BED ROCK, ICE AGE AND HOLOCENE ENVIRONMENT IN ORKNEY

John Brown

The modern Orkney landscape is a product of developments in farming over the past hundred years and the sweeping 600km coastline that cuts into the land at every opportunity. This coastline exhibits extensive exposures of the local Devonian flagstones and sandstones which easily split and break to provide first-class building materials. This has been a major factor in the preservation of the built heritage and culture of Orkney over the past 5,500 years.

The human geography of Orkney comes to prominence during the Neolithic when the first farmers cleared the land, built their homes and villages while erecting their elaborate tombs and stone circle observatories, and the effects of their farming activities persisted up to the 19th century. Developments in farming over the past hundred years reclaimed much of what had been lost. Evidence of the earlier Mesolithic occupation of these islands is meagre.

This paper will endeavour to present an overview of the geological processes forming Orkney with particular attention to the interaction between the geological environment and the historic - prehistoric inhabitants. Much of this will be speculative and is presented to stimulate thinking about the effect of climatic and environmental factors on population dynamics and the succession of cultures in a marginal agricultural environment in island locations.

Geology

The rocks of the Orkney archipelago are poorly representative of geological time from 4.5 billion years ago to the present (Fig. 1). Mineral resources such as copper, iron, coal and flint are not native except in trace amounts, therefore artefacts requiring these materials for production had to be imported. Sulphides of lead, zinc and silver (galena) in veins are widely distributed but difficult to extract from the ore.

The oldest rocks found in Orkney are 'basement' granitic-gneiss and schist exposed at Yesnaby, Stromness and Graemsay (Fig. 2). Although these rocks have never been directly dated their similarity to metamorphic rocks in Sutherland led geologists to assign them to 'the Moine Period' (1,500 million years old). After a long period of burial in the crust of the Earth, these rocks were thrust to the surface during the Caledonian Mountain building episode (500 to 400 million years ago). Considerable erosion of these mountains took place before the first sediments were preserved in the lower Devonian of Scotland. Collapse along large normal faults during a period of extensional tectonics formed a series of half graben structural basins that rapidly filled with conglomerate and breccia.

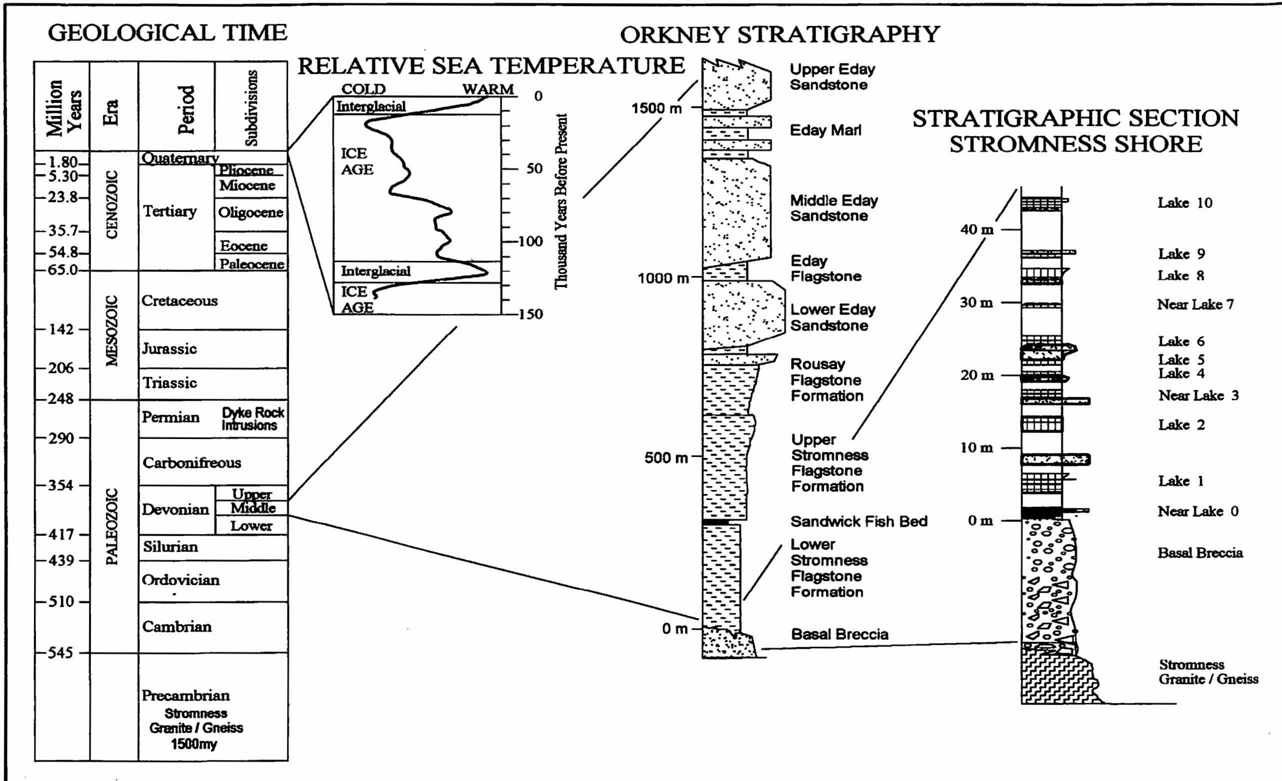


Fig. 1. Geological Time Scale and Orkney Stratigraphy.

