

1. EVIDENCE OF PAST CLIMATE CHANGE

Andrew Casebow



Figure 1.1 Wave cut erosion at Cobo bay.

Change is a normal part of geological history and Guernsey has abundant evidence of the past changes in our climate.

The average annual air temperature at the surface of the planet is just above 12°C. This is the average of day and night temperatures, summer and winter, from the Arctic through the tropics to the Antarctic.

We are living in what is scientifically known as an 'interglacial' period, but what is often thought of as a 'brief summer' that has lasted for about the past 10,000 years. These brief warm periods have occurred about every 90,000 years, so that there are known to have been 9 ice ages in the past 780,000 years. Scientists have examined deep ocean sediment cores and ice cores from Greenland and the Antarctic and they all provide similar evidence. For instance, the Vostock ice core taken from the Antarctic shows 4 glacial periods in the past 420,000 years. Professor Nick McCave will explain more in the following chapters.

The planet's temperature at the coldest time during the last glacial period was up to 10°C colder than the present, but the average temperature in the middle of the last 'ice age' was only about 5°C below today's average temperature. The difference now is that our burning of 'fossil fuels' has caused global average temperatures to rise by about 0.7°C in the past 100 years, and global climate models predict a rise in global average temperatures between 1990 and

2100 of between 1.5°C and 5.8°C, depending on future carbon dioxide emissions. However, the climate is not stable even without the greenhouse gases added by man.

When the weather became colder at the end of each 'interglacial period', water became trapped in vast sheets of ice covering much of the Northern Hemisphere, that extended as far south as southern England. As water was locked up in land ice, sea levels fell by as much as 120 metres; so Guernsey and each of the islands, were hills in a vast plain connected to both mainland France and England.

In the warm interglacial periods the sea levels rose as the ice melted. Temperatures during the interglacial periods varied, they were not always as they are today. In some periods the temperature was higher, resulting in greater glacial melting and higher sea levels, whilst in others the temperature was lower, less ice melted and the sea level was lower. For instance, it is thought that the temperature during the last interglacial period was slightly warmer than today and that this caused greater melting of the Greenland glaciers, resulting in a sea level that was several metres higher than the present.

To confuse us further, the level of the land surface has been rising throughout this period, caused by an uplifting of the European Tectonic Plate as Africa collided with Southern Europe. Evidence of the higher sea levels can be seen in the wave cut platforms, fossil cliffs, cliff notches, and raised beaches that can be seen in Guernsey at about 8 metres, 18 metres and 30 metres above current mean sea level. The wave cut platforms and raised beaches that are about 3 metres above the current high water level were created in the last 'interglacial' warm period about 120,000 years ago. There is a large raised beach area at Capelles, some 18 metres above sea level; and others at La Houquette, St Peters, and Rouvets, St Saviours that are 30 metres above sea level. Each of these beaches was created by the sea level during interglacial periods in the last 450,000 years.

The planet's temperature at the coldest period in the last ice age, was only about 5°C below the average temperature now.



Figure 1.2 (a) Wave cut beach at Bec du Nez and (b) a cliff notch clearly visible at Fermain.

Dr John Renouf will explain how sea levels rose 50 metres between 11,000 and 6,000 years ago to cut our islands off from France and England. This process will have occurred repeatedly over the millennia as each successive warm period came and then receded as the cold reasserted itself again. During these cold periods the land was frozen tundra, devoid of all trees and flowering plants. Therefore, trees, plants, wild flowers, birds, animals, and man, will have only repopulated this area since the ending of the last ice age. Dr Renouf and Guernsey States Archaeologist, Dr Heather Sebire, will explain.

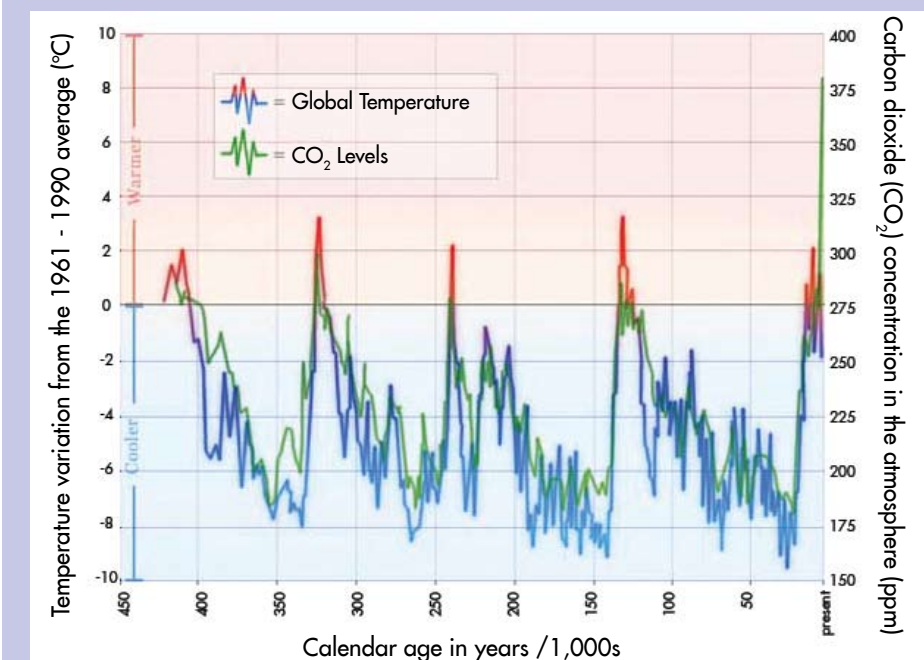


Figure 1.3 Graph showing the global average temperature and carbon dioxide concentration in the atmosphere. Note how closely these are related. For most of the past 450,000 years, the world has been much colder than it is today - but changes can be abrupt.

