Shaping the Landscape

Student Information Booklet

Learning Outcomes:
The students will develop an understanding of what Ireland was like in the Quaternary and the importance of climatic events in the Quaternary that shaping our landscape.

General learning points:
Students will demonstrate an ability to:

- Reimagine what life was like in the past
- Describe how Quaternary period links with the science, biology, geography and agriculture syllabi
- Develop investigation skills; understanding that Quaternary scientists use different strands of evidence to build up a picture of the past (environmental and cultural)
- Develop map reading and other graphical and interpretation skills
- Stimulate curiosity about plants and animals, and how they arrived in Ireland

STUDY NOTES

Topic Areas

- **Background**
- **Ice ages**
- **Glacial landforms**
- **Animals life in Ireland**
- **People**
- **Evidence for a changing climate**

BACKGROUND

Geologists divide the whole of the Earth's 4600 million year history up into smaller units of time; large units, hundreds of millions of years known as **ERAS** and smaller units of time known as **PERIODS** (Figure 1). Within periods, time is divided into even smaller **EPOCHS**. A period is defined or marked by particular features or events, for example the Jurassic is distinctive as the age of the dinosaurs.

The Quaternary is the most recent geological period and is defined by periods of glaciation. It began 2.6 million years ago (mya) and continues to the present day. It is characterised by cycles of temperate climate like today and Ice Ages when, global temperatures plummeted and thick ice sheets, almost 3km in places covered Ireland. Within the Quaternary are two epochs, the **PLEISTOCENE** (2.6 million to 11,700 years ago) and the **HOLOCENE** (11,700 years to present day). It was during the Quaternary that our own family of species, the hominids evolved. Mass extinctions and climate change in the geological past were caused by immense geological forces operating on and within the Earth.

Recently humans are contributing to the very rapid extinction of flora and fauna on a global scale and have had a significant effect on the Earth's climate, hence the reason why scientists are proposing the most recent epoch within the Quaternary, the '**ANTHROPOCENE**' (Human epoch). The start of the Anthropocene is still a matter of debate by the International Union of Geological Sciences (IUGS), and International Commission on Stratigraphy (ICS) the international organisations that name and define epochs.

Era	Period		Age (mya)
Cenozoic	Quaternary	Anthropocene*	1950 CE
		Holocene	0.117
		Pleistocene	2.6
	Neogene		26
	Paleogene		65
Mesozoic	Cretaceous		145
	Jurassic		200
	Triassic		251
Paleoproterozoic	Permian		299
	Carboniferous		353
	Devonian		417
	Silurian		443
	Ordovician		490
	Cambrian		543
Neoproterozoic			1000

Figure 1 The Geological Column (*proposed new epoch in the Quaternary)

ICE AGES

Planet Earth has experienced many ice ages, when global temperatures dropped considerably, ice sheets and glaciers spread far from the poles. The fact that we have ice today at the poles means we are still in an **ICEHOUSE** climate. Climate warming through the Holocene has seen the once vast ice sheets now confined to the north and south poles. In the past the Earth experienced periods of significant global cooling, known as **GLACIALS** and in between these glacial phases were warmer periods known as **INTERGLACIALS**. Within the Quaternary there were up to sixty glacial and interglacial periods. During glacial periods and in particular the most recent one (the Devensian), Ireland and northern Europe were both covered in thick ice sheets (similar to modern day Greenland) that scientists estimate could have been more than 1km deep in places (Figure 2). The mean annual temperature across the British Isles was about 5°C lower than today during the **LAST GLACIAL MAXIMUM (27-23K)**. Frozen ground, known as permafrost, extended as far south as southern France!

The last glacial period began forty thousand years ago (kya) and ended thirty thousand years later. During this period global sea level fell by over 100m and land bridges emerged, enabling animals and people to migrate between otherwise cut off areas of Britain and mainland Europe. Land and ice bridges connecting southern Britain and Ireland might have existed during some glacial periods but not during the most recent glacial phase, when Ireland appears to have remained an island. Early researchers envisaged the last ice sheet over Ireland as a huge static ice mass. Today we understand, from the shape of the landscape, that the ice sheet would have changed over time with shifting climate conditions and sea ice cover (Figure 2).

