CHAPTER 2: THE PHYSICAL BACKGROUND

2.1 GEOLOGY

G Collins (1986)

(The following is based on a report by the late Geoff Collins. It is offered here in memory of a good friend. Ar dheis Dé go raibh a anm)

The Outer Hebrides (Figure 5) are composed almost entirely of Pre-Cambrian basement rocks, known collectively as Lewisian (Smith & Fettes 1979; Fettes *et al* 1992). These rocks mostly comprise a series of monotonous grey gneisses, often with hornblendic streaks and patches, which are cut by dykes and sills of altered basic igneous rocks to form amphibolites and metadolerites. In south-west Lewis and Harris, extensive granite veins are to be found. Bodies of anorthosite occur in south Harris and east of the Butt of Lewis. Altered sedimentary rocks comprising biotitic, graphitic and calcareous gneisses, quartzites and rare marbles are locally important but form only a small part of the assemblage. In south Harris the metasediments are associated with large bodies of metamorphosed intermediate and igneous rocks. Black, glassy pseudotachylite, found in many localities in the islands, is especially common along the Outer Hebrides Thrust Zone, which extends along the length of the Long Island, generally near the east coast. East of the Outer Hebrides Thrust Zone in South Uist, the eastern gneisses include granulitic facies of gneisses, mylonites and intensely crushed rocks. The Lewisian rocks are cut by a variety of Permo-Carboniferous and Tertiary basic igneous dykes.

2.1.1 Quaternary geology

The Quaternary geology of the Outer Hebrides is the subject of a report by J D Peacock (1984) of the British Geological Survey. According to this, the earliest feature of probable Pleistocene age was the formation of a raised platform and cliff of marine erosion, remnants of which are found only in the extreme north of Lewis and the Eye peninsula. Their absence elsewhere in the Outer Hebrides may result from glacial erosion, a protective cover of glacier ice, or a tilt below sea-level. Raised beach gravels are found in patches on these platforms and also on the north-west coast of Barra, where they are overlain by till. The clasts of the gravels are mostly of Lewisian gneiss (Plate 6), but red sandstone and arkose, probably Torridonian, and possibly Cambrian quartzites, similar to those of the north-west Highlands, may be found. Micaceous psammites of Moine type are found in the gravels of Barra. Thus, there is evidence for the suggestion that the formation of the raised platforms took place before, or early in, the Ice Age during which ice from the Scottish mainland crossed the extreme north of Lewis and probably over the more southerly islands. Tills formed during this phase were probably reworked by the sea in warmer times to form the raised beaches.

A period of intense glaciation followed in which the whole of the Outer Hebrides except possibly the extreme north of Lewis) was heavily glaciated. Peacock divides this phase into the ‘Hebridean Ice-sheet phase’, and a later ‘valley glacier phase’. From observations of numerous features of ice-movement such as *roches moutonnees*, striations and plucked surfaces, Peacock suggests that the ice flowed from at least two, possibly three, centres. The first, and most spectacular, was on the high ground of south Lewis and north Harris, from which the ice flowed radially. The second was an elongated dome of ice close to the west coast of Barra and extending northwards off the west coast of South Uist and Benbecula into the western part of North Uist. The axis of the dome was roughly north/south, the ice flowing off to the east across the Uists. The direction of ice-movement near the west coast of the Uists is obscure, indicating that the ice-shed was very close to the present day coastline. The possible third centre was a shallow dome over north Lewis.

The ‘valley glacier phase’ was confined to south Lewis and north Harris. Peacock describes many features of this phase, including morainic drift, meltwater deposits and landforms. Included in this phase is the magnificent Glen Valtos meltwater channel of south-west Lewis.

Much of Lewis, north of Stornoway, is overlain by a peat-covered sheet of till. To the south the sheet is discontinuous; the till occurring on the distal side of rock knobs. Moundy till is found extensively in North Uist between Lochmaddy and Carinish. Brown sandy till, several metres thick, has been recorded in North Uist at Hoglan Bay and north-east of Newtonferry, brown sandy till, up to 2 m thick, forms part of Hornish Point in South Uist.

The presence of erratics foreign to the Uists and the islands to the south, has long been known (Jehu & Craig 1923a; 1923b; 1926). As well as the Torridonian and Cambrian rocks mentioned above, pebbles of hard chalk and flint have been found in Vatersay. Boulders of hornblende-porphyry are common along the western seaboard of North Uist and Benbecula and are found in the Monach Islands. These erratics are probably the remnants of the redistribution of the raised beaches in Barra and the southern islands by the Hebridean ice-sheet phase.

With the coming of warmer times and the disappearance of the ice-sheets, a period of slight submergence of the islands followed. In north-west Lewis, a number of lochs have been impounded by storm beaches. There are many records of archaeological sites and of peat deposits between tide-marks (Ritchie 1979).

Dunes and extensive flat or gently sloping stretches of blown sand characterise the hinterland backing sandy beaches. The blown sand, known as machair, is only a few metres above sea-level. It is usually siliceous, but may contain up to 80% calcium carbonate, in the form of comminuted marine shell fragments (Ritchie 1971, and below). Small areas are present in Lewis and north Harris on the north-west and west coasts, the largest (*circa* 1.5 sq km) being west of Barvas. In south Harris, the dunes and machair are associated with the huge sandy beaches of Northton and Traigh Luskentyre, on the west coast. The machair reaches its greatest development on the islands in the Sound of Harris, through North Uist, Benbecula and on to the southern end of South Uist. It has been estimated that dunes and machair occupy 10% of the land surface in these areas (Peacock 1984). Further south in Barra its development is slight.