2. HOW THE EARTH'S NATURAL CYCLES AFFECT CLIMATE

Andrew Casebow and Chris Regan ^[1]

The cycle of ice ages and shorter interglacial periods (and the changes of climate within the ice ages), and even seasonal changes, are caused by cyclical changes in our planet's movement around the sun. They are called Milankovitch Cycles after the astronomer who first calculated them, and there are three main cycles: -

1. Eccentricity - The Earth's Orbit around the Sun

The Earth's orbit around the sun is not a circle (fig 2.1), but an ellipse. The effect of this is to change the distance that the Sun's short wave radiation must travel to the Earth in the different seasons.

At the present time the orbit is at its least elliptical, which means that a difference of only 3% occurs between the extremes, but this still means that the

earth receives 6% more solar energy in January than it does in July each year. When the Earth's orbit is most elliptical (on a cycle of about 100,000 years), then the seasonal difference in solar energy would be 20-30%. This changing amount of received solar energy results in substantial changes in the Earth's climate, and in the change from glacial periods (ice ages) to interglacial periods.

The current stage of the cycle may mean that the world is nearing the end of its current 'interglacial period' and, without global warming, temperatures might have started to fall. However, temperature change would be very small compared to the large increases of temperature that are likely to be caused by global warming.

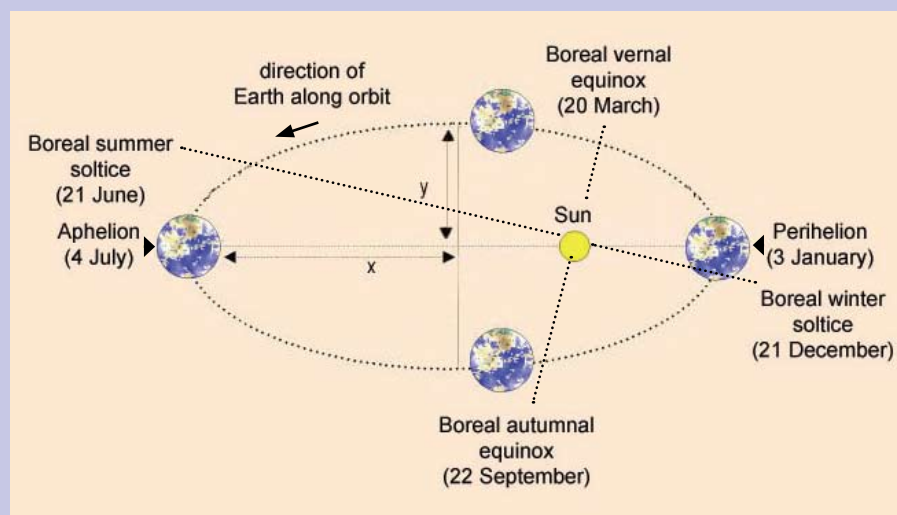


Figure 2.1 The eccentricity, e , of the Earth's orbit around the Sun is given by the equation $e^2 = 1 - y^2/x^2$. The term 'aphelion' means furthest point and 'perihelion' the nearest point from the Sun.

2. Axial Tilt - The angle of the earth's orbit to the sun

The Earth's tilt (fig 2.2) at the Equator varies from between 21.6° and 24.5° degrees in a periodic manner of about 41,000 years. The tilt today is about 23.5° . These changes in the earth's tilt affect the severity of the earth's seasonal changes and these seasonal changes are much more apparent towards the North or South Pole, away from the Equator.

3. Precession

'Precession' (fig 2.3) is the Earth's slow wobble as it spins on its axis, which causes a change in the timing of the annual equinoxes. The axis of the Earth

One suggestion is that the lower axial tilt might promote the growth of ice sheets. The reason for this is that warmer winters could support greater atmospheric moisture and then heavier snowfall. Summer temperatures would be cooler, leading to less melting of the winter snowfall, and greater annual accumulation.

wobbles from pointing towards Polaris (the North Star) to pointing towards the star Vega. Each cycle of this 'wobble' takes 23,000 years.

When the Earth's axis is pointed towards Vega the Northern Hemisphere will experience longer winters because the Earth is furthest from the Sun. This results in greater seasonal contrasts. At present the Earth is nearest to the sun very close to the winter solstice.

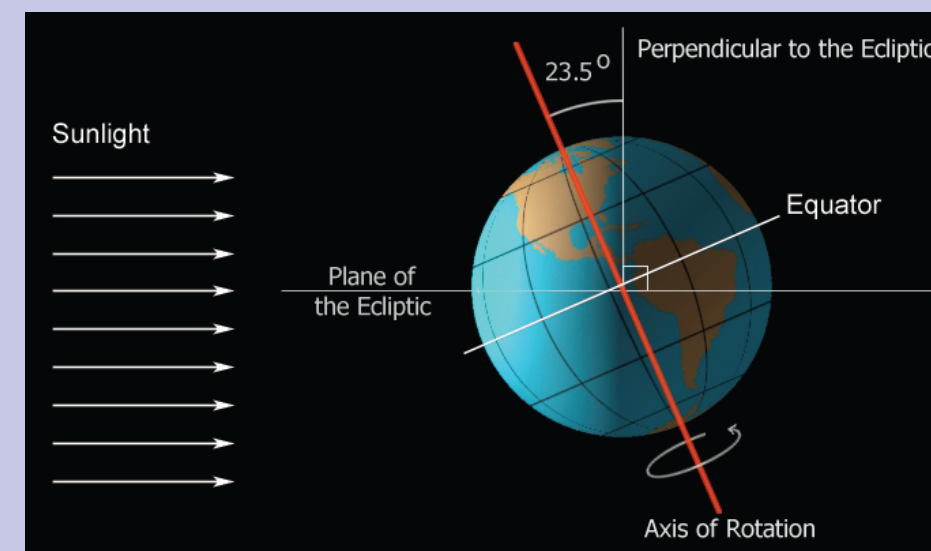


Figure 2.2 The axial tilt of the earth's orbit to the sun varies. Currently it is at an angle of 23.5° .