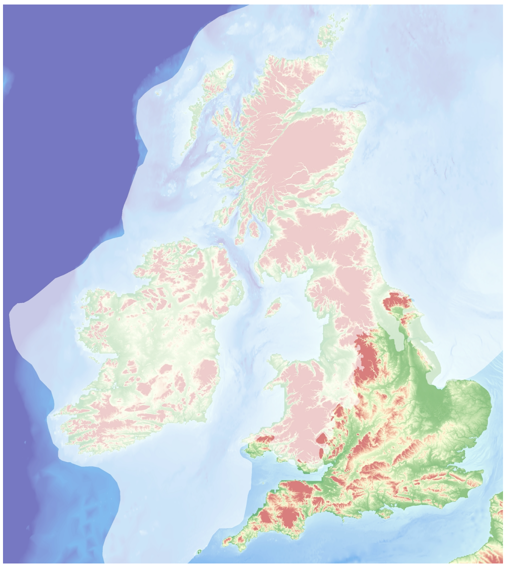

Figure 2 Map of Britain and Ireland during the last ice age (Source: Britice-Chrono)

MILANKOVITCH CYCLES are natural causes of global warming and cooling as a result of the Earth's orbit around the sun. When the Earth has a more elliptical orbit the climate is cooler; with a circular orbit, the climate warms (Figure 3). The tilt of the Earth's axis is also important, when it has a larger tilt more of the sun's rays hit the surface, so the climate is warmer, compared to a smaller tilt.

GLACIAL LANDSCAPES

Ice is the most powerful erosive force on Earth, which can both destroy landscapes and create new ones. As a glacier flows down a valley, it plucks coarse gravel to boulder sized blocks from the sides and the valley floor. These rocks are then transported within the solid ice flow and grind against other rocks on the sides and floor of the valley causing them to wear away by **ABRASION** (wearing down – like sandpaper, and **QUARRYING** (fracturing of large blocks in a leeside cavity) (Figure 4). Abrasion creates lots of sand sized rock particles as well as **ROCK FLOUR** (silt to clay sized particles).

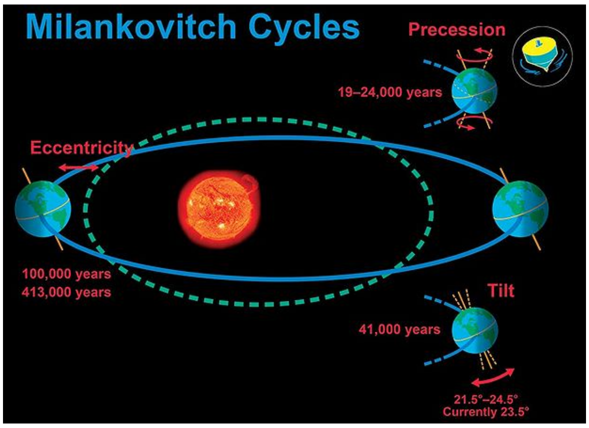

Figure 3 Milankovitch Cycles (Source: www.universetoday.com)

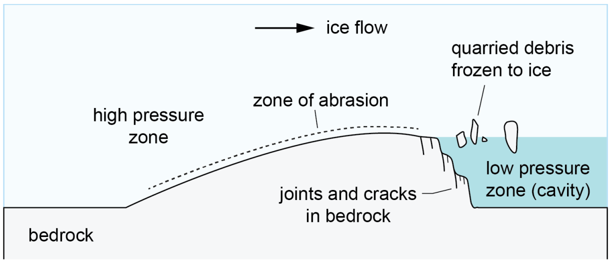

Figure 4 Glacial abrasion by small particles entrained in ice and quarrying (fracturing of large blocks in a leeside cavity) **(**Source: Antarcticglaciers.org)

Evidence of glacial quarrying is preserved in the upland landscape of Ireland in the form of **CIRQUES** or **CORRIES.** These huge bowl-shaped hollows are carved into the rock in the side of mountains (e.g. Lough Nahanagan in Co. Wicklow Figure 5). From Co Mayo in the west to Dublin in the east, Ireland is littered with more than 60 of these over-deepened rock hollows, that were carved out by the boulders transported in the ice. Spectacular **U-SHAPED VALLEYS** such as Glendalough in Wicklow and the Glens of Antrim are found all around Ireland; these widened valleys were carved out by a combination of glacial abrasion, quarrying and erosion by subglacial meltwater.

