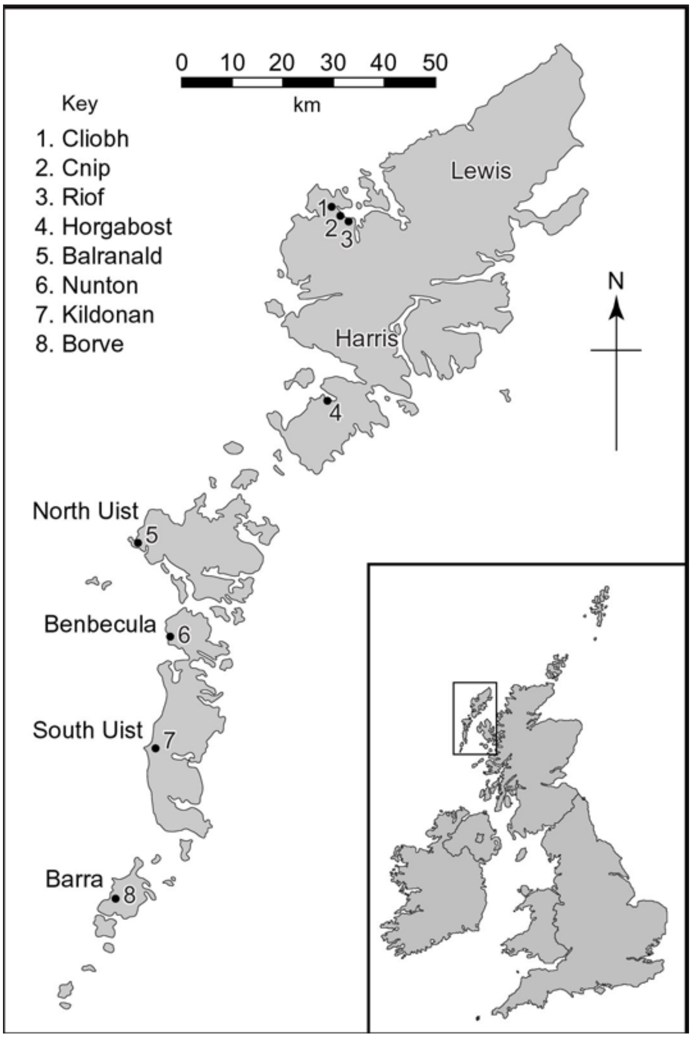
1 ABSTRACT

Lithostratigraphical and biostratigraphical investigation of marshes adjacent to coastal dune sequences in the Scottish Outer Hebrides show inland-tapering sand units enclosed within organic sediments. The sand sheets are considered to have been deposited by past windstorm activity, while radiometric dating appears to indicate deposition during the last 2000 years except for the well-known period of Medieval warmth that is here considered to have occurred between *c* AD 600 and 1400. It is argued that the episodes of sand-blow indicated by the deposits may reflect periods of increased cyclogenesis in the North Atlantic associated with increased sea-ice cover, an increase in the thermal gradient associated with the polar atmospheric and oceanic fronts as well as colder air temperatures. It is also noted that the diminished North Atlantic winter storminess during Medieval times was broadly coincident with the expansion of Viking culture.

2 INTRODUCTION

In recent years reconstructions of Late Holocene climate variability of the North Atlantic region have been enhanced considerably as a result of Greenland ice core research. In particular, our knowledge of changes in North Atlantic storminess has been transformed as a result of the published chronology of Na+ (sea salt) concentration changes from the GISP2 drill site (Meeker & Mayewski 2002). Annual changes in sea-salt concentration at GISP2 calculated for the last 1,400 years have been interpreted as a regional signal of North Atlantic winter storminess change. The sea-salt concentration time series is resolved to an annual scale and thus provides a high-precision long-term record of storminess change that can be compared with other records of change (e.g. meteorological time-series).