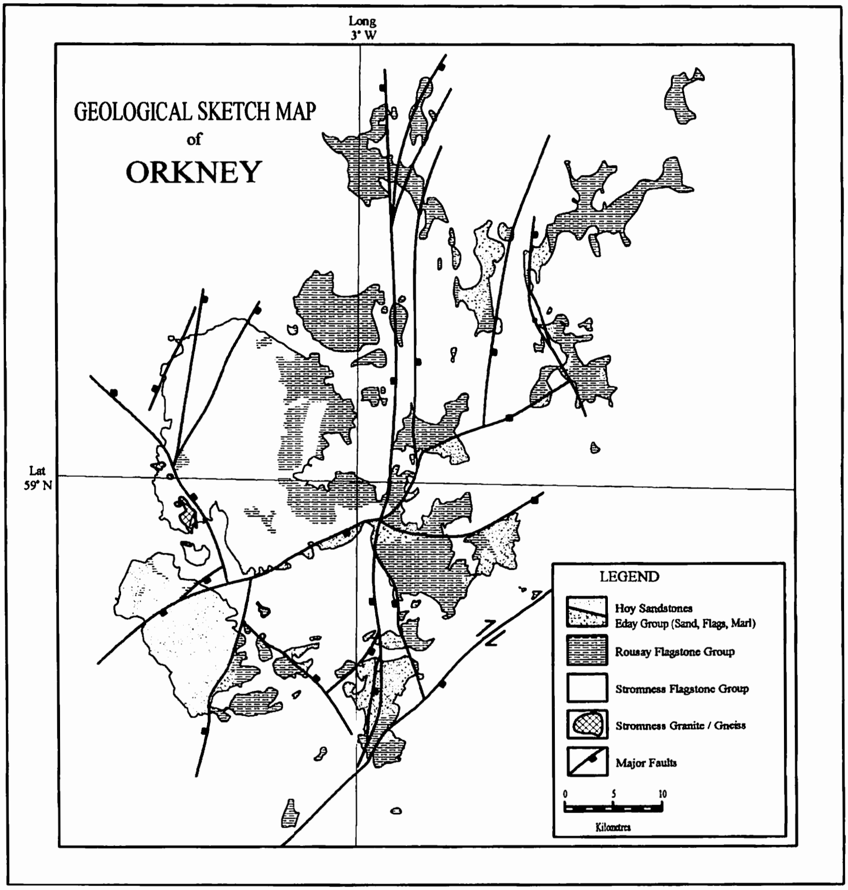


Fig. 2. Geological map of Orkney showing major faults, Hoy Sandstones and Eday Group are time equivalent.

Orkney was located approximately 16 degrees south of the equator during the middle Devonian in the centre of a large continental mass called 'Euramerica'. At this latitude, the Orcadian Basin would have been climatically located within the Southern Hemisphere continental desert belt. Evidence of this paleo-environment can be read in the Orkney rocks. The locally observed Devonian sand-dune bedding, salt crusts, gypsum crystal pseudomorphs (often in the form of desert rose) are also typical of modern deserts. The above sedimentary structures are found in conjunction with evidence of wetter climates. Rain pits, mud cracks, wind ripple marks are indicative of marginal lake mud flat conditions while finely laminated dark coloured sedimentary rocks containing fossil fish and plants formed in a 'Permanent Lake' environment. Current rippled sandstones, trough cross-bedding and sand sheet-floods demonstrating the presence of river systems are also common throughout the 1500 metres of Devonian sedimentary rocks in Orkney.

By middle Devonian times (Fig. 1) continued erosion and further depression brought the basin close to sea level. An extensive relatively flat land area stretching from the Moray Firth to the East Coast of Greenland and across to Norway was established. At times of maximum flood, this Basin filled with a fresh water lake. At other times, the Basin almost totally dried out and small saline lakes formed at the lowest topographic levels of the Basin. These lakes, sitting in the middle of a desert landscape, were interconnected by rivers and streams flowing to the Devonian Ocean in the Central North Sea. The Basin also contained internal ranges of hills, consisting of metamorphic basement rocks, extending along the upthrown sides of the normal faults. This area, known as the 'Orcadian Basin' when dry or 'Lake Orcadie' when substantially covered by shallow waters, was fed by large rivers originating in the surrounding high mountains and continental plateaux. These rivers cut gorges through the elevated margins of the Orcadian Basin filling the lake depression with mud, silt and sand. The primitive freshwater fish that were swimming around in the lake would die and settle to the anoxic bottom where they were covered by mud and preserve as fossil fish in the dark coloured laminite rock.

All the flagstones observed on the Orkney coastline are sedimentary rocks laid down in a lacustrine[1] environment within or at the margins of 'Lake Orcadie'. The stratigraphy of Orkney's sedimentary rocks shows a regular repetition from freshwater Permanent Lake conditions of Lake Orcadie to a mud/sand flat or desert environment every 10 to 15 metres of vertical section. This evidence indicates that there have been major oscillations between wetter conditions, when the lake reached its maximum water depth and extent, to a dry period of very little sediment input and desert conditions. In the 10.5 million years of Lake Orcadie's existence, approximately 108 such major cycles have been identified to give an average of about 97,000 years for each cycle. This long-term cyclicity is controlled by the eccentricity (Milankovitch cycle) of the Earth's orbit around the Sun. An observed fine scale (1-10mm) pattern of sedimentary deposition is controlled by seasonal variation of the water and sediment input from the rivers and the high evaporation rates from the lake. This also caused large fluctuations in the position of the lake margin through time.

A ubiquitous feature of the Orkney flagstones, in particular the dark laminite formed in the deep lake, is that they split in regular blocks with flat sides top and bottom which makes excellent building materials. The easy availability, from the shore or shallow cliff top quarries, of such first-class building blocks dictated that local structures were made of this 'Orkney Stone'. This is a major

1. Of or relating to lakes.

factor in the preservation of the abundant, diverse built heritage and archaeology from Scara Brae 5500 years ago through all the succeeding generations of Orkney peoples until the present.

Geochemical analysis of the Orkney fishbed lithologies suggests that they have been buried under at least 3-4000 metres of younger sediment. Evidence from other locations, North Sea and Atlantic Margin, indicate that sediment accumulation in the Orcadian Basin ceased in the early Permian. Tectonic inversion over the next 250 million years brought the Devonian sediments to about their present level in the crust. Erosion, during uplift, of these younger Carboniferous and Permian sedimentary formations removed the evidence of their former presence.