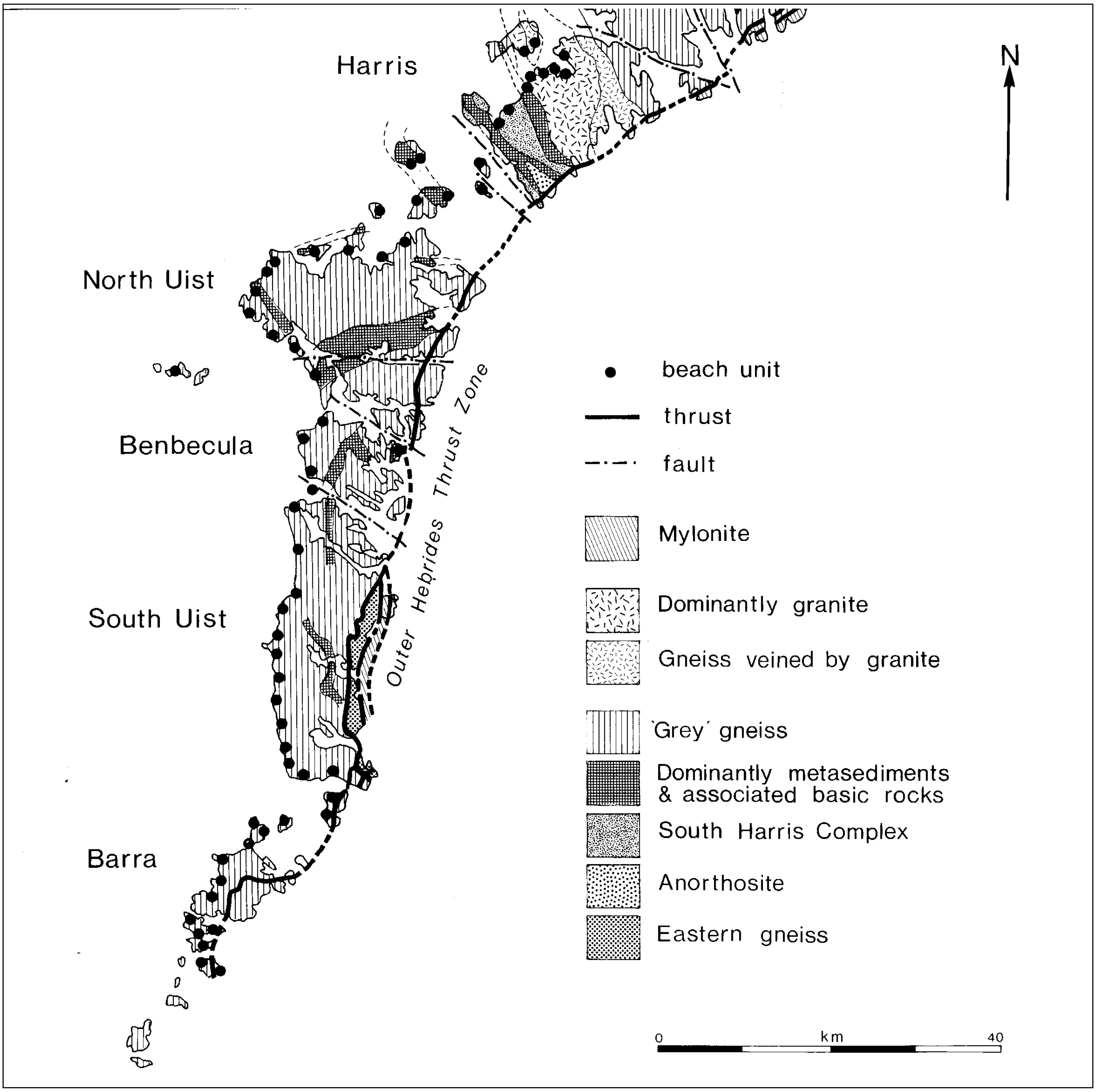

Figure 5. The solid geology of the Western Isles with machair beach units indicated

2.2 MACHAIR GEOMORPHOLOGY IN THE WESTERN ISLES

W Ritchie (1986)

From Sanday in the south to the northern tip of Lewis, most of the Atlantic coast is characterised by a series of blown sand landforms, collectively known as machair. The most extensive areas occur in Barra and the Uists and it is only in Lewis, north of the Eye Peninsula that machair occurs on the Minch coast. Figure 5 shows the distribution of these beach and machair units but the figure is misleading since each dot represents the centre of an area and in most areas the distribution is continuous, as for example in South Uist where the entire west coast is machair land (Plate 7).

Machair land varies considerably in form and extent. Of the 98 units of the Western Isles, 38% have little or no true dune ridges; the coastal edge consists of a narrow ridge of accreting sand with long dune grasses better described as edge accumulation rather, than as coastal dunes. Size also varies although most machair areas are relatively extensive. Small bayhead units are infrequent and largely confined to Harris and Lewis. One distinctive characteristic of machair in the Western Isles is the high shell content of the sand. In general, the shell sand content of Hebridean beaches, dunes and machair is the highest in Britain, but there are areas with little or no shell content. The actual distribution is described in Table 4.

Other characteristics of machair relate to relief and morphology, *viz* where there are dunes they have a mean height