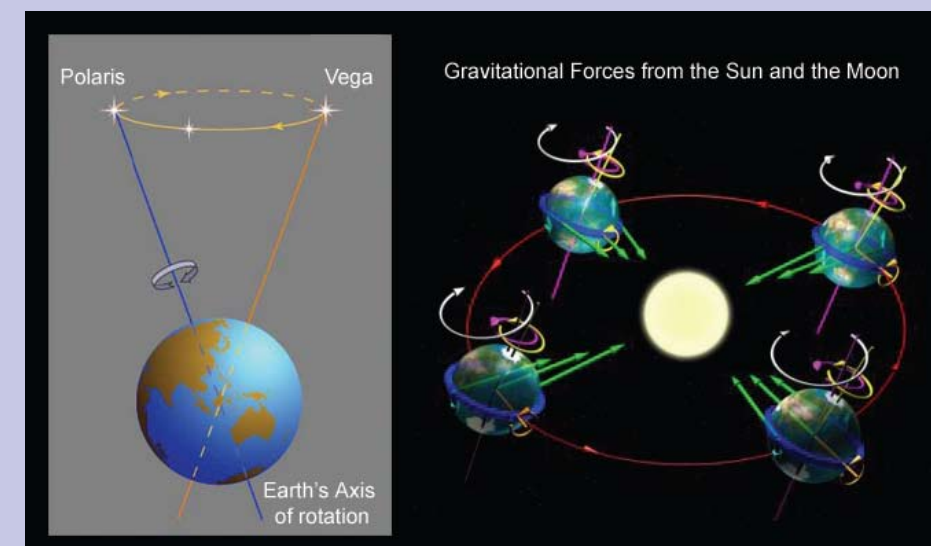


Figure 2.3 The Earth's precession, or slow wobble as it spins, is caused by the differential gravitational forces of the Sun and the Moon on the Earth. Currently it is very close to the winter solstice which means our winters are generally longer and summers shorter.

Conclusion

These variables are important because most of the world's landmasses are in the Northern Hemisphere. When the Northern Hemisphere summers are coolest because they are furthest from the Sun (due to greatest orbital eccentricity and precession) and the winters are warmest (due to minimum tilt), snow can accumulate and cover large areas of northern America and Europe. At present only precession is in the glacial mode, with tilt and eccentricity not favourable to the formation of glaciers.

Even when all the cycles favour the formation of glaciers, the increase in winter snowfall and decrease in summer melt is barely sufficient to trigger glaciation, and not sufficient to develop large ice sheets. The growth of ice sheets requires the support of a positive feedback loop. One such 'loop' might be the fact that ice masses reflect more of the sun's radiation back into space, thus cooling the climate and allowing glaciers to expand.

References

1. Chris Regan is a Marketing Communications Executive for the States of Guernsey. He is currently undertaking study with the Open University towards a BSc in Physical Science. Chris was born in Guernsey where he lives with his family.

3. LONG-TERM CLIMATE CHANGE

Nicholas McCave ^[1]

We are living in an Ice Age. We don't know whether we are in the middle or near the end, but it has been going on for around 30 million years so far.

The last major ice age lasted 50 million years; from around 330 to 280 million years (Myr) ago during what geologists know as the Carboniferous and Permian Periods. More recently, between 100 and 50 million years ago we can find little evidence of any ice at all, because the world was much warmer then. The evidence for these deductions lies in the distribution of fossils. For instance, trees grew in the far north (at a palaeolatitude of 80° N) in warm periods, and sediments such as ice-rafted gravel in deep-sea muds can be found much closer to the equator (at 35° N) during cold times.

So Earth's climate has been anything but stable in the long term. Figure 3.1 shows results from the most powerful climate indicator that we have, the ratio of oxygen isotopes in marine shells, called foraminifera (Figure 3.2). This indicator combines the effect of ice volume and temperature over the last 70 million years. The development of cooler climates over the past 50 million years is clear, and particularly the cold of the last 3 million years.