Ireland's glacial legacy is so pronounced that some words used as glacial terminology are derived from Irish names! Landscape features known as **DRUMLINS**, literally translated from the Irish, 'Droimnin' meaning little hill. Drumlins are low elongated and rounded mounds that were formed by the streamlined movement of fast-moving glacial ice. Their long axes roughly indicate the direction of glacial ice flow and can be found across large swathes of Ireland, for example the Ard's Peninsula Co. Down (Figure 6), Clew Bay Co. Mayo (Figure 7) and Co. Monaghan and Co. Cavan.

Figure 5 Lough Nahanagan (lower lake) glacial corrie. (Source: ESB Archives)

Figure 6 Drumlins in the Ards Peninsula (Source: s0.geograph.org.uk/photos)

Figure 7 Drumlins in Clew Bay, Co. Mayo (Image P.Coxon)

The name **ESKER** is derived from the Irish word 'Eiscir' meaning a ridge. Eskers are winding gravel ridges (Figure 8), deposited as the supply of water to subglacial channels was reduced. Large volumes of sand and gravel (an essential commodity in the construction industry) were deposited in lowland areas of Ireland as the ice sheet melted. Much of the countryside in Ireland is littered with sand and gravel pits, whereas most of Donegal is devoid of such thick deposits and so must import most of their sand and gravel.

MORAINES are mounds of glacial debris deposited at the end of glaciers and can be found as long ridges all over Ireland that help us understand the geometry of the ice sheet as it retreated.

Figure 8 Esker Eiscir Riada (Source: https://alchetron.com)

Quaternary deposits are important constituents of the modern landscape and can be of great economic importance. These are often unconsolidated sands and gravels, meaning that careful consideration must be given to major engineering projects on such deposits such as road building, tunnels and major residential and commercial building projects. Events such as slope failures have resulted from a lack of appreciation of the influence of glacial processes on materials and landforms.

As the ice erodes a landscape, it plucked and transported blocks of rock. These blocks were transported far from their source and deposited on top of rocks of a different composition as the ice melted and the glaciers retreated. Known as **ERRATICS** these blocks can be used to determine the direction that the ice flowed (Figure 9). The most iconic and well-known erratics are large, but most of what we know about ice movement comes from small erratic pebbles and more recently, the geochemistry of the glacial deposits. Erratics of granite from Ailsa Craig in the Firth of Clyde (Scotland) have been found in Derry and Donegal and blocks of rock eroded from Galway were deposited as erratics in Cork.

Figure 9 Glacial Erratic, Co. Clare (Image: C.Dalton)

Many of these glacial landforms are depicted in Figure 10 including drumlins, moraines and eskers as well as **KAMES** (irregularly shaped mounds), **KETTLE HOLES/LAKES** (a hollow created when blocks of glacier ice melt).

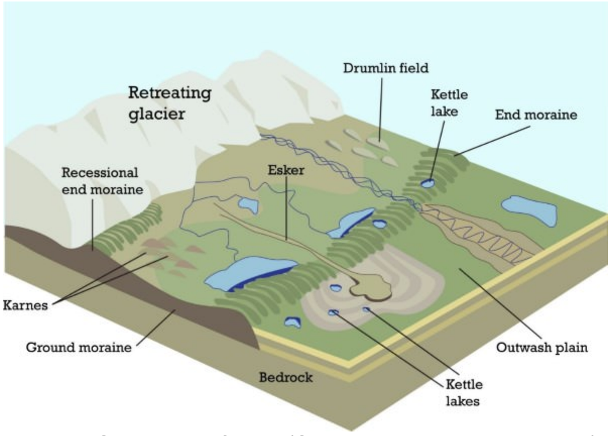

Figure 10 Glacial landforms (Source: www.iasmania.com)

SYDNEY MARY THOMPSON (1847–1923) (Figure 11) of the of the Belfast Naturalists' Field Club tracked the movement of glaciers in the late nineteenth and early twentieth centuries and could be described a 'Giant of Irish Quaternary Science'. She found of a piece of Ailsa Craig microgranite at Moys, Co. Derry in 1907 providing landmark evidence at that time of most westerly extent of Scottish ice during the last Ice Age.