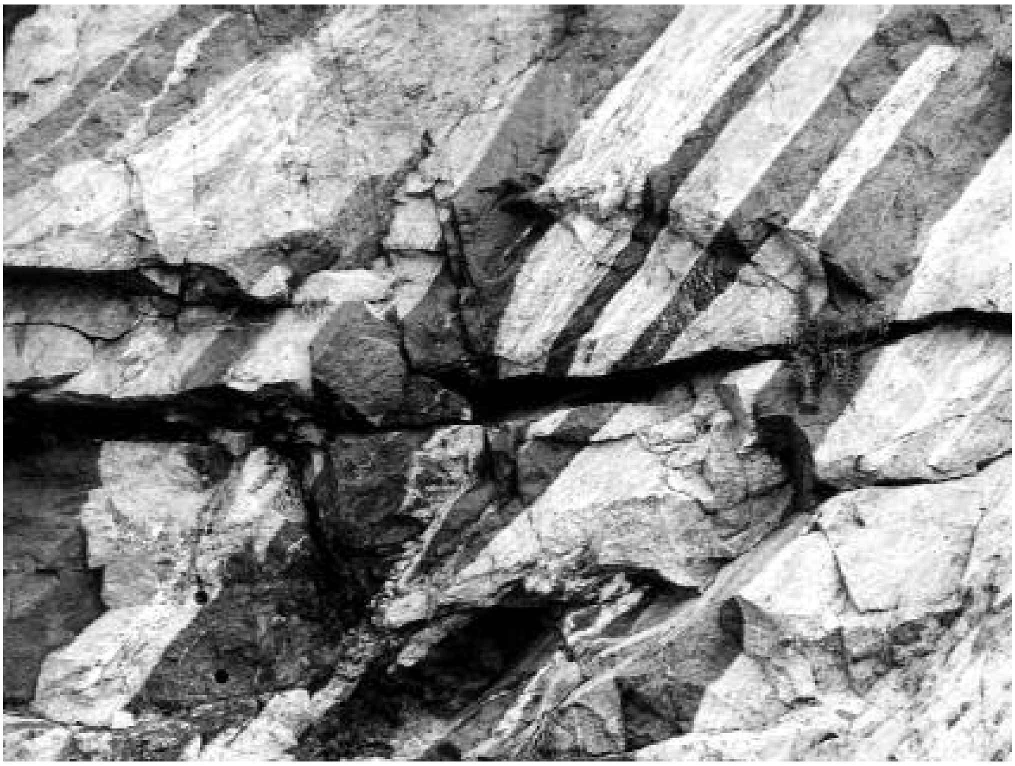

Plate 6. *Lewissian gneiss*

Plate 7. Machair plain at Ardkenneth, South Uist

$CaCO_3$ content	10%	11–40%	41–70%	>70%
No. of beach units	2	16	55	27

Table 4. $CaCO_3$ content of beach units

of 9.9 m in Barra, 10.1 m in Uists, 14.1 m in Harris and 10.1 m in Lewis; the Scottish average being less than 7 m. Equally striking is the altitude to which machair can extend uphill; 42 m in Barra, more than twice the range of most other areas in Scotland.

Considering machair *per se*, 31% of the total area is plain, 28% hilly, 5% hillocky, 31% undulating and 4% other. Thus the physical characteristics of machair vary considerably, partly as a result of the underlying surface upon which these distinctive landforms have developed. Machair usually rests on part of the ice-scoured Lewisian platform that occupies most of the low ground of the Outer Hebrides. This surface, as described above, tends to consist of a series of gentle basins and ridges with a variable cover of glacial till. Notwithstanding such subsurface control, the evolution of machair from a hypothetical origin as an extensive series of coastal sand dunes is long and complex. Sea-level changes (coastal submergence probably of the order of 3–5 m since *circa* 5164 BP; Ritchie 1985), substantial coastal erosion (Ritchie 1979) and numerous episodes of aeolian erosional and redepositional cycles have all pushed machair landforms eastward at the expense of adjacent lochs, marshes and peat-covered 'black land'. Erosion may take the form of discrete hollows, ie blowouts, or more extensive surface lowering and linear escarpment retreat, ie deflation. It is not known if these periods of wind erosion were in direct response to short term climatic changes or triggered by grazing or cultivation of machair land. Although this is a complex and only partly understood series of physiographic processes, an attempt is made in Figure 6 to illustrate possible models of machair evolution. These idealised profiles also give some indication of typical Uist-type machair land. This model does not take account of submergence which would alter water table levels and therefore, the base level of wind erosion, nor does it include coastline retreat. Figure 7 attempts to include the coastline erosion factor and the concept of escarpment retreat to account for the surface morphology and stratigraphy of some machair areas. The archaeological surfaces are tentative and included in order to illustrate the time-scales involved in machair evolution; a time span of probably around 6000 years.

The essence of machair geomorphology can be summarised under two headings: form and process.

2.2.1 Form

Most machair takes the form of low coastal plains with a variety of superficial features such as coastal dune ridges, redepositional hillock zones near the coast, some 'fields' of sand hills, localised bare sand blowouts which can occur on most higher surfaces, inner escarpments, usually stabilised and facing seawards with remnants of older higher sand plateaux sloping gently inland either to marshes, lochs or sloping 'black land'.

2.2.2 Process

Continuing coastline erosion is more severe in some areas than in others and this could be due to a combination of submergence and coastal sand deficiency. Wind erosion in this high-energy Atlantic seaboard can be severe if, for any reason, surface vegetation is disturbed. Blowouts and more general deflation carry sand landwards to be redeposited, sometimes at high altitudes, on adjacent hill sides. Very strong winds are most frequent from the north west, but the general resultant direction is south to north or south-west to north-east. Sand tends to encroach into adjacent lochs converting them to freshwater marshes. A significant process factor is grazing pressure, either natural such as rabbits, or husbanded such as sheep and cattle.

2.3 SOILS AND AGRICULTURE

I D Mate (1987)

'I never saw fields covered with a greater load of herbage than their cornfields are, but when you examine them hardly one tenth part is corn, the rest is all wild carrot, mustard, etc. The poor creatures do not know which way to clear their fields of weeds and think of nothing but to pluck up corn as their ancestors did which leaves the seeds of the weeds time to ripen.'
(Forbes of Culloden 1737)

The Devensian period is believed to have been just one of a number of warm and cold interstadials and stadials, but it was, in the main, a glacial period (Lowe & Walker 1984, 315) with a glacial maximum at or shortly after 18,000 bp (*ibid,* 326). The proposed ice limits, in the area of the Western Isles, are unreliable. Boulton *et al* (1977, Figure 2.11 in Lowe & Walker 1984, 38), suggest that the British ice sheet was an extensive ice-cap stretching seaward to the edge of the continental shelf. This model contradicts field evidence which suggests a rather more limited Devensian ice distribution (Synge 1977; Sissons 1981).

The theory that Scottish mainland ice overrode the Western Isles was originally propounded by Geikie (1878 in Sissons 1983, 166), but evidence now suggests that the Western Isles had their own ice-cap (von Weymarn 1974, 1979; Coward 1977; Flinn 1978; 1980). It is possible that the Western Isles were overrun by mainland ice in earlier glacial periods, but not during the Devensian (Flinn 1978, 1980; von Weymarn 1979, 97; Davies *et al* 1984, 61; Sutherland *et al* 1984, 261–72).