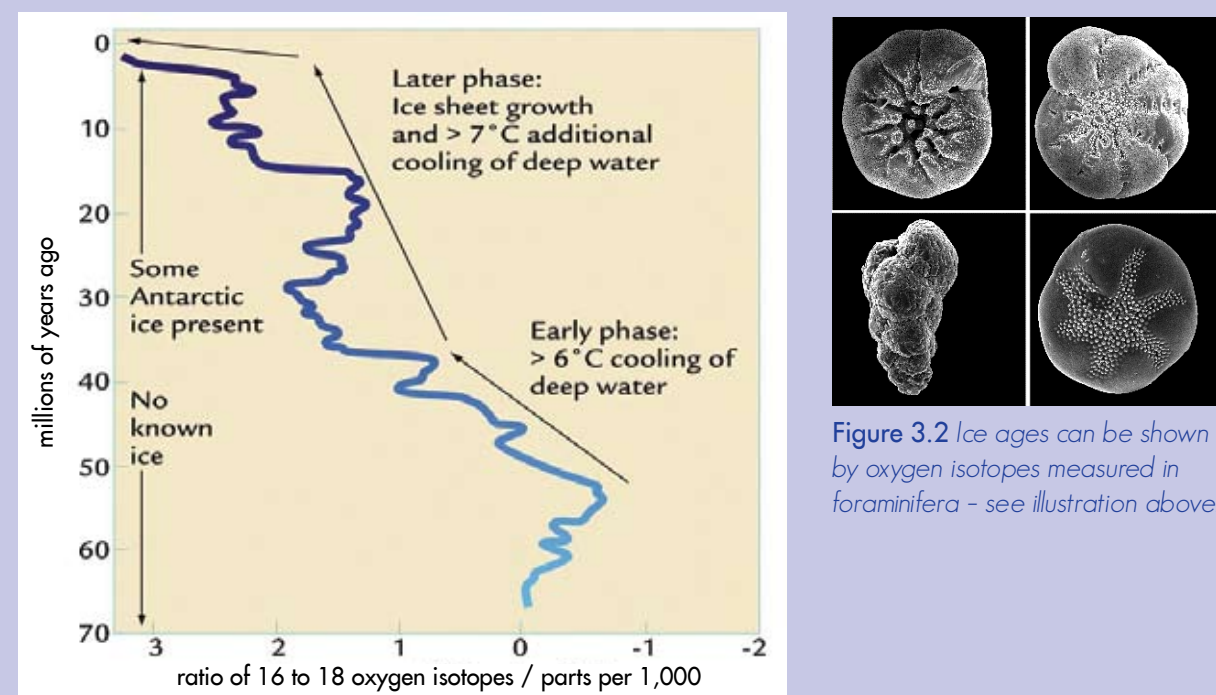


Figure 3.1 Ratio of oxygen isotopes in marine shells over the last 70 Myr ^[2].

In the last million years, perhaps the peak of the present ice age, climate has also been most unstable with around 10 major glacial periods of 100 thousand years duration. These glacial periods that we normally think of as 'ice ages', each lasted some 80-90 thousand years of cold conditions and 10-20 thousand years of warmer conditions. In the last million years there have been very few times when the global temperature has been as warm as it is now, and in the last 11 thousand years during which human civilisation has developed. The three most pronounced warm periods, known as 'interglacials', occurred at around 420, 330 and 125 thousand years ago.

Figure 3.3 is a graph showing the ratio of oxygen isotopes for the last 500 thousand years, and from them you can see the sequence of warm and cold periods following each other, with warm peaks at about every 100 thousand years. In the diagram, warm periods have odd numbers and one can see that only numbers 5, 9 and 11, which represent interglacial periods that occurred at 420, 330, and 125 thousand years ago, have values similar to the present time (number 1). Number 2 is the last glacial maximum that occurred about 20 thousand years ago, with other even-numbered glacial periods; and you can see that some were less severe than others.

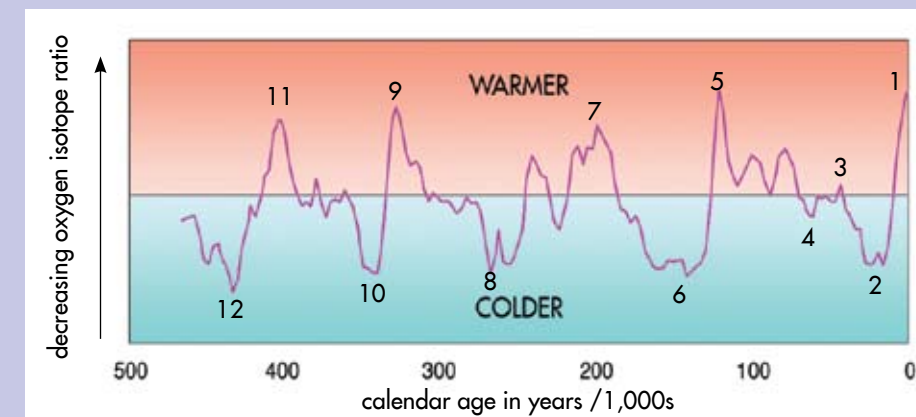


Figure 3.3 Ratio of 16 to 18 oxygen isotopes in the last 500,000 years. Cooler temperatures result in an increase, whilst warmer temperatures produce a decrease in the ratio. This process is significant in determining climate change. ^[3]

Therefore, it can be seen that most of the time over the past 500 thousand years the climate has been much colder than it is at the present, and that the cold was only broken by brief warmer periods, or interglacials. But even the warm periods have not had stable temperatures, as you will see in Chapter 4. Similarly, Figure 3.4 shows that the temperature in the last 'glaciation' fluctuated and grew progressively colder until the last glacial maximum that occurred about 20 thousand years ago, just before the climate warmed dramatically.

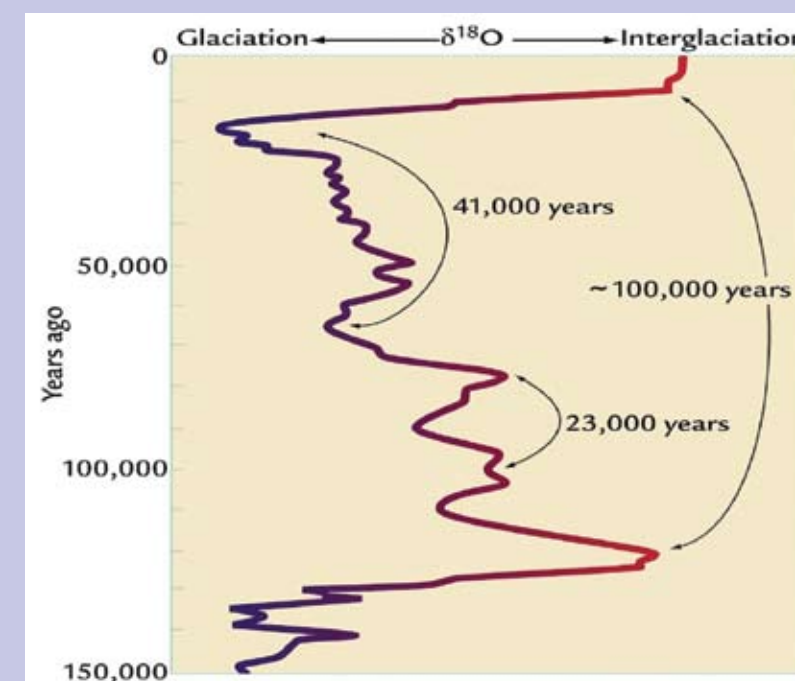


Figure 3.4 The peaks and troughs in the diagram above refer to Milankovitch cycles of 23,000 years, 41,000 years and 100,000 years.