Figure 11 Sydney Mary Thompson (Source: Ulster Museum).

ANIMAL LIFE IN IRELAND

During the glacial periods, much of Ireland was covered in ice making it inhospitable meaning that what animal life was around in the Quaternary lived in the lowland areas. During interglacial periods, species of Norwegian lemming, the Irish stoat, Arctic hare, Arctic fox, the snowy owl, and large mammals such as the musk oxen lived here.

As the ice retreated 20 kya the bare ice-scoured surfaces and soils were colonised by species such as birch, Scots pine, hazel, alder and oak. **PALAEO**, meaning ancient, is often used to describe past environments e.g. palaeovegetation, palaeoclimates, palaeolakes and palaeoceans. The climate would have been wet and large birds such as cranes would have stalked small fish in the shallower ponded water.

Archaeological excavations of Irish caves have made important finds which have helped our understanding of ice age animals. **BROWN BEAR** bones (Figure 12) have been found in multiple caves and date from 40 Kya and roamed across the lowlands of Ireland until as late as 3 Kya.

Figure 12 Brown Bear (Image: CDalton)

An iconic species glacial megafaunal species native to the Irish plains was the **GIANT IRISH DEER** (Figure 13). Giant deer would have roamed across the grasslands and sought refuge in the pine and oak forests. Giant deer were extinct in Ireland by 11.5 Kya and Europe by 6.5 Kya presumably as the result of increasing temperatures, wetter climate, woodland expansion and loss of grassland habitat. **WILD BOAR** (Figure 14) would have fed on forest shrubs and lived in small family groups. The boar was prey for the brown bear.

Figure 13 Giant Irish Deer (Source: Jay BizarreZoo Cooney)

Tusks and teeth of **WOOLLY MAMMOTHS** (Figure 15) were unearthed in Aghnadarragh near Crumlin Co Antrim, and dating suggests that they lived in Ireland around 100 kya years ago and were gone from most of Europe by 12 kya. These herbivores required vast amounts of grass and so lived in the interglacial periods. Remains of top predators like **SPOTTED HYENAS** (which live today in the Savannah in Africa, Figure 16) have also been found in Ireland 45-25 kya suggesting they probably still roamed the land up until the most recent glacial phase began. These hyenas had thick fur, which enabled them to adapt to the frigid temperatures. None of these animals, nor their descendants are found today in Ireland, either because they simply couldn't adapt to the new warmer climate in Ireland 10 kya or because they were hunted by humans.

Figure 14 Wild Boar (Image: C.Dalton)

Figure 15 Woolly mammoth **(**Source: Britannica.com**)**

Figure 16 Spotted Hyenas **(**Source wikipedia.com)

PEOPLE

The Quaternary is often referred to as the 'Age of Humans' as it is during this period that humans evolved. The Quaternary includes the whole history of our species. Scientists think that climate change may have accelerated the evolution of humans although why and how is contested. Modern man (*Homo sapiens*) appeared in Africa about 200 kya. By 40 kya, modern humans had begun to settle in Europe only reaching Ireland around 10 kya, after much of the ice had melted.

The success of hominin is attributed to his use of tools which enabled them to dominate other species and change and shape the landscape. Man's use of the most basic stone tools is described as the **STONE AGE**. The Stone Age can be divided into three periods, the Old, Middle and New Stone Age.

PALAEOLITHIC (Old Stone Age – from first hominin use of stone until the end of the Pleistocene)

MESOLITHIC (Middle Stone Age – in Ireland 8000BC-4000BC)

NEOLITHIC (New Stone Age – in Ireland; 4000BC–2500BC)

(Lith=stone, BC = Before Christ)