On reconsidered evidence, Flinn (1978, 196) depicts the position of the Western Isles ice-shed; it ran from the mountains of Harris southward, along the western seaboard of south Harris and the Uists, though it cut across the western part of North Uist.

Ice is less erosive at an ice-shed since horizontal movement is minimal (Sissons 1977, 83). In areas of minimal erosion, or unglaciated areas, pockets of deeply weathered profiles would be expected (Peacock & Ross 1984, 262); indeed fifteen such sites have been found in the Outer Hebrides (Glentworth 1979, 126). Another such site was discovered during excavations at Balelone. Its presence implies that local

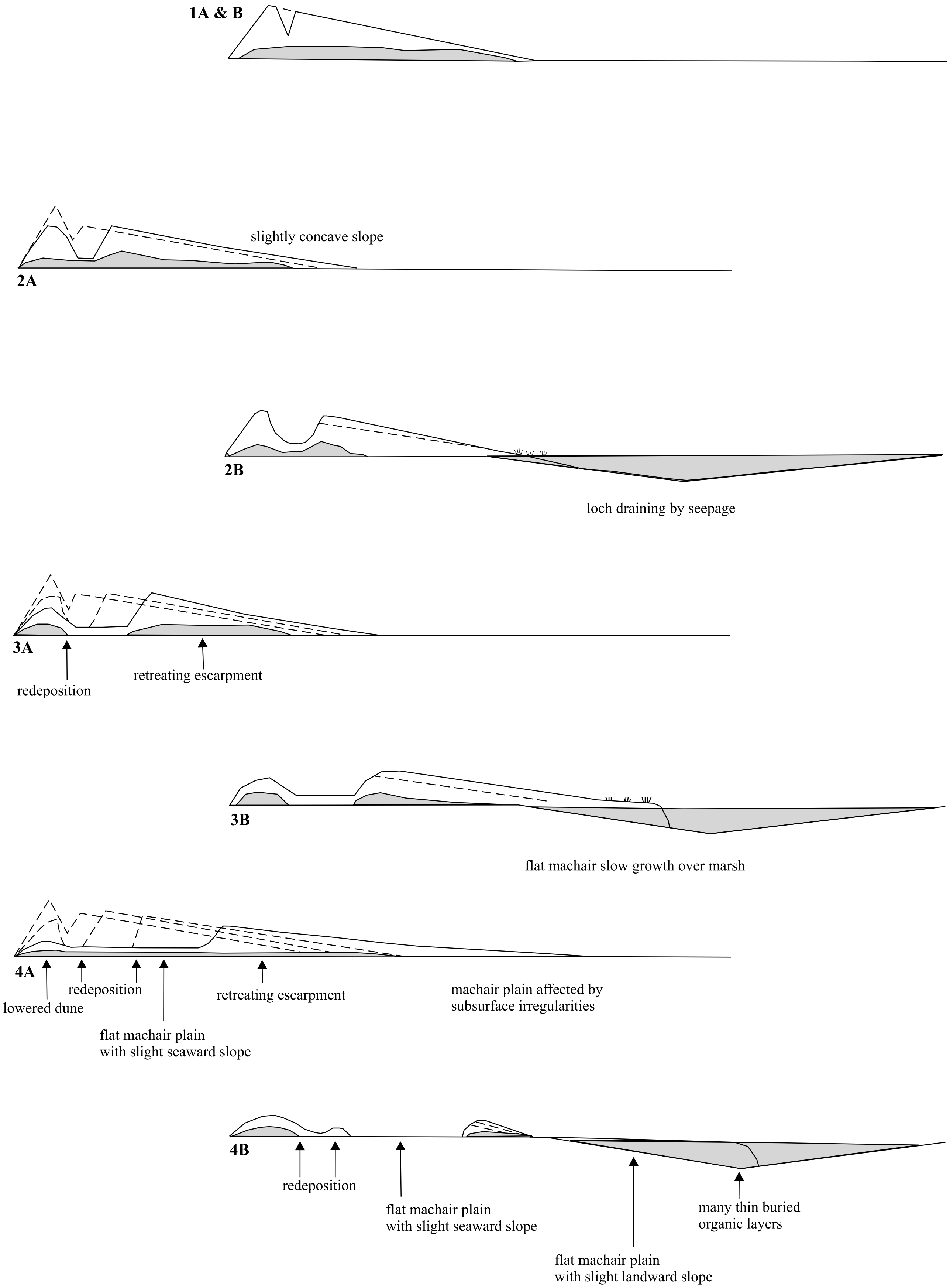

Figure 6. Models of machair evolution

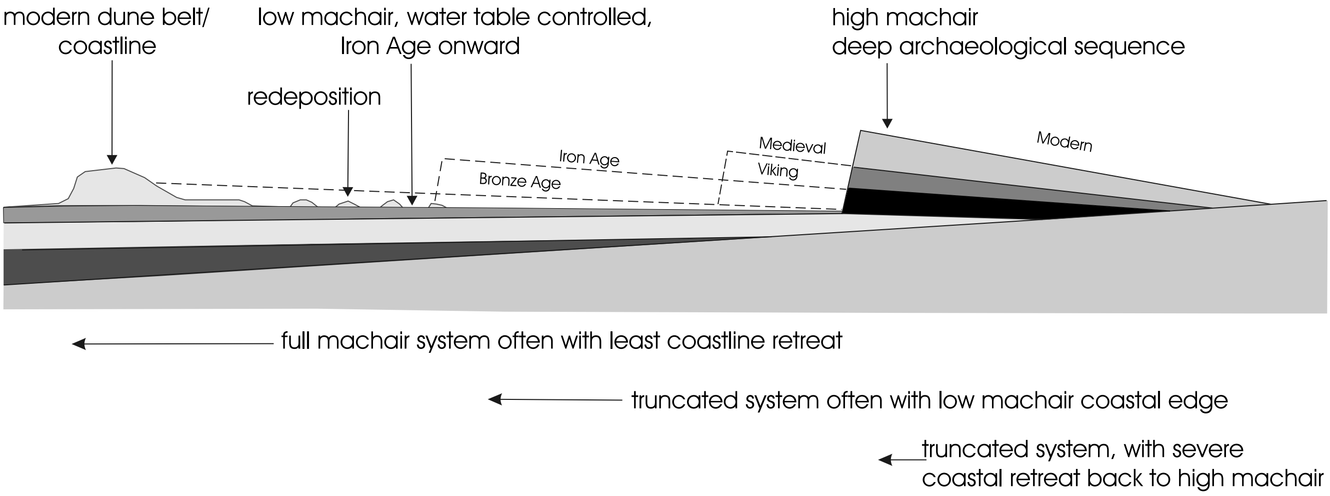

Figure 7. Machair morphology and archaeological deposits

soils, developed on till, may contain a considerable proportion of material from a previously weathered regolith.