More than 200 igneous 'trap dykes' crosscut the Devonian sediments in Orkney. These hard black, one-time molten, magmatic intrusions were injected along lines of fracture in a general NE-SW trend with a small group running in a N-S direction. They vary in width from 1 to 2 metres, are traced over lengths of 2 to 3 kilometres, and have been dated by the Potassium-Argon method to be 252 +/- 10 million years old (late Permian age). The dyke rocks contain an exotic collection of mantle derived xenolithic inclusions that indicate rapid transport of the host liquid from great depth. It is considered that these igneous magmas never actually reached the surface of the Earth to be extruded as volcanoes. Weathering of the trap dykes produces widespread smoothly polished boulders and pebbles. These beach rocks, due to their hardness and natural shape, would produce pounders, hammers and grinders to fashion the much softer flagstones and sandstone.

The Ice Age in Orkney

The smooth rolling landscape of Orkney was formed by the scraping transit of vast ice sheets passing over the islands at various times during the 1.8 million years of Quaternary glaciation. Over the past 2.4 million years in excess of 20 Glaciations are observed worldwide each lasting about 100,000 years and interspersed with interglacials lasting approximately 15,000 years. Each Glaciation (Ice Age) consists of several Stadials (shorter cold episodes) and Interstadials (short warm periods). We are presently approaching the end of the current Interglacial warm period.

Glacial to Interglacial oscillation is calculated to involve a potential exchange of up to 50 million cubic kilometres of water between the oceans and the ice caps. This exchange produced a global change in mean sea level of about 150 metres with Stadial-Interstadial cycles producing smaller changes. Concomitant changes in seawater salinity, Oxygen Isotope composition and ocean surface temperature also occur.

On a world scale the timing and extent of ice coverage during the Ice Age varies with respect to geographic position and the local climatic environment at that time. The driving mechanism for these variations is the amount of solar radiation (insolation) reaching the surface of the Earth in a particular area. Insolation varies with the cosmic positioning of the Earth with respect to the Sun and alterations in the orbital parameters of the Earth. This solar variable, Milankovitch cycles (Fig. 3), relates to the three major components of the Earth's orbit about the Sun:

1. The orbital eccentricity of the Earth around the Sun, varying from a circular orbit to an elliptical orbit with a change in seasonal incoming solar radiation of about 30 per cent, takes 95,800 years.
2. Changes in the inclination (obliquity) of the Earth's axis alternate between extreme values of 21.39 degrees and 24.36 degrees with a periodicity of 41,000 years. An increase in axial tilt results in lengthening the period of winter darkness in Polar Regions. These changes therefore cause significant variation in the insolation at high latitudes.
3. The precession of the equinoxes over a period of 21,700 years requires the northern hemisphere to be tilted towards the Sun at successively different points on the Earth's annual orbit affecting in the northern hemisphere the lengths of and the absolute temperature of summer and winter.

The combined influences of changes in eccentricity, obliquity and the precession of the Equinox produces a complex pattern of insolation variations that give rise to increased seasonal contrast in one hemisphere of the Earth and diminished contrast in the other.

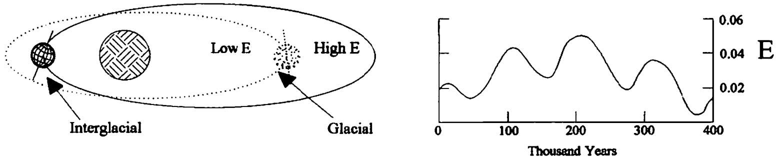
A high degree of correlation exists between the combined insolation curves and the fine structure of observed Stadial and Interstadial episodes within the last major Glaciation (115,000 years) as seen in the relative sea temperature curves for the northern hemisphere (Fig. 1). Despite this correlation some argue that the relative change in insolation from orbital forcing, giving rise to 1 or 2 degrees variation in average temperature, is insufficient on its own to cause the major rapid changes observed. Various methods of positive feedback have been suggested to amplify these effects.

The Quaternary glaciation history of the Orkney Islands is still poorly understood. What is known has been inferred from wider regional studies onshore and offshore Scotland. A major problem in this research is the fact that younger glaciations will normally remove all evidence of previous events. Although the Ice Age started about 2.4 million years ago there is no evidence of glaciation in Scotland until about 850,000 years ago. It has been suggested that the first presence of small glaciers on Hoy may actually date from this period.

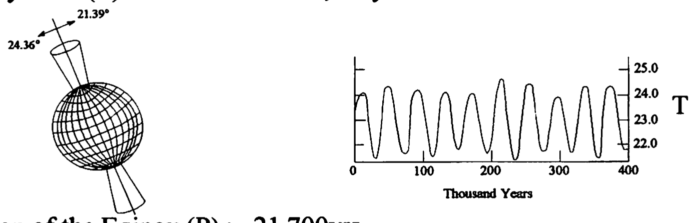
About 750,000 years ago there appears to have been a switch to more extreme climatic oscillations with the first of several extensive glaciations by

ORBITAL COMPONENTS OF THE MILANKOVITCH CYCLES

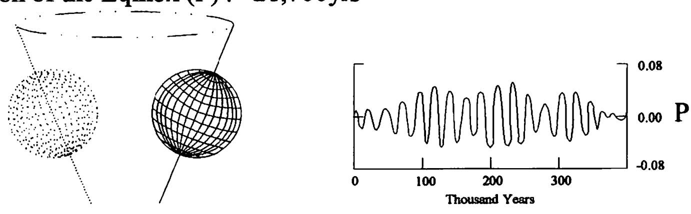
Orbital Eccentricity (E) of Earth about the Sun : 100,000yrs



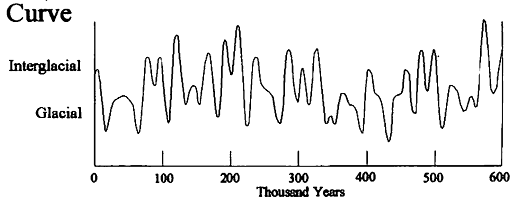
Obliquity / Tilt (T) of the Earth : 41,000yrs



Precession of the Eqinox (P) : 21,700yrs



Combined E - T - P Curve



INTERGLACIAL (E - T - P)	GLACIAL (E - T - P)
High Eccentricity High Tilt Small Earth - Sun distance in Summer (Warm Summers cool Winters)	Low Eccentricity Low Tilt Large Earth - Sun distance in Summer (very little seasonal contrast)

Fig. 3. Orbital components of the Milankovitch Cycles.