Professor McCave says "we use data based on oxygen and carbon isotopes, skeletal chemistry, species abundances, organic molecules and physical properties of sediments as a basis for inferring past temperature, salinity, density, nutrients and flow speed of oceanic water masses".

An ice age is a geological period during which great glaciers and ice sheets extend from the Polar Regions towards the equator. Individual ice ages wax (glacial phases) and wane (interglacial phases) in strength. The present day climate is an interglacial phase within the Quaternary Ice Age, which began in the Northern Hemisphere about 3 Myr ago and in Antarctica about 30 Myr ago.

References

1. Professor Nicholas McCave. Woodwardian Professor of Geology at Cambridge University since 1985. Fellow of St John's College, Head of the Earth Sciences Department from 1988-1998. His research interests include the deep circulation of the oceans in relation to climate change. A Guernseyman by birth.

2. Ruddiman, W.F., 2001 Earth's Climate: Past and Future. WH Freeman, New York, 465 pp. (Figs. 3.1, 3.4).

3. Data from Lisiecki, L. E. and M. E. Raymo, 2005, Paleoclimatology, vol. 20, PA1003. (Fig. 3.3).

4. THE PRESENT INTERGLACIAL PERIOD

Nicholas McCave



Figure 4.1 Land ice sheets, such as this one in Greenland, contract during the period between ice-ages. This period is called 'interglacial'. The current Holocene interglacial has persisted since the Pleistocene, about 10,000 years ago.

Anthropologists have argued that the relative climatic stability of the past 10 thousand years has allowed development of modern human civilisation, including the farming of plants, the domestication of animals, and the building of cities. It was only in the past 25 thousand years that our species *Homo sapiens* emerged as the dominant hominid with the decline of the Neanderthals. However the period from 25 to 11 thousand years ago saw huge climate shifts in the transition from full glacial (with ice down to the Isles of Scilly) to present interglacial conditions, with both major warmings and coolings; which was not good at all for the establishment of stable human communities.

Then about 10 thousand years ago the climate became relatively stable, with estimated global mean temperature shifts of less than 1° C (compared with 5° C glacial to interglacial global change - though obviously much more adjacent to ice sheets). There was one blip on this stable warm climate, that occurred about 8,200 years ago. This was caused by the final collapse of the Canadian ice cap. This produced a sudden discharge of fresh water, that had gathered in

a vast lake as the ice melted, into the North Atlantic. It is thought that this sudden influx of cold, fresh water caused a temporary weakening of the current system that brings warm waters from the Gulf of Mexico to north-western Europe. This system - The Gulf Stream and North Atlantic Drift at the surface - depends on the water being dense enough to sink in the Norwegian Sea when it gives up its heat, but the extra fresh water made it too light, thereby slowing the system down.

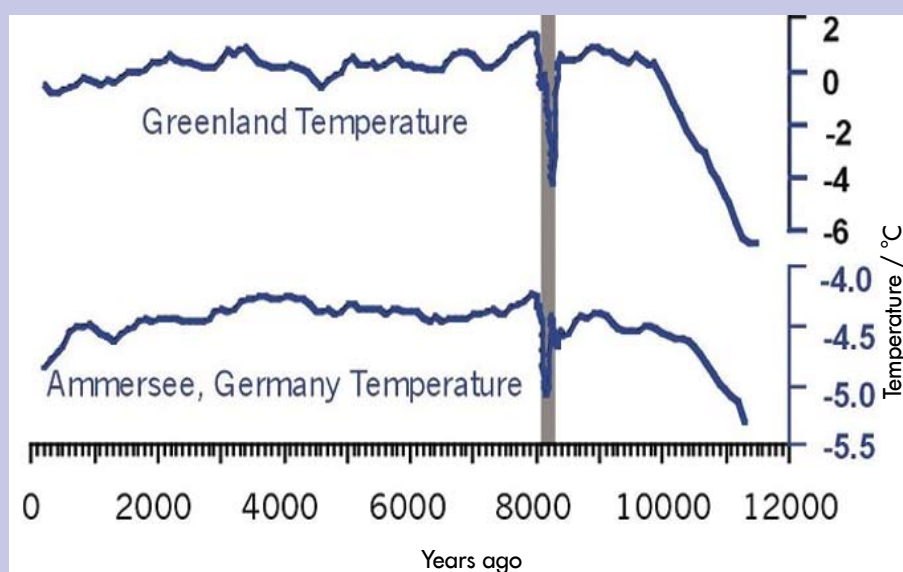


Figure 4.2 Temperatures both on the Greenland ice cap and in a record from a central German lake show at least 1° C of change [1].

Figure 4.2 shows that ice and sediment records from Greenland and from a German lake show the same story; that a sudden dramatic fall in temperature occurred about 8,200 years ago. The warmer temperatures seem to have returned after about 200 years, probably as the circulation returned to normal interglacial conditions.

Since then there have been minor oscillations of climate, shown by sediments excavated from the Atlantic. This suggests 8 cooler periods in the last 10 thousand years. Figure 4.3 shows a higher percentage of sand grains (dropped from icebergs) indicates colder conditions.