2.3.1 The agricultural capability of the machair units

In the following discussion Ritchie's nomenclature (1979, 120, Figure 6) is adhered to. His machair landscape units, low machair and high machair plains, together with dunes or dune systems, also form significant land-use capability units.

2.3.2 Low machair plain

Constraints

The low machair plain can be taken to include the backlands. The position and level surface of the low machair plain is determined by the ground-water table (GWT), itself determined by the level of the lowest outlet from underlying, rock-carved basins which elsewhere give rise to a lake-dominated terrain (Waterston & Lister 1979, 329–51). In summer, it may be estimated theoretically that the water table generally lies less than 1 m below the land surface. Since wet sand is more erosion resistant, the sand level must be set at that which remains relatively wet even through the summer. Water entering a soil system will drain rapidly from larger pores but be stored in the smaller pores where the forces of surface tension are stronger than gravity. The coarse-textured nature of the sand leads to a predominance of large pores and, thus, in turn, to relatively small field (water) capacity (Marshall & Holmes 1979, 12); though capillary rise can be rapid, the pore size distribution means that the maximum rise is about 0.5 m (Brady 1974, 181, Figure 7:13). Thus the water table must lie about 0.5 m below the soil surface. It is probably slightly higher since it rains on most days in the Outer Hebrides.

In some areas the backlands can seem to form part of the low machair plain, with no apparent break in slope between them, as at Balelone Farm in North Uist (see Chapter 4). These are sometimes on a slight rise of slope, away from the level coastal plain. In both cases, the backlands form an area influenced by processes of peat formation and till soils with calcareous sand additions.

Soils

The soils of the low machair plain are a complex mixture, determined by sand supply, organic matter growth and water table levels. They therefore include peats, calcareous humic-sandy gley soils, typical sand-pararendzinas and typical brown calcareous sands.

The larger parts of the low machair plain at Balelone were typical sand-pararendzinas which graded inland to typical brown calcareous sands. The reported chemical characteristics of machair soils, largely of sand-pararendzinas, are, as expected, anywhere between 0–80% $CaCO_3$ (Ritchie 1971); pH of 8.0 to 7.2 (Randall 1976), and soil organic matter content of usually less than 10% though occasionally less than 2% (Dickinson 1977), with a rapid fall off from the A-, to B-horizons (eg 2.2% organic carbon in the A-horizon as opposed to 0.7% in the B-horizon (Roberts *et al* 1959, 223)). Similar results have been reported from Ireland (Bassett & Curtis 1985, 1–20). Soils with A-, and B-horizons developed to 60 cm have been reported in freely drained situations (Glentworth 1979, 133), but these are rare.

The presence of brown calcareous sands need not indicate a longer period of pedogenesis; rather, they may result from an equilibrium between the soil forming factors of sand supply, peat growth, and peaty waters with fluvial additions of mineral matter. Such soils grade into peats and humic-sandy, gley soils and may better be regarded as members of a complex of humic-sandy gley soils, though their cultivation will have emphasised the distinctions and improved the structure of the more freely-drained, brown, calcareous sands. At Balelone, these soils lay at the back of the machair plain. Soil characteristics have not been reported and are likely to be variable but may have organic matter content of 10–40%, pH 6–7.5 and $CaCO_3$ content of 0–30%. Field capacity is probably adequate, but these soils commonly lie on a slope where natural drainage controls the GWT, ameliorating problems of winter flooding, root zone depth and adequacy of summer water supply.

Agriculture

Low machair suffers from flooding in winter. Since the flooding is due to a rise in the regional GWT, amelioration of the condition by drainage is generally ineffective, though large-scale open ditch systems can sometimes help. Flooding may cause problems with seed germination and emergence and result in heavy crop losses (Cannell *et al* 1980). It also restricts the rooting zone. Despite these problems, the soil can be excessively dry in summer because of its low field water capacity and low water conductivity, properties associated with its pore size distribution and low organic matter content. Erosion of the substrate, *en masse*, is unlikely to be a problem, but erosion of the seed bed may be. At Balelone all freely-drained soils on the low machair plain which had been subjected to cultivation had very thin (<20 cm) A-horizons indicating probable loss from the soil surface. Weed competition on the machair plain is severe, but ploughing, which reduces the competition, also increases the risk of loss of A-horizon material. Ideally, cultivation produces a system of very shallow furrows into which seed is sown and then covered by harrowing. Rolling is also recommended, but weed competition remains severe.

2.3.3 High machair plain

Constraints

The position of the high machair is determined by a number of factors, some of which have already been discussed. The high machair lies to the leeward of the dune system, its height above the GWT determined by the height of the dunes. Its stability is due to high rainfall and lack of a soilwater deficit (ie rainfall more than compensates for water lost by evapo-transpiration, except in June) which enables vegetation to survive and a protective sward to develop on what is an excessively-drained parent-material. No differences in vegetation are discernible between the low machair plain and the high machair plain, only between stable areas and areas being actively supplied with sand (Dickinson & Randall 1979, 275).