Scottish ice observed in the outer Moray Firth. This early Cromerian Glaciation may be the first time that the Scottish ice sheet reached Orkney. During the Anglian Glaciation 440,000 years ago, Orkney was almost certainly covered by ice sheets although no glacial sediments of this same age are known. At this time, the Scottish and the Scandinavian ice sheets may have been confluent. Even later, approximately 300,000 years ago, the Saalian ice sheet was present in the northern North Sea and this would indicate that Orkney was again probably covered by ice.

The Devensian Ice Age which started approximately 115,000 years ago is characterised by at least four ice advances (Stadials) interspersed by shorter intervals of ice retreat with consequent changes in global sea level of between 20 and 40 metres. The late Devensian glaciation removed most of the evidence of earlier events from Orkney as it passed across the islands. This ice sheet, which built up and advanced from about 30,000 radiocarbon years ago, reached its maximum about 24,000 radiocarbon years ago. The ice retreated and thinned around 15,000 radiocarbon years ago with its final retreat from Orkney about 13,000 radiocarbon years ago. This ice sheet carried rock materials, sand and mud derived mainly from local sources. Erratics (rocks transported by ice and deposited far from their point of origin) are also present and include chalk, flints and shells from the bed of the North Sea and granites and metamorphic rocks from as far away as Norway. These rock materials concentrated in the base and margins of the ice sheet acted like sandpaper and efficiently eroded the land surface. The rocks entrained in the ice left scratch marks, known as striations, on the bedrock giving the movement direction of the ice sheet. There is evidence from crossing striation marks to indicate that the flow direction in Orkney fluctuated through time from a generally SE-NW direction to an E-W direction (Fig. 4).

The rocks, sand and mud frozen in the ice sheet were deposited as the ice melted, forming a layer of Boulder Clay (or till) in most of the low lying areas of Orkney. This Boulder Clay varies from a few centimetres thick up to 20 metres. Small rounded hills or 'morainic mounds' of boulder clay cover substantial regions of Orkney. The Orkney Boulder Clay at any location is normally a single unit of uniform texture and composition nevertheless more than 20 multiple till sections have also been observed. As the difference in colour reflects the bedrock composition up-ice, these contrasts between individual units relate to changing ice movement patterns over the local geology. The absence of soil horizons or weathered surfaces between these tills indicates that melting of a single ice sheet (13,000 radiocarbon years ago) was probably responsible.

The northwest end of the island of Hoy exhibits most of the classical valley-glacier mountain landforms. The two deep valleys either side of the Ward Hill are U-shaped valleys formed by the presence of local glaciers. The Trowie Glen was a hanging valley glacier where deeper erosion by the ice was prevented by the presence of the glacier in the main valley. Several small corries are also

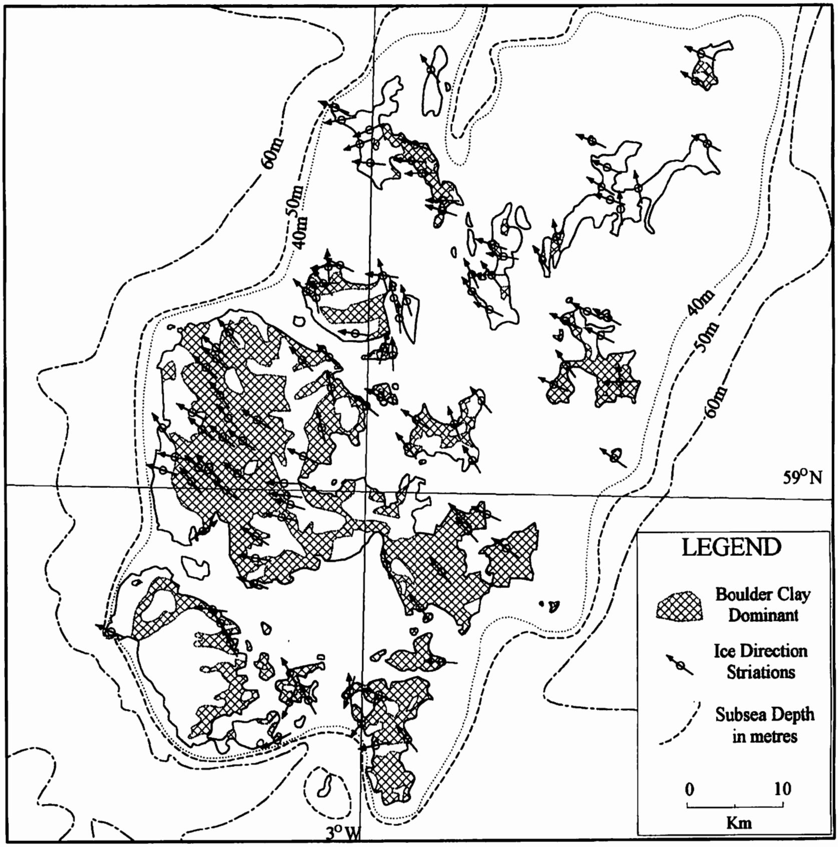


Fig. 4.

observed. Other glacial features such as truncated spurs and terminal moraines are common. An excellent exposure of a lateral moraine is seen at the east end of the Rackwick beach where the angular rock debris, which had fallen from the valley side on to the edge of the glacier, is observed. Linking all these features on Hoy is difficult because they were sculpted over a long period. This complexity derives from the fact that they may well have been actively reworked during each Glaciation and Stadial when the ice sheets first advanced and then again when they retreated. The evidence suggests that the climatic conditions during the Interglacial and Interstadial intervals were similar to or warmer than the present suggesting that ice was totally absent from Orkney, and plants and animals would have colonised the area.