Much of the Quaternary saw Ireland in a freezer, an environment inhospitable to humans. Sea level was low so land bridges connecting southern Britain and Ireland might have existed at some period, although not during the most recent glacial phase. Early humans were hunter-gatherers and moved around in a nomadic lifestyle. No evidence of **PALAEOLITHIC** man has yet been found in Ireland and Mesolithic sites are very difficult to find. The **MESOLITHIC** (middle stone age) inhabitants would have crossed the Irish sea on dugout canoes. They did not build major monuments like the stone tombs we get from the **NEOLITHIC** period. A team of archaeologists digging on the banks of the River Bann uncovered a site at Mount Sandel, (Co. Derry) that had potholes that contained dark soil, charcoaled remains and blackened stones. This find provided the most convincing evidence for the earliest humans in Ireland circa 10 kya for many years. Other examples of Mesolithic sites are Lough Boora, Co. Offaly, Hermitage, Co. Limerick and Fanore, Co. Clare. The latter unearthed remains of a dwelling found along with burnt seashells hazelnuts and stone axes. Recent re-examination of cave bones has provided important new evidence. A brown bear bone discovered in Alice and Gwendoline Cave, Co. Clare had marks consistent with cutting/carving, strong evidence of human presence on the island then (Figure 17). Dating of this bone suggests humans may have been in Ireland as early as 12.5 kya pushing back the dates for the first arrival by 2500 years.

Figure 17 Brown bear bone found in Alice and Gwendoline Cave, note the markings **(**Source: IT Sligo)

STONE AXES are a major feature of the archaeological evidence for Ireland's prehistory, with over 20,000 examples recorded. Nineteen 'Porcellanite' axes were uncovered on the Malone Road (the Malone Hoard) (Figure 18) in Belfast and are the most compelling evidence of human habitation in Ireland during the Holocene. Porcellanite can be formed by a range of different processes and is a very hard metamorphic rock which has a source in Co. Antrim. The rock was shaped and polished into axes in the Neolithic period and used for hunting.

Figure 18 The Malone Hoard polished stone axes (Source: Wikapedia.com)

EVIDENCE FOR A CHANGING CLIMATE

Each individual cold and warm period had unique climate conditions as well as distinctive habitats, plants and animals. The fossilized remains of plants and animals in Quaternary deposits indicate the habitat they occupied and therefore the climatic conditions of their time. Remains of mammoth, bear, giant deer and wolf have all been found by Quaternary scientists but are very rare finds. The loose, eroded material deposited in glacially scoured lakes, river valleys, estuarine deltas, and on coastal shelves in contrast is very common and contains abundant materials that can give clues about past environments. Quaternary scientists read these deposits by examining physical, chemical and biological evidence to compile an accurate picture of the climate during the Quaternary. They could be called CSI's (Crime Scene Investigators) of past environments. **ROBERT LLOYD PRAEGER (**1865-1953**)** (Figure 19) is one such CSI or 'Giant' of Quaternary science. Praeger was an expert in ecology, botany and zoology and used knowledge of contemporary patterns and processes to interpret reconstructions of past archaeology and Quaternary landscapes.

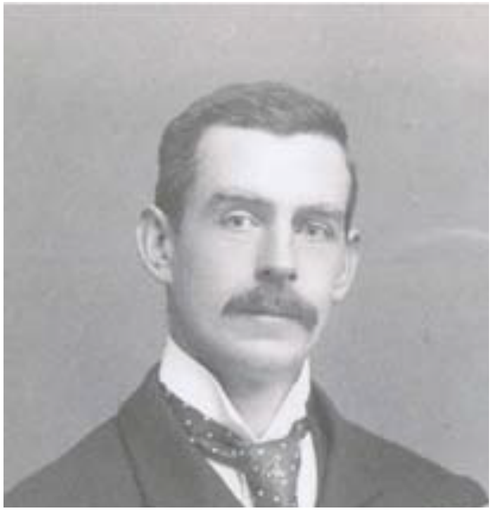

Figure 19 Robert Lloyd Praeger (1901)

Fossils

Source materials that are used to reconstruct the past include pollen from plants, single celled algae called diatoms, insect remains, shells of microscopic snail-like organisms called foraminifera. All of these sources are very common hence their usefulness and a further advantage of microscopic organisms is that they are more likely to stay intact and survive over long periods of time.