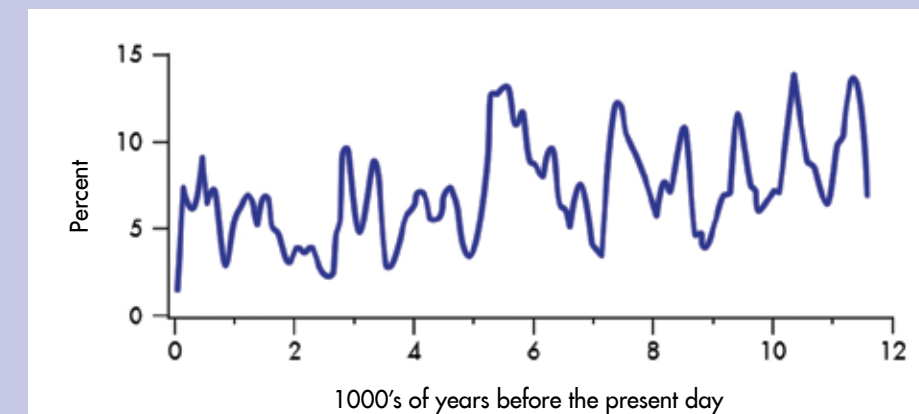


Figure 4.3 A higher percentage of sand grains indicates colder conditions [2].

The most recent of these warm/cool oscillations was the Mediaeval Warm Period that peaked between 1000-1200 AD, when there were vineyards in England as far north as Leicestershire; and the succeeding Little Ice Age that peaked between 1550-1800, when the Thames used to freeze over in winter (Figure. 4.4). This temperature fluctuation is clearly evident when tree-rings, that record the conditions when the tree was growing, are analysed. From this it can be seen that at no time in the last 2 thousand years has it been warmer than the present, and that the current trend is taking global temperatures beyond the maximum attained in the past half million years. We are entering uncharted territory.

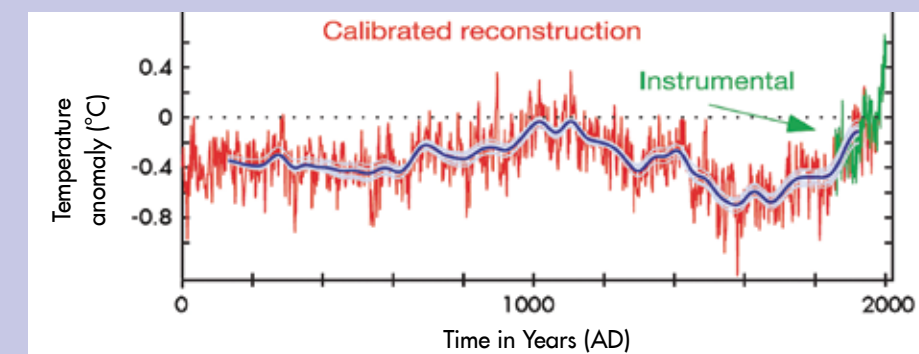


Figure 4.4 Temperature variations over the past 1,000 years, clearly showing the medieval Warm Period (peak 1,000 - 1,200) and the Little Ice Age (peak 1,550 - 1,800). [3].

It may be salutary to reflect that whatever we do, the Earth will continue, with or without us. That is the lesson of the cataclysms recorded in the rocks.

As Ronald Wright [4] has so pungently put it

"If we fail - if we blow up or degrade the biosphere so it can no longer sustain us - Nature will merely shrug and conclude that letting apes run the laboratory was fun for a while but in the end a bad idea."

2. Bond, G.C. and others, 2001. /Science/, vol. 294: 2130-2136. (Fig. 4.3).

3. Moberg, A. and others 2005, /Nature/, vol. 453: 613-617. (Fig. 4.4).

4. Wright, R., 2005. /A Short History of Progress/. Canongate Press, Edinburgh, 211 pp.

5. SEA LEVEL RISE AROUND THE CHANNEL ISLANDS

John Renouf^[1]

During the glacial periods Guernsey had a much colder climate and was a part of the mainland of France and of England for long intervals. Figure 5.1 shows that the sea around Guernsey was part of the European landmass during these times.

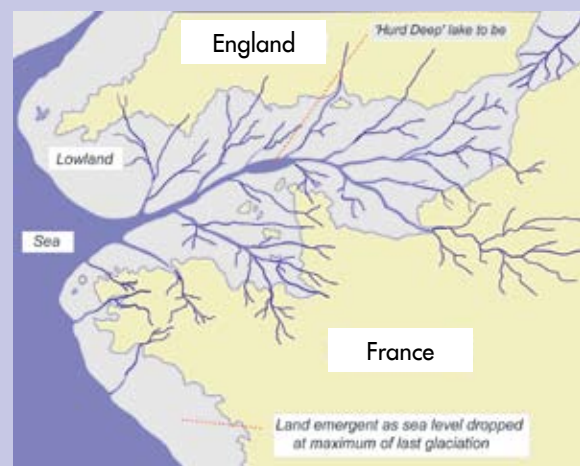


Figure 5.1 Guernsey was part of the European landmass during the glacial periods. Sinel Map of 1923 (redrawn).

In the course of the warm Interglacial periods, sea levels globally were several metres higher than the present day, due to differences in temperature and glacial melting. There was, however, one important difference: the land that was at sea level 450,000 years ago is now 30-35 m higher, since the whole of the Channel Islands and adjacent areas has been rising by about 7 cm every thousand years ever since.