Towards the end of the Devensian, the short cooling period of the Loch Lomond Stadial, 13,000 to 11,500 years ago (about 11,500 to 10,000 radiocarbon years ago), marked the end of the last Ice Age. On Hoy, there is evidence for this phase of local glaciation with the presence of small end moraines at Dwarfie Hamar and the interior of Enegars' Corrie. Following this there appears to have been a long period of very cold climatic conditions when the ground was still without vegetation. This is demonstrated by frost shattering, churning and solifluction on the top of the boulder clay deposits and barren rock surfaces. It is from this time that the bare rocky 'pavements' and 'patterned ground' of the summits of the Hoy Hills originate, and the great gashes cut by torrents of meltwater in the glens. Arctic tundra conditions continued to between 11,500 years and 10,500 years ago when the climate changed to warmer conditions than the present time and sea water levels rose rapidly.

Holocene Environment

The Holocene Interglacial, in which we are now living, started 11,500 years ago with the final retreat of the polar ice caps and rapid global warming. Evidence from southern Greenland ice cores suggests that a 7-degree C warming may have taken less than 50 years. The recession of the ice sheet uncovered vast areas of new land in higher latitudes, which then became available for human occupation. Rapid flooding of the low-lying coastal plains due to rising sea levels put further pressure on the human population to move. This change also coincided with the transition from Upper Palaeolithic technology to Mesolithic and Microlithic technologies with its improvement in hunting tools. Between 16,000 and 10,000 years ago, many large mammals such as mammoth, woolly rhinoceros, musk ox, steppe bison and the cave dwelling predators became extinct. Controversy continues about the cause of this extinction ranging from climate change, contact diseases in previously isolated groups to the increasingly efficient predation by human hunters. During the Holocene vegetative cover, human occupation and climate appear to be interrelated. Historians and archaeologists have perhaps underestimated the effect of climate change on population dynamics in the Northern Isles.

Holocene global and local climate changed through time. Climate involves a combination of average temperature, precipitation, days of frost, sunshine days and length of 'growing season', and is difficult to quantify the further back in time one goes. Climate, in terms of how far north, or how high up a mountain, certain foods can be grown controls the range and extent of colonisation by human farming groups. The viability of such settlement requires a stable or improving climate. Deterioration in climate may initially have little effect, other than lower crop yields, particularly in southern communities; while at the same time marginal areas may suffer famine, disease and population migration. Where the marginal area is an island such as Orkney, worsening climate could lead to decimation of the indigenous people and leave behind an impoverished culture. This has happened several times in Orcadian prehistory.

The evidence shows that, within dating error, climatic optimums coincide with flowering of relatively advanced cultures that end suddenly as the region goes through a climatic crisis (Fig. 5). A human contribution to this environmental deterioration in the past cannot be ignored, forest clearing for farming about 3500BC being just one.

The major change to the landscape of Scotland at the beginning of the Holocene was the establishment of a forest cover. Pollen studies from the West Mainland of Orkney indicate forest cover occurred much later than the rest of Scotland with heathland replaced by tall herb grassland in the period 11500 to 8900 BP. Birch and hazel are estimated to spread and colonise at a rate of 1,000m/year and would therefore be expected to reach Orkney earlier than they did. This time lag is indicative of a physical barrier to natural spreading of the forest. Potential barriers are the water gap of the Pentland Firth and the high ground barrier of the Ord of Caithness (Elaine Bullard, personal communication). Natural variation in climate (see below) could eventually give rise to prolonged intervals of higher average temperature (greater than 1 degree) enabling the forest to traverse the Ord. The Pentland Firth represents a different problem. The land bridge requires sea level to be -70m and that would have only occurred in the earliest Mesolithic (earlier than 10,000 years ago) long before trees were established. Seed dispersal across the Pentland Firth would therefore require an abnormal, but not impossible, set of circumstances such as high velocity southerly winds carrying seeds and birds with seed to south-east Orkney.

Once established, extensive open forest woodland consisting of hazel, birch and willow with a more restricted distribution of alder in the West Mainland continued until 5600BP. The understorey taxa[2] recorded by the pollen are similar to the present day tall herb communities found in the preserved remnant of this ancient woodland at Berriedale in Hoy. There is some evidence of a local climatic profile across Orkney during the Mesolithic. In the Eastern part of the archipelago, on the early colonisation path, and in more sheltered locations there is a greater variation of tree species with changing abundance of pine, oak and alder making up to 30% of the pollen assemblage. The growth range of elm does not reach as far north as Orkney.

It seems likely that during the Mesolithic the Orcadian landscape may have been a mixture of thick forest in the lower regions with open woodland, grassland and heath on the hillsides. The scarcity of Mesolithic archaeological sites may relate to this distribution of tree cover with communities established in clearings at the edge of the forest, along the seashore and on the hillsides. Post Mesolithic sea level rising would have inundated many of the coastline settlements leaving only the hillside sites for modern archaeology to discover beneath

2. A lower tier of shrubs and small trees under the main canopy of forest trees.

the blanket peat now covering these areas. Microfossil evidence from 'Keith's Peat Bank' in mid Hoy indicates the possibility of Mesolithic human impact in the area from about 6800 to 5800BP. The abundance of available wood at this time would undoubtedly mean that all their tools and buildings would have been made from this perishable material. The only observed fossil wood of this period is found in the 'submerged forests' associated with the sand-covered peat deposits found at low spring tides in sheltered bays within Scapa Flow.

The transition from the Mesolithic nomadic hunting gathering society to the Neolithic settled farming economy is generally coincident with the decline in forest cover over most of Scotland. In Orkney, this took place around 5600BP, the actual timing varied from area to area with evidence occasionally of woodland regeneration. Human induced pressures such as grazing densities, changing fire regimes, direct clearance for cultivation and leaf foddering probably constituted the main causes of the decline. At about this time the climate deteriorated and probably gave the final deathblow to what was at best a marginal area for tree growth. The loss of wood as a major resource for building undoubtedly led to increased use of local stone for this purpose. After the forest decline, a mosaic pattern of heath, woodland and farming landscape may have existed well into the Bronze Age, 3700 years ago, where tree pollen in samples show twice the present-day abundance.

