AGSO

Geoscience Education

Climate Change

Throughout Earth History

Teacher Notes and Student Activities

by Gary B. Lewis

Record No. 1995/21

AGSO

AUSTRALIAN
GEOLOGICAL SURVEY
ORGANISATION

Climate Change

Throughout Earth History

Teacher Notes and Student Activities

Gary B. Lewis
1995

Further Information : (06) 249 9570

Record No. 1995/21

Supported by

Science and Technology Awareness Program

Administered by the Department of Industry, Science and Technology

DEPARTMENT OF PRIMARY INDUSTRIES AND ENERGY
Minister for Resources: Hon. David Beddall, MP
Secretary: Greg Taylor

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION
Executive Director: Dr Neil Williams

AGSO Record No. 1995/21
ISSN: 1039 - 0073
ISBN:0 642 22334 3

Developed and Written by: Gary Lewis

Scientific Advice : Elizabeth Truswell

Other Education titles in this Series include
Earthquakes -- Student Activities
Volcanoes -- Teacher Notes and Student Activities
Time & Life -- Teacher Notes and Student Activities
Plate Tectonics -- Teacher Notes and Student Activities
Silicate Chemistry -- Teacher Notes and Student Activities
Australian Earthquake Slide Set

For information and sales call the AGSO Sales Centre on (06) 249 9519

Table of Contents

Climate Change

The modern debate on Climate Change is really about human impact on the Earth's dynamic changing climate. The Earth's climate is continually changing, fluctuating between ice ages and warmer periods, the evidence for which is recorded in the rocks making up the Earth's continents. These past climates are known as *palaeoclimates*.

To gain a better appreciation of the effects human activity will have on our climate, we should have an understanding of the Earth's climate over geological time. This booklet will provide you with information and activities which will help you to include this information in your teaching of climate and climate change.

1. Climate

We are all used to term "weather" as it affects us all every day. Stormy, rainy, fine, showers, hot, windy, humid are all words that we hear used to describe the short term, normal day-to-day, atmospheric conditions which prevail at a given place at a given time.

Climate can be considered as the "average weather" of an area over a much longer time span, often hundreds or thousands of years.

The Earth's climate can be seen as a simple system (Figure 1.) into which there are a number of inputs (solar radiation, position of the earth in space, carbon dioxide etc.) which are processed by the system (interactions between the atmosphere, oceans and the land) producing a number of outputs (climate variations).