In this paper, we explore in more detail the results of Dawson et al (2004) that described Late Holocene coastal windstorm deposits from the Scottish Outer Hebrides. Radiocarbon dating of peat deposits enclosing the sand units were used to construct a local chronology of Late Holocene windstorm events that were, in turn, used to test the Meeker and Mayewski (2002) hypothesis that an increase in winter storminess took place after *c* AD 1400–20 during the so-called Little Ice Age (LIA), this having been preceded by a period of negligible storm activity during the Medieval Warm Period (MWP).



Illus 1 Field site locations, Scottish Outer Hebrides

3 STUDY AREA

The Outer Hebrides island chain (illus 1) extends from broadly north to south across a latitudinal range of 56ºN–58ºN, thus occupying an area presently influenced by the North Atlantic storm track. The islands are characterised by Lewisian gneiss bedrock that rises to heights locally in excess of 500m, but along the Atlantic margin the bedrock is characterised by sub-horizontal rock surfaces located a few metres above sea level. These are mantled by largely stabilised dune systems consisting of coastal dunes to seaward and a gently sloping surface to landward, where the system ends within peat areas, rocky outcrops and many small lochs. The sand-dominated landscape is locally known as machair, a Gaelic word that describes a low-lying, grass-dominated coastal plain composed of calcareous sand, with a calcium carbonate content up to *c* 80% (Ritchie & Whittington 1994). Notwithstanding the apparent uniformity of the machair surface, the occurrence of organic horizons within dune sediment exposures implies a complex evolutionary history.

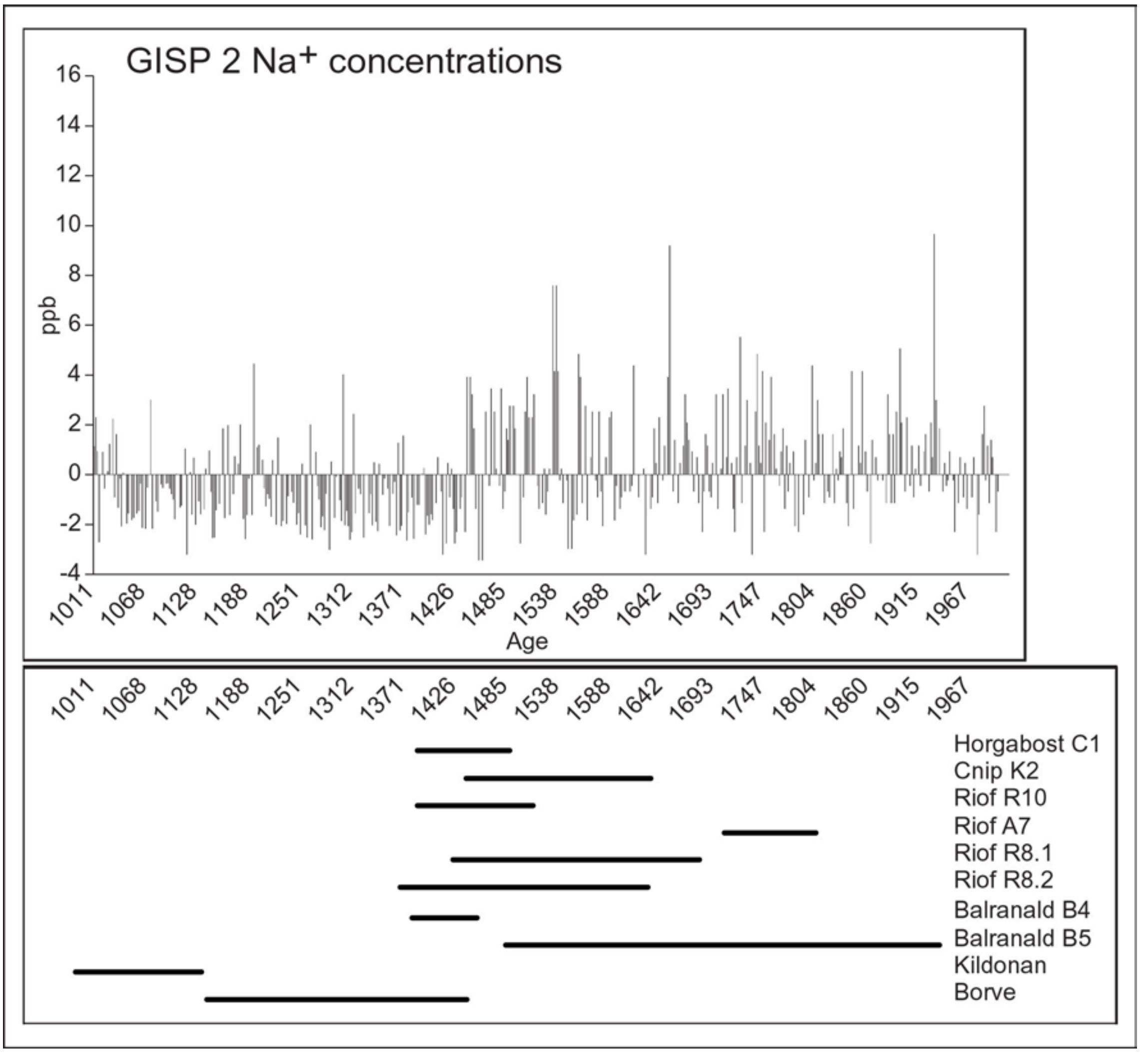
Studies of sediment exposures and of foreshore peat deposits have been undertaken by several researchers, including Ritchie (1979, 1985), Ritchie and Whittington (1994) and Gilbertson et al (1996; 1999) that, in turn, have led to the development of a model of machair evolution. The model is based on the concept that during the Holocene rise in sea level, glacially-derived sands from offshore were mobilised and mixed with comminuted shell debris. This material was reworked into coastal ridges and moved onshore over pre-existing lacustrine and organic deposits (Ritchie 1985).