Peat has persisted in Orkney from early Holocene times as indicated by dating a core sample from Scapa at 9110BC (9860 +/- 80 radiocarbon years BP). By the middle of the Bronze Age (1500BC), the pollen record shows a dominance of heather species indicating wide spread take-over of the landscape by heath and blanket peat bog. On mainland Scotland, and in Orkney, there is evidence of prehistoric settlement and land use below a cover of peat due to changes in the environment during the Bronze Age. Among the possible agents involved in this process of environmental change are:

- Increases in grazing indicators prior to heath development in Orkney suggest human pressures.
- Removal of the natural tree canopy reduced the transpiration demand of vegetation and interception of precipitation. More water would be available for raising groundwater levels thus favouring peat development.
- Hardpans of podzol type related to removal of trees may also have led to some waterlogging of the soils impeding drainage and increasing acidity.
- Continued use of a plough induces compaction in the subsoil (plough sole). This impedes soil drainage, decreases the availability of soil nutrients, and encourages colonisation of wet ground plants such as sphagnum and heather.

- Downturn in climate during the Bronze Age.
- Increased acid rain from volcanic activity.

The major impact of human activity in Orkney occurred shortly after the decline in forest cover. Subsequent changes in human activity and settlement pattern had less impact on the pollen record suggesting that land use patterns remained constant while other aspects of human activity altered. Evidence from other sources therefore is used to interpret the environment of the late Holocene.

The study of mountain glacier expansion and contraction indicates that during the historic period the climate has been marked by colder episodes lasting for 600 to 900 years separated by warmer periods. Warm periods such as the Roman period from 300BC to 400AD, the medieval 'Little Optimum' 750AD to 1300AD and the present warm period from 1850AD saw maximum temperatures one to two degrees greater than today. Between 1080AD and 1180AD, the coast of Iceland was relatively free of ice. In Britain at this time, vineyards producing wines equal in quantity and quality to France were to be found as far north as York. The 'Little Optimum' in the Orkney context was within the Viking period when the land could support larger populations with the free time and resources to invest in Cathedral building and major expeditions.

The last cold period (1300AD to 1850AD) known as the 'Little Ice Age' reached its peak between 1650AD and 1750AD. This period showed a complex pattern of warming and cooling with severe winters and hot summers such as that preceding the Great Fire of London in 1666AD. Although not uniform in time and space the climatic changes of the 'Little Ice Age' had some major consequences for contemporary society in Northern Europe that were somewhat overshadowed in history by political happenings:

- In Britain, this was a time of social and political turmoil with increasing urbanisation of the population. Emigration and the deportation of large numbers of criminals to the colonies were probably exacerbated by the downturn in climate and the consequent productivity of the rural economy.
- The upper limits of Highland cultivation in Norway and Britain dropped 100m to 200m.
- The chances of crop failure in the Lammermuir area went from 1 year in 20 down to 1 year in 3.
- A substantial number of people in Scotland perished though famine in the last decade of the 17^{th} century.
- Famine in 1740AD killed 300,000 people in Ireland.
- The end of Greenland colonisation.

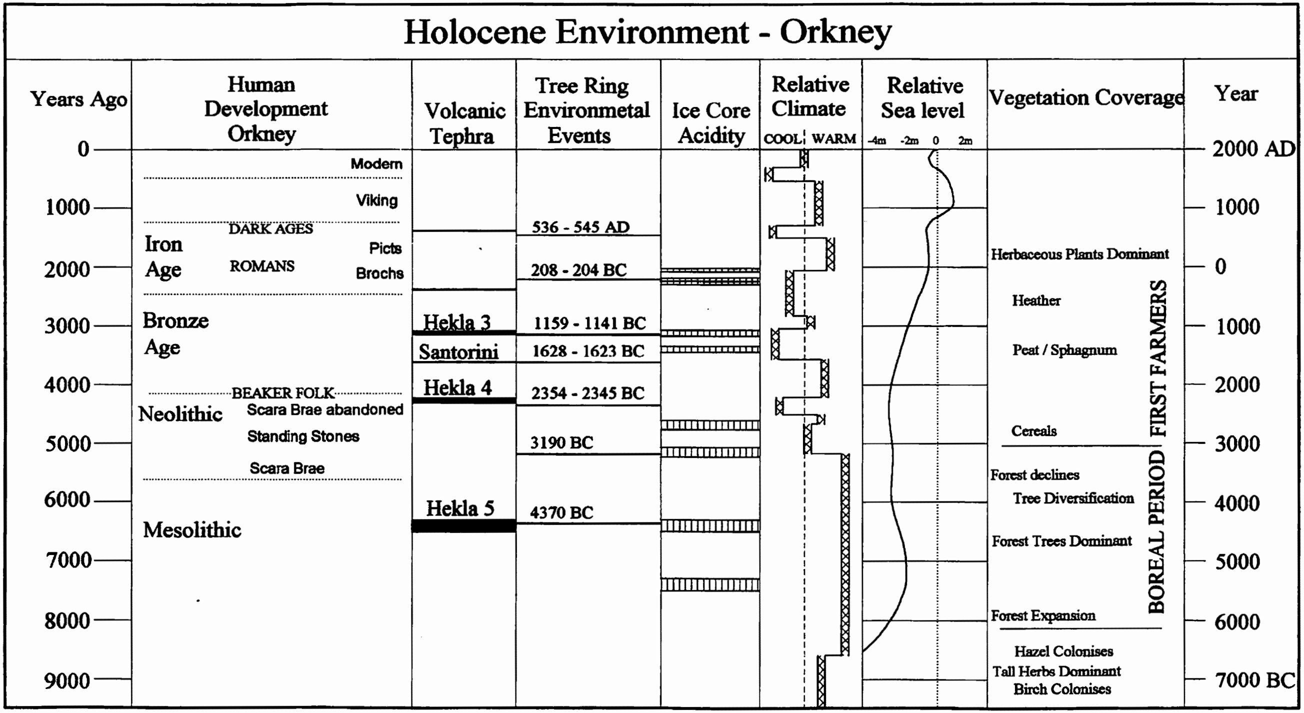


Fig. 5. Holocene Environment — Orkney.