Soils

Mapping of the machair system soils at Balelone (below) showed that the dune soils were raw sand, grading to typical sand-pararendzinas (Avery 1980), with no recognisable B-horizons and A-horizons less than 0.2 m thick. On the remnants of the high-machair plain and on stable dune back slopes, sand-pararendzinas dominated, often with A-, and very poorly developed B-horizons which together totalled but rarely exceeded, approximately 0.2 m. There appeared to be little significant increase in clay content or in other characteristics which would hold the soil, other than an increase in thickness of the Ah-, organic-horizon. The soils could not be described as brown calcareous sand; the next step in pedogenetic development. The increased depth and organic matter of the A-horizon is associated with a better field water capacity, noted by Dickinson and Randall (1979, 273) as rising to 18% in such soils.

Agriculture

The high machair escapes the problems of flooding but suffers those of excessive drainage, the soils being extremely 'droughty'. It has been suggested that the presence of a stable high machair surface is due to the low evapotranspiration rate and the high frequency of and high total rainfall. Plants growing on this surface must be aphreatophytes, that is, not groundwater dependent. To survive the environment, native plants must develop special strategies, such as extensive shallow rooting systems to collect as much rain as possible or deep tap roots. Once the surface horizon is broken, these high machair soils are extremely susceptible to erosion, the entire substrate being available for transport.

2.3.4 Dune systems

Dune systems form at sites of active erosion or abundant sand supply.

Soils

On dune soils initial processes tend to decrease the calcium carbonate content and increase organic matter in the surface horizons. Continuing sand supply counteracts both of these pedological processes. *Ammophila sp* (Marram grass) is the characteristic dune vegetation in the islands (Dickinson & Randall 1979, 268). It can tolerate accretion rates of up to 1 m per year and indeed has more vigorous growth where accretion is taking place. Also, it readily regenerates from rhizome fragments, often found in eroded dunes, and thus quickly re-colonises breaks once erosion has halted. It has been found that only about 10% of the organic matter of the standing crop of *Ammophila sp* is living and it is thought that the transfer of the dead plants organic matter back to the soil is a key factor in the development of dune grasslands (Boorman 1977, 165).

Estimates of field water capacity of young dunes are about 5% (Dickinson & Randall 1979, 273; Salisbury 1952); 'good soils' typically have values above 15% (Hall *et al* 1977, 57–60), those of soil organic matter are about 0.4% (Boerboom 1963); while carbonate values are generally higher than on the machair surfaces, eg 70% as opposed to 50% (Randall 1972).

Agriculture

The dune soils have little or no agricultural significance.

2.3.5 General comments

The backlands

The backland soils of the machair plain are sometimes very good soils. Their land-use capability class may be '3', ie land with moderately severe limitations on crop growth, range of profitable crops restricted; suitable for some arable crops and grassland (Glentworth 1979, 131), with the chief limitation being climatic rather than edaphic. They are probably as good as any soils found in the islands and West Highlands. They can have a good structure, are stone free, have moderate pH values with a good nutrient supply and capacity. The high organic matter content ensures that erosion is slight. The current settlement pattern in the Western Isles is noticeably coincident with the back edge of the machair where these soils lie, rather than with the machair itself (cf Boyd 1979, 10).

Nutritional deficiencies

However, high soil pH reduces the availability of nutrients to plants. At pH values greater than 7, iron, magnesium, zinc, copper, cobalt and phosphorus all become less readily plant-available (Brady 1974, 388, fig 14.8) and sheep grazed on machair alone would suffer from cobalt deficiency (pining). Due to soil conditions there are also serious deficiencies in potassium (Darling 1955, 190; Glentworth & Muir 1963, 259) and nitrogen (Grant 1979, 530). The lack of nutrients can be overcome with fertilisers, but machair soils have a very low retention capacity. Dressings of some minerals can be made at critical times during plant growth and are economically justified (Roberts *et al* 1959, 224). Before the advent of modern fertilisers, only seaweed and animal manures would have been available.

2.4 CLIMATE

The unsettled cool-maritime climate of the Western Isles is, to quote Professor Manley, '...an extreme modification of that of the British Isles generally...' (Manley 1979, 47). It is markedly windy, often wet and usually humid and cool. The influence of the sea does much to ameliorate the worst effects of the islands' latitude and the islands enjoy the advantages of a maritime climate, *viz* small annual variation in temperature, high wind speeds and high rainfall, evenly spread throughout the year.

On the western, machair lowlands the average total annual rainfall is relatively small, ranging from about 1000 mm, in the south to 1200 mm, in North Uist. This latter, is just under that level of rainfall which facilitates the formation of peat, and considerably less that the annual rainfall of the adjacent mainland. It is also significantly less than the rainfall on the higher, peat-covered, eastern side of the islands (1400 mm to 1600 mm).

However, even on the lowland of the west coast area the influence of the low rainfall is considerably increased by its persistence. Throughout the year, there is measurable (ie >2 mm) rainfall on three out of every four days. Allied to persistence, the high humidity (annual average 85%) inhibits evaporation with the unhappy consequences for agriculture noted by Mate.

Almost one third of the recorded winds at the Butt of Lewis are 'strong to gale force', ie in excess of 21 knots, making this the most storm prone station in the British Isles. Further south the situation is rather better, with only fifty 'storm-days' a year, on average at Stornoway, for example. However the average annual wind speeds are extraordinarily high with mean winter speeds of 10 m per second and mean summer speeds of 5 m per second, they are amongst the highest recorded in the world (Hudson *et al* 1982, 15). Exposure to such persistent, damp, chilling winds is a major constraint, not only on agriculture, but on all spheres of human activity in the isles. Manley (1979, 48) has commented on the exhausting demands made on the human body by working in areas with exposure to wet chilling winds at temperatures below 13 degrees centigrade.

The average of the mean daily temperature for Stornoway is 8.3 degrees centigrade, in a range of 11 degrees to 5.6 degrees centigrade (mean daily maximum to mean daily minimum). The impact of these low temperatures on the growing season are, however, ameliorated by the number of daylight hours during that season, so that an annual average of 1244 hours of sunshine are recorded at Stornoway; 1383 at Benbecula. Further, the isles are almost free of frost. The number of days on which the air temperature drops below 0 °C, at Stornoway, is 47; at Benbecula, 33; at Tiree, 17. These values compare with values of 65 to 70, for the Scottish Lowlands and up to 130 for the Highland straths (Manley 1979, 51).