The complex nature of machair evolution was demonstrated by research undertaken in the Uists by Ritchie and Whittington (1994), who showed that locally variable stratigraphic sequences had resulted from non-synchronous sand-blow (windstorm) events. Ritchie and Whittington (1994) demonstrated that the earliest sands represent 'overlapping landform suites' which, through long-term erosion, outcrop today in the present intertidal zone. They argued that the onset of sand movement was non-synchronous across the Outer Hebrides and had been strongly influenced by local coastal configuration. They maintained that the culmination of the Holocene rise in sea level resulted in a reduction in offshore sediment supply to the coast. Since relative sea level reached its approximation position *c* 2000 years ago, it was argued that coastal sediment transport during recent millennia has been principally associated with a recycling of pre-existing coastal sediments and a possible degradation of pre-existing coastal dunes and machair.

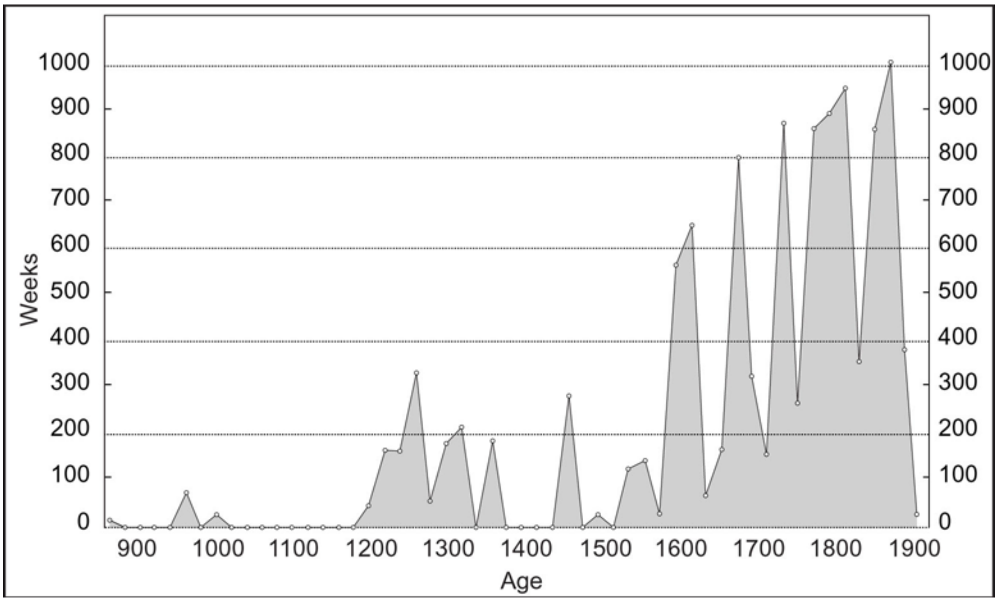
Dawson et al (2004) described dated storm events for seven sites across the Outer Hebrides that exhibit distinctive age clustering. Only three of the dated storm horizons exhibit standard errors that place the sediments within parts of the MWP time interval. By contrast, the majority of the uppermost dated horizons appear to have been deposited after *c* AD 1300. The stratigraphical evidence indicates that a sustained period of machair and dune development in which shelly sands encroached inland ended between the end of the MWP and perhaps as recently as 200 years ago.