- In Iceland corn growing decreased after 1300AD and ceased altogether in the 16th century.
- The silver mines in central Europe were subjected to increased flooding after 1300AD.

Climate

The astronomical Milankovitch cycles (Fig. 3) discussed above controls the incoming solar radiation (insolation) and the broad climatic configuration. Shorter cycles appear to dominate the Holocene climate pattern. These shorter period cycles tend to cause variations of 1 to 3 degrees centigrade while the longer cycles are associated with temperature changes in the tens of degrees and mark the onset of glacial and interglacial climatic conditions. The moderating effect on climate of the North Atlantic Drift current and the Arctic Conveyor current is understood but their stability throughout the Holocene is unknown. Cloud cover, relating to moisture in the atmosphere, also affects insolation acting as a thermal blanket and thus tending to reduce extremes of temperature.

Several short-term cycles have been noted during the Holocene. Sunspot abundance associated with solar flaring and increased solar energy (insolation) reaching the surface of the Earth is one such cycle going from a maximum to a minimum in 11 years with 22 years for a complete Hale cycle. Cycles of 70 to 90 years are also postulated giving some credence to the often-heard comment, 'the weather was never like this when I was young'. Between 1640 and 1710 AD, 'the Maunder Minimum', there was a near absence of sunspots. It is perhaps significant that this minimum coincided with some of the extreme years of the 'Little Ice Age' when the River Thames froze over regularly. Longer-term oscillations in the Camp Century (Greenland) ice core are noted at 78, 181, 400 and 2400 years. Causes of these longer-term variations in solar activity are still poorly understood. They may relate to zones of fine interstellar matter, through which the Earth passes and in combination with the sunspot activity give rise to the observed patterns.

Increased concentrations of the greenhouse gases, carbon dioxide and methane are closely correlated with increased temperatures. Air bubbles from ice cores show that during the last glacial maximum (about 20,000 years ago) carbon dioxide concentration in the atmosphere was 50% of the present level and methane was about 60%. This pattern of high concentration of greenhouse gases during interglacial and interstadial periods and a low concentration in glacial and stadial periods is significant but the relationship between cause and effect is still questionable.

Retreating ice caps during interstadials expose vast areas of bog land. As this is a major source of methane production, it will increase the warming of the Earth, and accelerate the melting of the ice. Land plants and oceanic phytoplankton utilise carbon dioxide. Ocean transgression (rising sea level) over shallow continental margins gives rise to increased planktonic productivity in the warm nutrient rich waters. These plankton remove carbon dioxide from the air, which eventually leads to global cooling. These feedback systems are self-controlling. Although some of these changes are gradual there is increasing evidence from ice core data that some major climatic shifts can involve rates of change of one or two degrees per year in average temperature. This could be potentially catastrophic for farming populations in marginal areas.

Superimposed on the cyclical changes in local and global climatic regimes is the effect of natural geological processes. The most critical of these are volcanic eruptions that can adversely affect the local climate for one or two seasons. Being 900km downwind from the active Icelandic volcanic regions, Orkney has had an increased potential for major shocks to the local climate throughout history. Mount Hekla intermittently put vast amounts of volcanic ash into the upper atmosphere (Fig. 5). Some of these ash fragments (tephra) are distinguished in the peat deposits of Orkney (Hekla 5 about 4400BC, Hekla 4 in 2340BC and Hekla 3 in 1140BC). Major catastrophic explosive eruptions affect not only local climate but can have major consequences for the global climate over a period of decades. For example:

- On August 27 1823, a cataclysmic 100 megatons explosion (Hiroshima 20 kilotons) on the island of Krakatoa (Indonesia) put volcanic ash 50 miles into the stratosphere affecting the world's weather patterns for years.
- About 1628 BC, the island of Santorini (Aegean Sea) underwent an explosive eruption four times more powerful than Krakatoa. The effect on the global weather pattern lasted for decades.

There is growing evidence that the Earth has been in contact with various interplanetary objects such as comets, asteroids and meteorites in the past. They could have had variable impacts on the climate regionally and globally depending on the size of the object and where it landed. An asteroid hit the southern Gulf of Mexico 65 million years ago. It is thought to be responsible for the extinction of the dinosaurs and numerous other life forms. While the impact would have killed many individuals directly, species extinction came through inability to adapt to the change in climate that ensued. In Northern Arizona 50,000 years ago, a meteorite, about 46m across and weighing several hundred thousand tons, struck leaving a crater 213m deep and over 1220m across. On June 30 1908 in the Tunguska Region of Siberia a fireball air blast devastated 500,000 acres of timber.

Many historical records exist of spectacular close passes by comets affecting the climate, followed by disease and famine. These are discussed in a recent publication (Baillie 1999) where evidence from the tree ring record of Irish bog pine and German oak show climatic crises (narrow growth rings) lasting several years. He has identified seven such events since 5000BC and it is argued that they are due to near misses by comets. These events at 4370BC, 3190BC, 2354-2345BC, 1628-1623BC, 1159-1141BC, 208-204BC and 536-541AD are plotted (Fig. 5). Where these tree ring events, within the error limits of the dating methods, show coincidence of tephra and ice core acidity, from volcanics, then there has to be an element of doubt about the causal agent. The recorded: dry fogs; dust veils, famines in Ireland, Britain and China and the Justinian bubonic plague, of the mid 6th century may be due to volcanoes or comets. The tree rings do show a global environmental downturn that peaked in 540AD, the beginning of the Dark Ages. There is some evidence that poor climate continued for some time after 540AD and, if true, the economy of Orkney and many other marginal areas would have been badly affected. This period also saw the movement of nomadic tribes from northern Europe into settled farming areas.