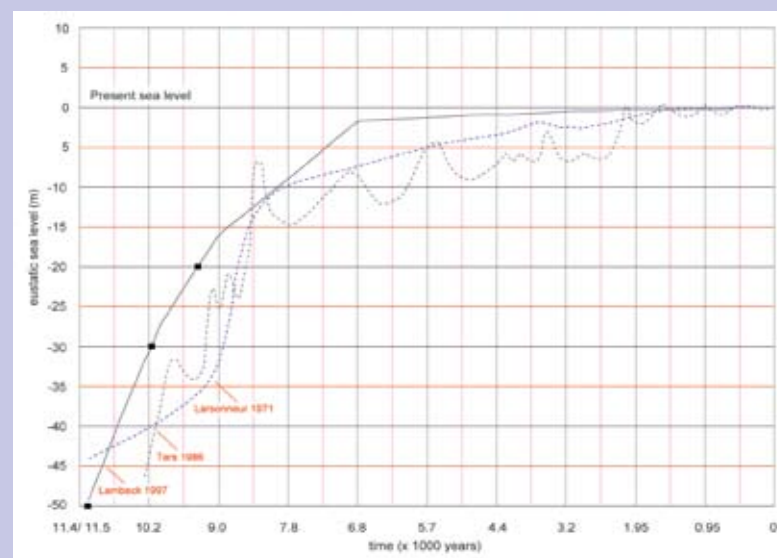


Figure 5.2 Sea level rise over the last 11,500 years. Points plotted at levels 50m, 30m and 20m lower than present are visualised on page 21 (fig 5.4c, d, and e). source K Lambek.

The sea level of 450,000 years ago had pebble beaches and wave cut platforms, and these can now be found at a height of over 30m above Guernsey Datum, as at La Houquette in St Peters, and Rouvets in St Saviours. Other raised beaches and platforms are found at 20-25m (from the Interglacial period about 350,000 years ago), at 15-18m in Capelles (caused during the interglacial 250,000 years ago), and at just above the present high water mark of spring tides (120,000 years ago).



Figure 5.3 Evidence of a raised beach on the west coast of Guernsey. Large rounded stones are situated below smaller pebbles, upon which smaller material from the end of the last Glacial period is deposited.

An example of this beach on the west coast of Guernsey is shown in figure 5.3. Large rounded stones are to be seen below smaller pebbles, and these are overlain by more angular small stones in a finer orange yellow material, known as loess, a wind blown deposit from the end of the last Glacial period.

The coldest time during the last Glacial period occurred about 18,000 years ago. Following this the great northern ice sheets began to melt as the climate became much warmer. By the time the Glacial period officially ended about 11,500 years ago, the sea level had already risen by more than 50 metres from its minimum height, that had been more than 100m below that of the present. The scene becomes particularly interesting for Guernsey between 10,000 and 11,000 years ago when the rising sea was cutting the island off from the mainland of France.

Figure 5.4 Sea Level Rise



Figure 5.4a Land and sea at about 18,000 years ago. Sea level over 100 metres lower than today. At the height of the last Glacial maximum, the seashore was well out in the Western Approaches. The Hurd Deep to the north of Alderney is a lake.



Figure 5.4b Land and sea at about 14,000 years ago. Sea level about 75 metres lower than today. As the great northern ice sheets began melting, the sea level rose rapidly.

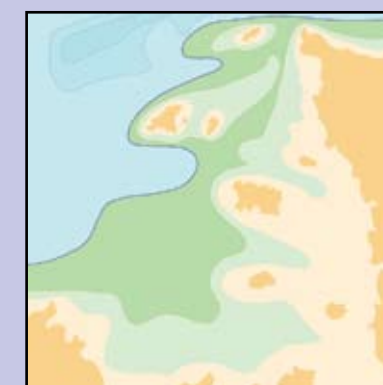


Figure 5.4c Land and sea at about 11,400 years ago. Sea level about 50 metres lower than today. The Hurd Deep to the north of Alderney is now a deep in the sea. The sea level is still rising rapidly.



Figure 5.4d Land and sea at about 10,200 years ago. Sea level about 30 metres lower than today. The shore-line is very close to the west of Guernsey and the island, along with Sark and Alderney are now cut off from France.

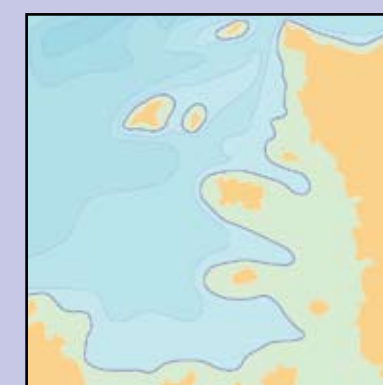


Figure 5.4e Land and sea at about 9,400 years ago. Sea level about 20 metres lower than today. Guernsey separated but Jersey is still not an island.



Figure 5.4f Land and sea at the present time. More recently than 10,000 years ago.

The rate of sea level rise slowed considerably and there is difficulty in knowing the precise outline of the seashore at any given time during the last 9,000 years.

The sea level continued to rise but there were fluctuations caused by both general and local causes. The general causes were mostly climatic in nature but the local ones were often caused by the erosion of soft sediments and the effectiveness of sea and tide to remove it. There might have been long periods when a dune barrier at the high tide could have held back the sea before, quite suddenly, it was breached and the sea claimed a significant land area overnight. Thus a clear distinction has to be made between sea level rise and sea encroachment. There is still active erosion going on at present of soft sediments around the coast. This sediment has been at the same level since the sea reached its present height but erosion has only now reached back far enough for the sea to be attacking it.

References

1. Dr John Renouf was formerly Curator of the Museum in Jersey. He trained as a geologist at London University and studied geology in Brittany for his doctorate. He now specializes in the study of former sea levels and consults as a geologist on archaeological matters.

6. LANDSCAPE AND CULTURAL EVIDENCE OF CHANGE IN GUERNSEY

John Renouf and Heather Sebire^[1]

At the end of the last ice age the climate of north-western France and the Channel Islands was an open, dry steppe-like tundra with no tree cover and a low herbaceous ground cover (Figure 6.1a). The loessic (silty) soil of the main plateau of Guernsey was possibly being blown into place at this time.