POLLEN (Figure 20) looks like a fine yellow powder and is made up of the male reproductive cells (or grains) of flowering plants such as trees, grasses, and weeds. Pollen grains have unique shapes and sculpted marks which enable identification of the host plant in the same way that leaves are used to identify trees. Analysis of the pollen found buried in Quaternary sediments suggest that during warmer climate phases Ireland's forests were dominated with oak, birch hazel, pine, elm, alder, and yew. By looking at present day environments in which these trees grow we can estimate the temperatures during the Quaternary. The scientist **FRANK MITCHELL** (1912-1997) pioneered the use of pollen to reconstruct past vegetation in Ireland. Over his career Quaternary 'Giant' Mitchell published 55 pollen reconstructions and several books, the most significant being, *'Reading the Irish Landscape'.*

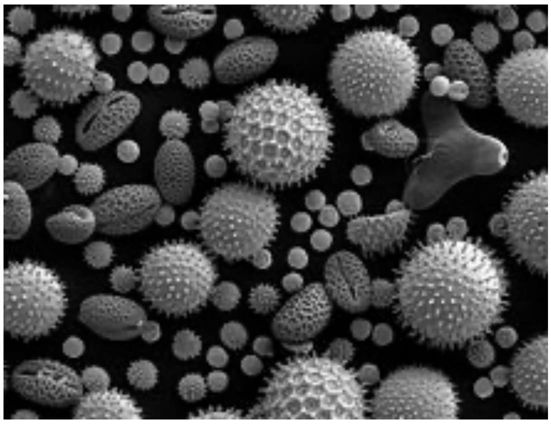

Figure 20 Pollen grains (Source: Dartmouth Electron Microscope Facility)

DIATOMS have been called 'plants with a touch of glass' (Figure 21). These microscopic plants are found in lakes and seas and make up about a quarter of plant life by weight and produce a quarter of Earths oxygen. Their uniquely patterned siliceous skeletons enable their preservation. Diatoms have additionally played an important role in conjunction with microscopy development. Their small size, distinct surface ornamentation made them the preferred test objects for microscope lenses. A Victorian popular hobby arranged diatoms in artistic assemblages on microscope slides while today diatoms have enabled reconstructions of past ocean and lake productivity as well as onset of pollution.

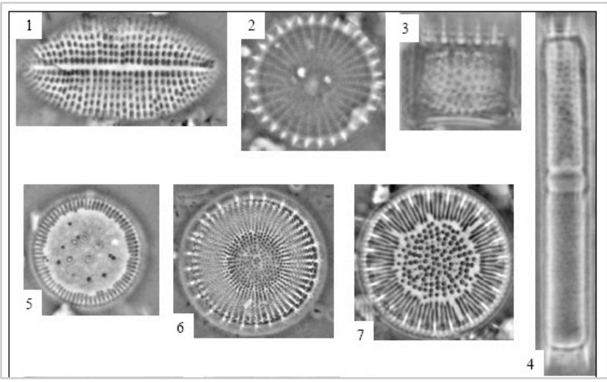

Figure 21 Diatoms (Image: G.Chen)

FORMAMINIFERA are tiny marine organisms that have tests or shells made of calcium carbonate ($CaCO_3$) which aids their preservation for thousands of years in ocean sediments (Figure 22). There are an estimated 4,000 species that float in the water, live on or in sand, mud, rocks and plants at the bottom of all oceans. They can be very particular about the environment in which they live, whether deep ocean, coral reefs brackish estuaries or intertidal salt marshes and thus the temperature and nutrient conditions. Because of their particular environmental preferences and their abundance and ability to fossilise they are good **INDICATORS** of past environments.

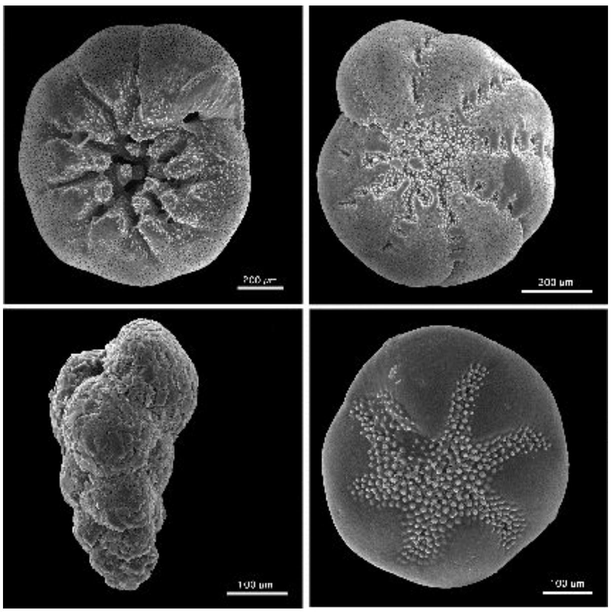

Figure 22 Foraminifera test (Source: Wikipedia)