Could this climate change, with mass mortality from famine and plague, have led to the end of the Pictish broch culture and virtual abandonment of the Northern Isles? Slow recovery of the economy and population could explain why the subsequent Viking occupation was relatively peaceful. The climatic warming, two centuries later (750AD) would have increased the area available for agricultural development and the Islands could have sustained a much larger colonial population without the need to fight for land.

Sea level

Climatic change affects the amount of snow melting, snow precipitation and ice accumulating on the polar ice caps and mountain glaciers. This in turn affects the volume of water in the sea and thus the global rise or fall in sea level. The sea level at any location is measured relative to the nearby land which is subject to tectonic movement up and down. When the ice caps melt during an interstadial the sea level rises globally (eustatically). The weight of this extra water consequently depresses the ocean floor. Total melting of the present day ice caps would raise the sea level by 66m but hydro-isostatic sinking of the ocean floor reduces the relative sea level rise to about 44 m.

During the Ice Age, there was approximately 2km of ice over central Scotland. On melting, the downward pressure (weight of ice) was released and the land surface moved up (isostatic rebound) more quickly than sea level rose. This gives a relative sea level drop over much of Scotland during the Holocene. In Orkney where the ice thickness was considerably less, eustatic sea level rise was greater than isostatic rebound giving a local sea level rise. The effects of these changes are seen along the shorelines. Where the relative sea level is dropping, evidence of emerged shorelines consists of platforms backed by steep cliff slopes (raised beaches), marine shell beds and stranded beach deposits. A raised beach deposit at about 7m in the cliff face near Braebuster, North Hoy, is covered by glacial till evidence of higher relative sea level during

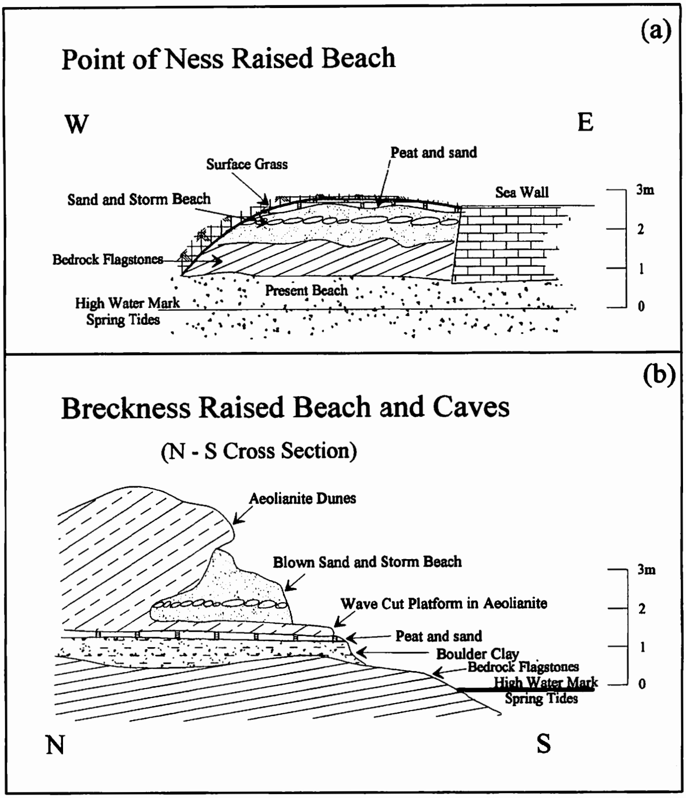


Fig. 6.

one of the interstadial episodes of the last Ice Age. Where the relative sea level is rising, evidence of submerged coastal features consists of drowned river valleys (rias), submerged dune chains, remnants of forests and peat layers below sea level (as noted in Scapa Flow) and notches with benches in the submarine topography. On the chart of Orkney waters (Fig. 4) a well-defined notch is noted between 40m and 50m with a less well-defined notch at about 10m. These features may relate to pauses during the Holocene sea level rise but equally may have formed at any time during the last Ice Age.

In the Stromness area there is evidence for an approximately 1m - 2m higher relative sea level in the past (Fig. 6). It is inferred that this high stand occurred about 1000 years ago (Fig. 5) in the Viking Period. The 'fossil forest' and submerged peat under the sand at low water spring tides East of the Inner Holm, Stromness, probably dates from the Mesolithic. Approximately 4m separate these two features giving a rise in relative sea level of at least 10cm/100 years between 3000BC and 1000AD. Orkney is currently rising (isostatically) at a rate of about 5cm/100 years while the eustatic sea level is rising globally at about 25cm/100 years.

Conclusion

The interplay between geology, landscape, climate and human demographics in Orkney is complex. Because information shrinks rapidly backwards through time clarity of detail is apparent for things chronologically close but it becomes blurred for those further away. During the Devonian, 380 million years ago the eccentricity of the Earth's orbit about the Sun controlled the sedimentary processes associated with rhythmic repetition of 'wet period' deep lake deposition approximately every 100,000 years. The effects of the 100,000-year orbital eccentricity cycle combined with the shorter obliquity and precession of the equinox cycles (Fig. 5) can be resolved to explain the waxing and waning of glaciation and stadial ice sheets over the past 2 million years. Much finer scaled insolation parameters effect 2 to 3 degree temperature changes during the latest Holocene interglacial period.

Cycles of climatic optimisation and deterioration throughout the Holocene were critical to the human ecology of Scotland's Highland and Island areas. It is considered that too little attention has been paid to the role of climate by archaeologists and historians when considering the cultural history of a marginal area like Orkney. Although politics and war undoubtedly have a role to play climatic deterioration over a period of years associated with famine and plague may well have exerted a much greater influence on population dynamics in these islands.

With the forest clearance by the first farmers in Orkney, it is too easy to describe the human impact on the natural world solely in terms of 'degradation' and 'impoverishment'. In fact, agriculture has generally been an agent of ecological diversification replacing the primeval forest ecosystems by a mosaic of habitats in the landscape. The long interplay between human production and different natural habitats makes it difficult to separate natural from cultural influences. Modern, urbanisation, efficient transportation links and the adoption of modern scientific agricultural practices will serve to insulate the population of Orkney from many of the effects of future short-term climatic changes.

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