Initially the climate rapidly warmed for a thousand years or more, but then became colder again. It was a cold, arctic environment of mostly low, shrubby vegetation but with the odd patch of open woodland (Figure 6.1b).

Then the climate rapidly warmed again about 11,000 years ago and, within something over a thousand years, a well-established forest became widespread. Birch, hazel and pine were quite common (Figure 6.1c). By 8,750 the forest had become dense and birch and pine were in decline. About this time the island of Lihou provides evidence of Mesolithic human habitation. Hazel nuts were in ready supply as shown by their recovery from the sediments.

The first Neolithic farming peoples arrived in the Channel Islands about 7,000 years ago (Figure 6.4). There is little pollen evidence available to determine

the vegetation accurately, but it suggests that a typical oak forest existed at that time, with areas of other vegetation types on wetland and on more open areas. The pollen record provides the first evidence of human activities affecting the vegetation. Forest clearance is revealed from the pollen and vegetation remains. This is the pivotal moment in the story of the island's vegetation as from this moment on the human influence becomes significant, and has remained so to this day. The climate during this period was also about 1°C warmer than today, and witnessed the climax development of the mixed oak forest in northwest Europe. Subsequently the climate has been cooler, often wetter and generally more uncertain but the distribution of the natural vegetation cover that would have developed under these varying conditions is no longer identifiable since human agricultural and pastoral practices have modified it in many different ways.

Figure 6.1 Views looking west from Lihou showing the dramatic changes in vegetation as the climate ameliorated from the intense cold of the Ice Age. **Figure 6.2** Early evidence of Neolithic man.



Figure 6.1a 18,000 years ago - Open, dry steppe-like tundra are typical of the Channel Islands climate.



Figure 6.1c 8,000 years ago - Birch, hazel and pine forests are widespread.



Figure 6.1b 13,000 years ago - Low vegetation and patches of open woodland are quite common.



Figure 6.2 6350 years ago - Les Fouaillages Dolmen, first evidence of early Neolithic human activity.

Cultural changes in the human habitation of Guernsey occurred both within the Neolithic and during the succeeding Bronze and Iron ages (Figure 6.3).

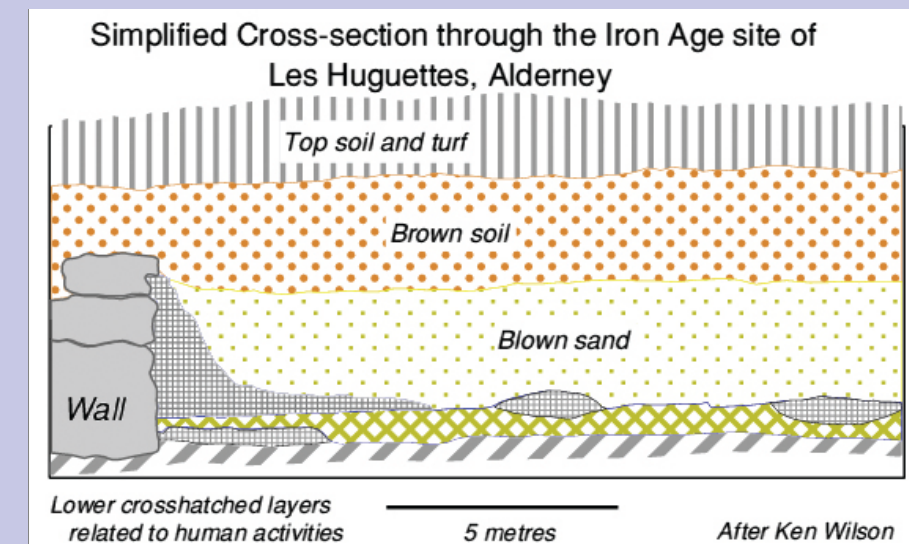


Figure 6.3 Iron age pottery manufacturing site of nearly 2,500 years ago at Les Huguettes in Alderney. Abandoned probably because of blowing sand.

During Gallo-Roman times, there is widespread evidence of the establishment of small centres around Guernsey's coasts evaporating seawater to produce salt – the so-called briquetages. A Medieval site at Albecq (Figure 6.4) on the west coast is of value to any discussion of climate in Guernsey since it represents a time when there was a significant climatic change under way: that from the earlier Medieval Warm Epoch to what is usually called the Little Ice Age. The site here was buried by wind blown sand, which is quite likely to be part of a widespread phenomenon in northwest Europe during the 14th/15th centuries. Serious wind blow and sea encroachment associated with much increased storminess is well documented.

Guernsey Climate and Landscape

18,000 years ago

The landscape lacked trees apart from the smallest of shrubs. The climate was cold not unlike today's arctic tundra. Woolly Mammoth and Woolly Rhinoceros roamed the plains around Guernsey.

14,000 years ago

The landscape still lacked trees and the climate remained cold. Woolly Mammoth and Woolly Rhinoceros were possibly gone from the area.

11,000 years ago

The climate has warmed considerably and there is, along with the grassy plains, open woodland with much birch but also oak, hazel and other trees that have spread from the south. Guernsey is about to become an island.

8,000 years ago

A richer tree cover has developed, probably covering much of the landscape. The climate is mild and not too different from the present.

7,500 years ago

Oak and hazel woodland are now fully established and will remain the dominant vegetation cover over large areas to the present day, except that human interference has modified that natural situation to a major degree. Open heath and grassland cover significant areas of cliff and dune.



Figure 6.4 The site at Albecq (Medieval period, Guernsey's west coast) show the occupation layers overlain by blown sand as a result of storms and sea encroachment, indication of some degree of climatic change.

References

1. Dr Heather Sebire is Archaeology Officer at Guernsey Museum. She has carried out extensive rescue excavations in the Bailiwick of Guernsey over the last twenty years and has particular research interests in the prehistory of the Channel Islands.