__Ice Cores__

Much of the evidence for the climate during the Quaternary has come from glacier ice in Antarctica. Ice laid down over hundreds of thousands of years has been drilled. The **ICE CORES** have been analysed to examine records of global climate 800,000 years ago by measuring **CARBON DIOXIDE (CO_2)** levels in air bubbles trapped within the ice cores. CO_2 levels can be used to give us an idea of climate as CO_2 is a greenhouse gas, good at absorbing the suns heat. Higher CO_2 levels in the atmosphere suggest a period of global warming. During the last glacial phase, the CO_2 level in the atmosphere was roughly 180ppm. Compare that to todays which is 410ppm, although not as high as CO_2 levels in the deeper geological past.

__Isotopes__

Microscopic organisms such as foraminifera use **OXYGEN** dissolved in ocean water to build their shells. Oxygen has 3 **ISOTOPES** (atoms that are either missing or have extra electrons), ^{18}O, ^{17}O and ^{16}O . Two of these isotopes are useful in determining temperature; ^{18}O is the heavier of the two isotopes and is less easily evaporated, so remains in the same quantity in the oceans while ^{16}O is lighter and so is more easily evaporated.

During glacial periods, the ratio of ^{18}O to ^{16}O ratio is higher as the lighter oxygen isotope is evaporated and not returned to the sea as it is locked within ice sheets. When the climate warms the ice sheets and glaciers melt and the ^{16}O is released back into the sea, so the ratio of ^{18}O to ^{16}O decreases (Figure 23). Foraminifera shells are composed of $CaCO_3$ so the measurement of these two oxygen isotope ratios from these small organisms can be used to infer water temperatures in the past. ^{18}O to ^{16}O ratios can also be measured from air bubbles trapped in ice cores.

Interglacial	Glacial
During interglacials temperatures are higher. 0_{16} gets evaporated but falls as rain that is returned to ocean. ^{18}O to ^{16}O ratio is low.	During glacials temperatures are lower. 0_{16} gets evaporated but falls as ice that is locked in glaciers so in the ocean ^{18}O to ^{16}O ratio is high.

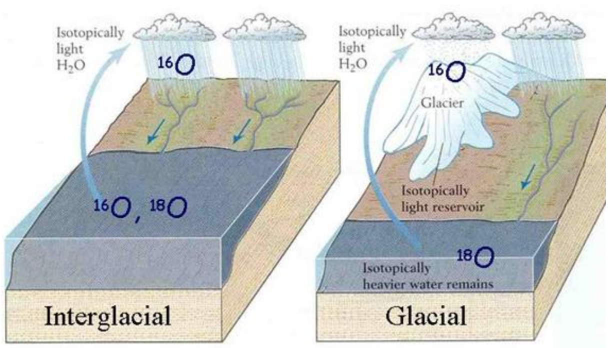

Figure 23 The changing ratio of oxygen isotopes (Source: https://globalchange.umich.

Volcanic Ash

Volcanic ash or **TEPHRA** studies have become increasingly important in Quaternary research providing detailed evidence for palaeoenvironmental and archaeological research. Tephra is a Greek word meaning 'ash' (Figure 24). Ash plumes are ejected and dispersed into the atmosphere after a volcanic eruption. Tephra from the Eyjafjallajökull volcanic eruption in Iceland in 2010 grounded flights across Europe. Lightweight tephra has been dispersed and deposited over wide geographical areas throughout the Quaternary period. Tephrochronologists look for ash layers in sediment deposits (peat and lake sediment) and are able to fingerprint these layers through microscopic and chemical analysis and link them to different volcanic eruptions during the Quaternary period. These layers with their unique chemical fingerprint allow scientists to date, link and establish relationships across geological, palaeoenvironmental, or archaeological deposits or events.