It is tempting to develop a hypothesis in which the frequency of storm events is related to past episodes of climate change, normally described in terms of former air temperature characteristics, with greater storm frequencies during periods of cold (e.g. the LIA), and periods of reduced storminess during episodes of warmth (e.g. the MWP). Such explanations, however, are fraught with difficulty since the westerly winds associated with severe North Atlantic cyclones (storms) are normally associated with higher than average winter temperatures. Equally, it can be argued that the coldest episodes of the LIA may have been associated with significantly reduced storminess owing to the expansion of the polar anticyclone and a southward movement of the polar atmospheric and oceanic fronts across the North Atlantic (Lamb 1995).

Meeker and Mayewski (2002) provided the most



Illus 2 Top: concentrations of Na+ (ppb) at GISP2 drill site, central Greenland, AD *987–1987 shown as departures from the long-term average (after Meeker & Mayewski 2002). Bottom: 2-sigma calibrated radiocarbon dates showing the start of windstorm sedimentation at study sites (see also illus 1).*



Illus 3 Graph showing the number of weeks with ice around Iceland, for 20-year intervals from AD 860–1935 (based on Koch 1937).

comprehensive record of North Atlantic storminess for the last *c* 1,400 years based on measurements of sea-salt (Na+) concentrations in the GISP2 Greenland ice core (illus 2). Their measurements show that reduced storminess was a feature of the MWP that lasted between *c* AD 600 and 1400. They detected a marked increase in storminess frequency (increased Na+ concentration) that commenced at this time and observed that this 'state' of increased storminess has lasted until the present.

These observations should also be considered within the context of the classic research of Lamb (1979), who argued that the cold conditions of the LIA were associated with an increased meridional (north–south) thermal gradient across the North Atlantic that, in turn, led both to a southward displacement of the North Atlantic storm track (the polar atmospheric front) and of polar waters (the southern limit of the polar oceanographic front). Considered together, the results of Lamb (1979) and Meeker and Mayewski (2002) point to an increase in winter storminess across the British Isles after *c* AD 1400–20 and preceded by diminished winter storminess during the MWP. It is argued here that such increases in the thermal gradient in the North Atlantic atmosphere provide a simple explanation for the greater frequency of windstorm sediment deposition and machair formation post-AD 1400 (and possibly also for the time interval studied here prior to the MWP).

The dated sand units are plotted on the same timescale to illustrate the clustering of the dates during the LIA time period. This pattern of storminess increase also coincides with an increase in Icelandic sea ice cover that commenced during the late 13th century (Koch 1937) (illus 3).