In analysis of the differences between climatic records from different stations, Manley has noted the benefits to be gained from the provision of local shelter. In general he estimates that the daily temperature over the growing season would be increased, on average, by 0.5 °C in sheltered areas. With growing seasons ranging in duration from 225 days in Lewis, to 250 days in the south of the region, this increase in temperature adds over 100 day-degrees centigrade to the accumulated temperature of a location. This could be sufficient to convert a 'cool' area to a 'warm' area (*sensu* Hudson *et al* 1982, 10–15), and make the difference between success and failure for crop husbandry at given locations. This observation implies that 'invisible' micro-environments may have existed in the past, which would have influenced the siting of settlements and cultivated areas.

Manley has also noted that the impact of climatic change on the islands would have been moderated by the preponderating influence of the sea. Thus, for example, the climate during the summer of 1968, the sunniest on record and the hottest for over 100 years, was largely determined by conditions in the Atlantic (Manley 1979, 53; Murray & Ratcliffe 1969). In general Manley notes that cooler Hebridean seas would occasion later Springs while warmer seas would probably occasion greater rainfall, especially in the Autumn.

Parry (1978, 81) has determined the absolute climatic limits to cultivation for areas in Scotland, mainly in the Southern Uplands. He estimates that the limits for oats lie close to an accumulated temperature of 1050 day-degrees centigrade above a base of 4.4 degrees, a Potential Water Surplus (PWS) of 60 mm and maximum exposure at 6.3 metres per second. In the case of barley he records limits of 1200 day-degrees centigrade, PWS of 20 mm and 5.0 metres per second average wind speed. It can readily be seen, from the mean annual values cited above, that conditions on the machair approach these marginal values in most years. Thus, the machair is currently a marginal zone for cereal cultivation. It thus necessarily follows that the settlement potential of the machair varies considerably in response to relatively minor climatic variation.

The general pattern of post-glacial climatic development in the British Isles has seen a progressive improvement in climate up to about 5500 BC, the Atlantic/Boreal transition. Thereafter the rate of change diminished and the climatic optimum was reached in the Atlantic Zone, between 4000 and 3500 BC. After 3000 BC, ie from the Sub-Boreal Zone onwards, the climate has been marked by great and sometimes abrupt fluctuations, imposed on a generally deteriorating trend. The period from 1300 to 900 BC witnessed a reduction in mean annual temperature, of about 2 degrees centigrade. The following period was, for the west coast of Britain, a period of unprecedented wetness, and Tregaron Bog, in west Wales, put on a full metre of peat in the period 800 to 400 BC (Turner 1965). The deposition of the next metre of peat took a further two millennia. After 400 BC, the climate seems to have improved and the period from 400 BC to AD 500 was significantly warmer and drier than the preceding period.

Plate 8. Evidence for progressive drowning of the landscape: a) Inter-tidal peats at Baleshar e b) Surface peats now being eroded by the sea at Benbecula c) The Neolithic chambered cairn at Geirisclett now partly submerged at high tide

2.5 THE PHYSICAL LANDSCAPE AS A SETTLEMENT RESOURCE

2.5.1 Geological deposits

The Lewisian Gneiss bedrock of the islands is a particularly poor building stone: it does not produce regular slabs or blocks, is friable and disintegrates when heated. Its ubiquity is in marked contrast with the virtual absence of stones useful to early settlers. The islands are all but devoid of readily available, good quality rock suitable for chipping, like Arran's pitchstone (Thorpe & Thorpe 1984) or the bloodstone deposits of Rhum (Wickham-Jones 1990). Flint is not readily available either (Wickham-Jones & Collins 1978). However, mylonite was occasionally worked. This poverty of raw materials continues into later epochs as the islands are also devoid of useful mineral deposits or metal-ores. Clay deposits suitable for pottery manufacture are similarly rare and localised; a consequence of the heavy and extensive glacial scouring of the gneiss shield. In general, the geological deposits of the Outer Hebrides were resource-poor for the prehistoric settler.

2.5.2 Landscape formation

It is generally assumed that eustatic sea rise has outpaced isostatic uplift of the land in the Hebrides throughout the post-glacial period (Sissons 1977, 131). Ritchie's radiocarbon dates (1985) from now sub-marine peats range from 9000 bc to 2400 bc and indicate that, in freshwater lochs on the western margin of the islands, peat development continued, free of substantial sand inundation, into the late Neolithic Period.

2.5.3 The chronology of machair formation

The absence of machair sand from deposits underlying earlier sites has also been noted. At Northton, Harris, the earliest Neolithic deposits rest on brown earths formed on tills as do the earlier Neolithic settlements at the Udal (Evans 1971, 52–62). The earliest archaeological deposits overlying shell sand at Northton have been radiocarbon dated to 2461 ± 79 bc (BM 705) (Evans, *ibid*; Simpson 1976, 222). The corresponding deposits at the Udal seem to date to the same period. At Paible, a date of 2110 ± 270 bc (GU-1088) has been returned for the lower levels of a thin cultural deposit which yielded AOC Beaker material and which overlies a thin deposit of shell sand (I Shepherd pers comm). The Beaker period deposits at Rosinish, similarly overly shell sand (Shepherd 1976) and earliest dates from this site are contemporaneous with the latest of the sub-marine peat dates. This latter implies that in the Late Neolithic period deposition of shell sand had begun, at least on the seaward margin of its current distribution, and that this deposition continued into the Early Bronze Age, but that some areas remained sand-free, even at this time. Taking this archaeological evidence together with Ritchie's evidence for progressive drowning of the landscape, one interpretation is indicated; that the machair soil has been progressively moving eastwards as the west coast is progressively inundated by the rising sea (Plate 8). The eastern edge of the machair reached what is now the islands' west coast in late Neolithic/early Bronze Age times but had not become fully established in the current coastal zone in the early Bronze Age.