Quaternary 'Giant' **VALERIE HALL** (1946-2016) initiated the first studies of Icelandic volcanic ash deposits in Ireland. Some 35 different ash layers have been identified in Ireland to-date, each from a different volcanic eruption (Figure 25).

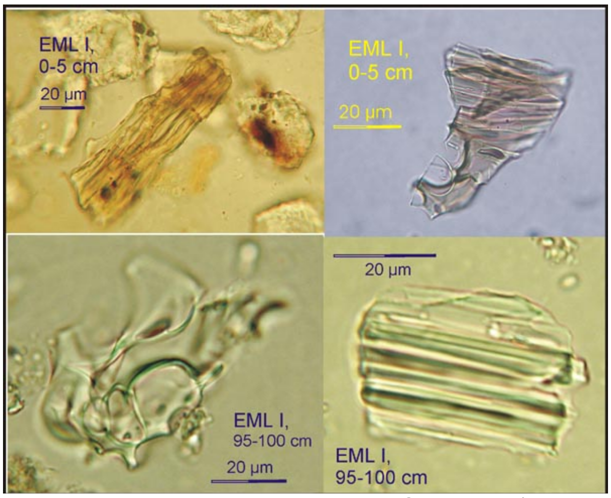

Figure 24 Tephra shards, Emlagh Bog Co. Meath (Image: M.oConnell)

Dating

The age of Quaternary sediment can be dated using several different scientific methods such as **INCREMENTAL** or **RADIOMETRIC** dating. Incremental methods involve measurements of regular accumulations of sediment or biological materials through time. For example, a continuous record of seasonal and annual climate change has been established using tree rings (**DENDROCHRONOLOGY**) and covers the past 7300 years. Records can also be developed using lake sediment layers and ice cores. Radiometric methods are based on the radioactive decay of certain unstable element isotopes (e.g. carbon and uranium). **RADIOCARBON DATING** can be used to date deposits that contain wood, shells or bones up to c. 40 kya. Uranium methods determine much longer geological time periods because it has a much longer half-life.

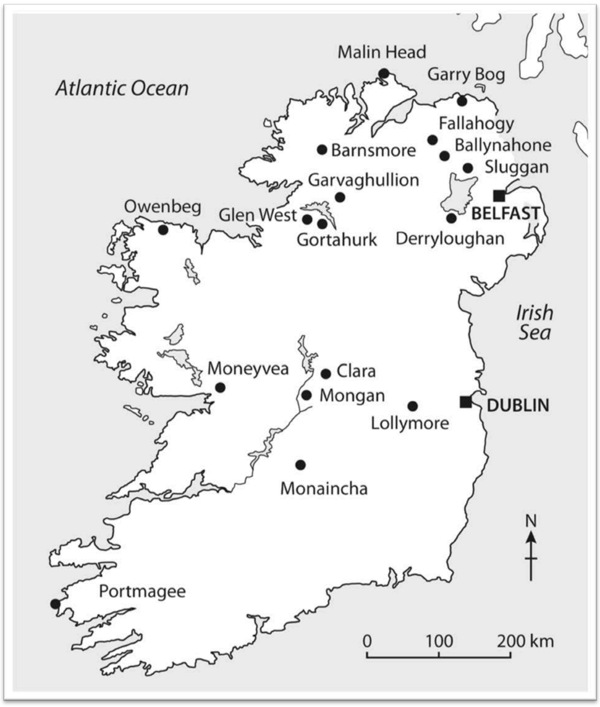

Figure 25 Distribution of some Irish Tephra layers (Hall and Pilcher 2002, The Holocene)

Useful resources for teachers and students

Antarctic Glaciers www.antarcticglaciers.org
British Geological Survey
https://www.bgs.ac.uk/discoveringGeology/geologyOfBritain/iceAge/
Encyclopaedia Britannica
www.britannica.com/science/Quaternary#ref260439
Fossils www.fossils-facts-and-finds.com
Geological Survey Ireland Schools
page: http://www.gsi.ie/education/
Geology for schools in Ireland geoschol.com/ireland.html
Irish Quaternary Association www.iqua.ie
Quaternary Research Association
https://www.qra.org.uk/educational-resources