Stratigraphical studies from sites along the Atlantic margin of Scotland and Ireland, as well as from the North Sea region, provide support for the chronology of sand mobilisation described here. Gilbertson et al (1999) also describe late Holocene phases of sand movement in the Outer Hebrides *c* 200–600 years ago (*c* AD 1400–1800), *c* 1,300–1,700 years ago (*c* AD 300–700) and *c* 3,300–3,800 years ago (*c* 1800–1300BC) based on luminescence dating of calcareous machair sands. Orford et al (2000) concluded that the majority of coastal dune systems in eastern England were produced during the LIA. Similarly, Delaney & Devoy (1995) noted that in western Ireland remobilisation of sand across back barrier lagoonal sites took place over the last *c* 400 years.

It could be argued that some of the dated windstorm events in the Outer Hebrides may be related to anthropogenic activity related to overpopulation, animal grazing pressures and the harvesting of marram grass for domestic purposes during the 18th and 19th centuries (cf Angus 1994, 1997). Although such processes were undoubtedly important in machair destabilisation and aeolian sediment transport, we maintain here that the increase in North Atlantic storminess that commenced at *c* AD 1400–20 and has continued until the present was the key factor accounting for the ages of the windstorm deposits described from the sites examined within this paper.

5 IMPLICATIONS FOR ARCHAEOLOGY

A key implication for archaeological research is that North Atlantic winter climate may have changed dramatically between the MWP and LIA. For example, during the MWP a diminished thermal gradient in the North Atlantic may have resulted in a substantial decrease in cyclogenesis that most probably also coincided with a marked decrease in sea ice extent and a significant decrease in winter rainfall. By contrast, a marked increase in winter storminess coupled with an increase in rainfall took place during the LIA. Considered together, these factors imply that it is misleading simply to consider the principal difference between the MWP and the LIA as a marked change in temperature. The real difference between the two time intervals is a radical difference in the atmospheric circulation of the northern hemisphere. During the time interval between *c* AD 600 and 1400, North Atlantic winters were rarely characterised by extreme storminess and high rainfall, while sea ice cover was never as extensive as it was during parts of the LIA. The ice core data point to the most benign conditions of the MWP as having occurred during the 9th and 10th centuries AD, and it may not be a coincidence that this time interval coincided with the first European settlements of Greenland and Iceland. Similarly, the disappearance of Viking civilisation in Greenland during the first decades of the 15th century AD coincides not only with a dramatic increase in winter storminess (a phenomenon not witnessed by earlier Viking generations), but also by a dramatic increase in the extent of sea ice that may have greatly hindered navigation. Whatever the ages of specific coastal sediment units at Viking sites in the Outer Isles, the Vikings themselves are likely to have developed styles of land use that were unsuited to the stormy and wet winters that accompanied the onset of the LIA.

In respect of coastal change, it may be useful to envisage many coastal Viking settlements as having been buried as a result of LIA windstorm activity and sand drift. Thus, it may have been the case that many Viking settlements in the Outer Hebrides may have evolved in landscapes where coastal dunes were much rarer features than they are at present. It is recognised, however, that many areas of machair in the Outer Hebrides may already have been in existence prior to the MWP, having owed their origins to windstorm activity during earlier intervals of stormy conditions during the Holocene.

6 CONCLUSION

This paper has considered the age and origin of sand sediments enclosed within organic deposits at sites within the Scottish Outer Hebrides and has also discussed patterns of North Atlantic climate change for the last *c* 2,000 years. It is suggested that a chronology of past storminess is recorded in the coastal sand dune sequences along the Atlantic coastline of the Outer Hebrides. The morphological and stratigraphical evidence indicates a concentration of windstorm activity during the LIA with a major reduction in sand drift during Medieval times between *c* AD 600 and 1400. The geological data indicate that windstorm deposition may have taken place during periods of climate deterioration and sea-ice expansion across the northern North Atlantic, associated with an increased thermal gradient favourable for increased production of winter storms. Dated inferred sand-drift episodes across the Atlantic seaboard of north-west Europe show a broad synchronicity with increased sand mobilisation in eastern England, south-west Ireland and the Outer Hebrides, implying a regional response to a change in northern hemisphere atmospheric circulation (Lamb 1995; Gilbertson et al 1999; Wintle et al 1998; Wilson et al 2001).

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