Bronze Age sites, later than those of Beaker period date are almost unknown in the machair while sites of the Iron Age are found in large numbers, in and on machair deposits. It may therefore be assumed that the machair plain continued to develop throughout the Later Bronze Age. Examination of the Iron Age midden sites exposed by coastal erosion reveals that they now exist as rounded to hemispherical knolls with no stratified links into the surrounding shell sand deposits of the machair (Plate 9). This implies that, at some time after their formation, the surrounding machair was completely deflated, at least in the immediate areas of the sites. It is possible that more than one such period of destabilisation of the machair occurred but documentary records exist of the most recent. In his description of his tours in the Hebrides made in 1774, Pennant noted that the machair plain appeared as a strip of bare sand with little or no vegetation cover. This may reflect the response of the local ecosystem to the Little Ice Age of, approximately 1550 to 1850 AD (Lamb 1982, 31).

2.5.4 Peat formation

The formation of peat in confined mires or raised bogs can have begun very early in the post-glacial period. A radiocarbon date of 7190 ± 140 uncal BP has been returned for basal peat in the Little Loch Roag area (Birks & Madsen 1979) and, earlier deposits very probably exist in the Isles. I have discussed elsewhere a model for pedogenesis and peat formation on Scotland's West coast (Barber & Brown 1984, 169). From the beginning of the Post-Glacial period, soils will have improved, until Brown earths developed on the glacial tills. Following the Post-Glacial climatic optimum (*circa* 3500 BC) conditions over wide areas in the isles were such as to facilitate the emergence of blanket, or climatic peat. While they remained available, the soils developed on tills would have been more fertile, and more easily cultivated that were the machair soils.

The period during which the climatic peat developed is not known, for the Western Isles, but some indications are available from the archaeological record. All of the Neolithic sites which have been excavated rest on soils developed on tills. This is true of both settlement and funerary sites. We have already noted that at both Udal and Northton (Evans 1971, 52–56; Simpson 1976, 222) the earliest Neolithic deposits lie on till soils. Scott (1951, 1-3) observed that the pottery rich deposits at Eilean an Tighe also lay on till soils. Scott also noted that the tombs of Clettraval and Unival, although in peat, are not on peat (*ibid,* 2), an observation reiterated by Henshall (1972, 115). Inland, but still relatively close to the coast, Neolithic sites have been found on boulder clay. At Bharpa Carinish, North Uist, pottery and hearth deposits dating to 4300 to 4400 ± 100 uncal BP have been interpreted as the remains of Neolithic houses (Crone 1993, 364). The initial Neolithic land-use at Callanish, Lewis is interpreted as rig-and-furrow cultivation, apparently on mineral soils (Ashmore 1995, 30), albeit that this must await radiocarbon dates for confirmation. It is clear that, although many peat deposits had begun to form in the Neolithic period, soils developed on tills covered the greater part of the present area of the islands and climatic peat had not yet begun to spread.

Plate 9. The domed structure of Baleshare midden viewed from the seaward side

The picture for the Bronze Age is less clear. The hut circles and field fences now emerging in peat cuttings at North Dell, Lewis, are directly comparable, at least in their gross morphologies, with Inner Hebridean sites such as those on Islay (Barber & Brown 1984, 173–78; RCAHMS 1984) and on Jura (Stevenson 1984, 127–160) and elsewhere on the Scottish west coast (Barber 1997). In part these are probably later Bronze Age in date, and they lie on mineral soils under peat. Throughout mainland Scotland, the LrBA was a period of large scale expansion into marginal areas and it is highly improbable that this should not also have happened in the Outer Hebrides, especially as it is so clearly evidenced in the Inner Hebrides (RCAHMS 1980; 1984). The apparent absence of visible remains of the Later Bronze Age expansion in the Outer Isles may be accounted for by the fact that peat now covers the LrBA landscape. Recent archaeological and environmental work has revealed later Bronze Age remains in and under peat, in apparent confirmation of this view. At Sheshader, on the Eye Peninsula, Newell (1989) investigated a wall lying on peat, the latter dated to 2900 ± 100 uncal BP (GU-1665). At Loch Portain, Mills *et al* (1994) investigated a similar phenomenon, dated to 2630 ± 110 uncal BP (GU-2452). The walls in peat at Tob Nan Leobag, near Callanish, have been dated to roughly half way between 3320 ± 65 BP and 2355 ± 65 BP (Bohncke 1988; Bohncke & Cowie forthcoming). Similarly, peat-covered walls form an enclosure abutting a Neolithic Chambered cairn at Carinish, North Uist, and these have been dated to 2750 ± 50 BP (GU-2457) and 3100 ± 80 BP (GU-2689) (Crone 1993). These sites are variously associated with arable or pastoral land use, or both, but essentially confirm that the Outer Hebrides were sufficiently extensively occupied during the Later Bronze Age to have some settlement pushed out onto the peatlands.

The known distribution of Iron Age sites is consistent with the idea that peat cover in the Isles had reached its present extent by the beginning of that period. The settlements primarily associated with tillage are concentrated in the machair, while the domestic economy of the duns and brochs of the peatlands seems to have been based, primarily, on animal husbandry. On balance, then, it seems likely that climatic peat began to spread over the till soils during the Bronze Age period, and that it may have reached its present horizontal extent by the Iron Age.

To the total of useable land lost beneath peat must be added the significant areas lost to the sea. The average slope of the seabed west of the Hebrides is 1:250. If Ritchie's estimates are correct and the sea has been gaining on the land at an average rate of 1 m per millennium, a strip of land, 250 m wide, is being lost to the sea, per millennium. If, then, the Uists extended some 1.25 km further west than the current shoreline during the Neolithic Period, the implications for settlement during that, and subsequent periods are considerable.

Unlike the geological deposits, the landscape of the Isles was a considerable settlement resource at almost every period in the past. During the earlier periods, the brown earths on the tills were readily cultivable. When these were lost beneath peat the machair, for all of its constraints, was still the best agricultural land in the region; cultivable, albeit with some effort, and providing grazing over the greater part of the year.