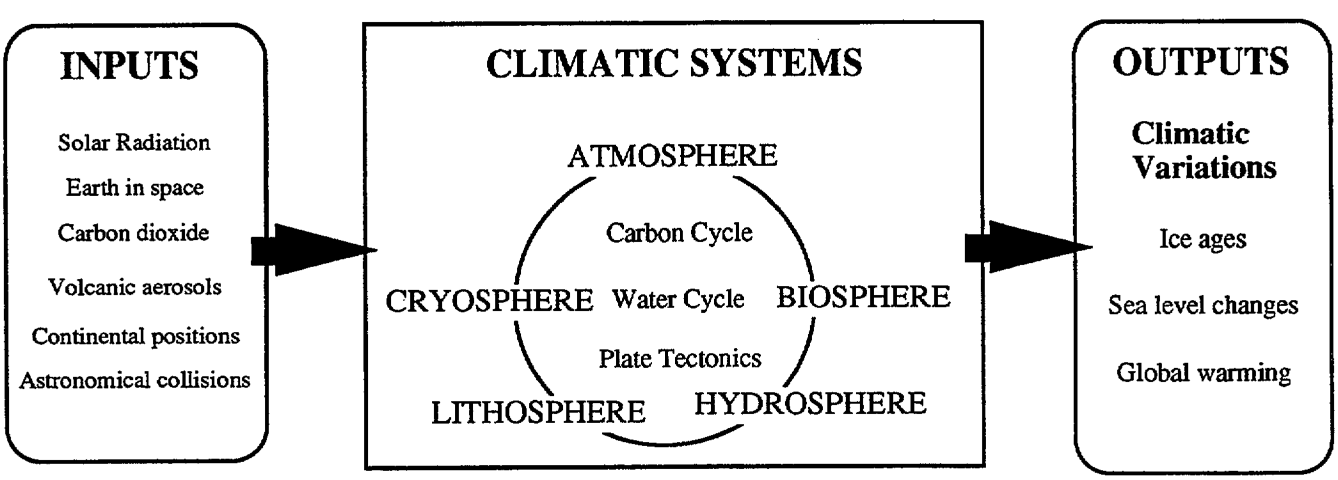


Figure 1. The Earth's Climate System

2. Climatic Inputs

The major inputs for the Earth's climate are solar radiation, the position of the earth in space, carbon dioxide in the atmosphere and the position of the continents. Some other inputs are volcanic aerosols and collisions with meteorites. None of these can be considered in isolation as it appears that only when these inputs "vary" together can they produce long term climatic changes.

2.1 Solar Radiation

The total amount of radiant energy reaching the Earth from our Sun plays a significant role in Earth's climate. The amount of solar energy which reaches the Earth every minute is about equal to the total amount of electrical energy which is generated on Earth every year. (The amount of energy humans *use* each day is actually only about 10^{-4} of the rate of solar energy reachng the Earth's surface). The release of solar energy from the Sun is thought not to have been constant over time although exactly what changes occur is not clearly understood.

One sun cycle which has been well documented is that of sun spots. Records of sun-spot activity have been collected since about 1700 and show a cycle of 11 years. This sun spot activity releases more particles as part of a stream of material known as the *solar wind.* An increase in solar wind is associated with a small decrease in radiation. This could affect the heating of the upper atmosphere.

More important is the effect of the shape of the Earth on the amount of radiation which falls on any given area of the Earth's surface. (Figure 2.)

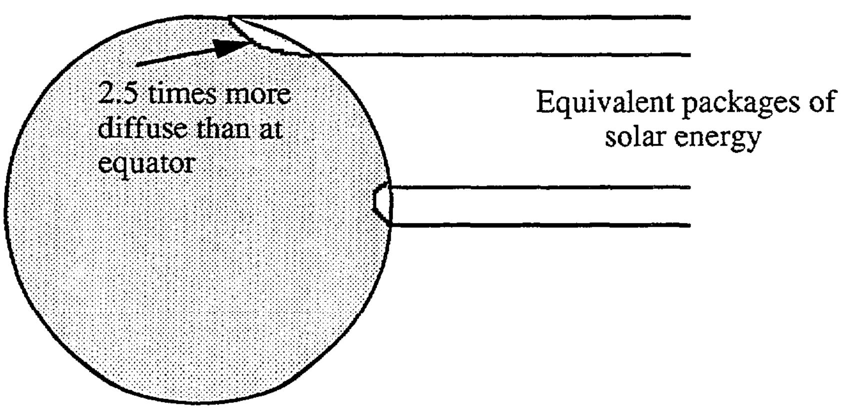


Figure 2. Solar energy hitting the Earth

While the same amount of energy reaches all parts of the Earth's atmosphere, when the energy is spread over the Earth's surface, due to the angle of incidence, the energy becomes diffused. At the equator the diffusion is least and at the poles the diffusion is greatest. Obviously changes in the Earth's tilt through the seasons also affects the diffusion. For example, during the southern hemisphere summer, the North pole does not even face the sun and therefore is in 24hr darkness. The least diffuse zone on Earth during this time is around the Tropic of Capricorn.

Also, the shape of the Earth (valleys and mountains) will affect the amount of time and diffusion of energy in local areas. For example, in the Snowy Mountains the snow lasts longer on the south east and southerly facing slopes than on the north or westerly slopes due to the amount of sun reaching these slopes.

The type of material on the Earth's surface also influences the amount of solar radiation that is absorbed or reflected back into the atmosphere. This is referred to as the *albedo* effect. A mirror has 100% albedo as it reflects 100% of light. Snow has an 80% albedo, forest 15-20%, desert 25-30, ocean at noon 5%, ocean at dawn 40%. The reflected radiation is either trapped in the atmosphere or reflected back into space.

2.2 Earth in Space

A Yugoslav engineer, Milankovich, suggested in the 1940s that the movement of the Earth through space had, and will, affect climate. The *Milankovich model* refers mainly to three astronomical cycles.

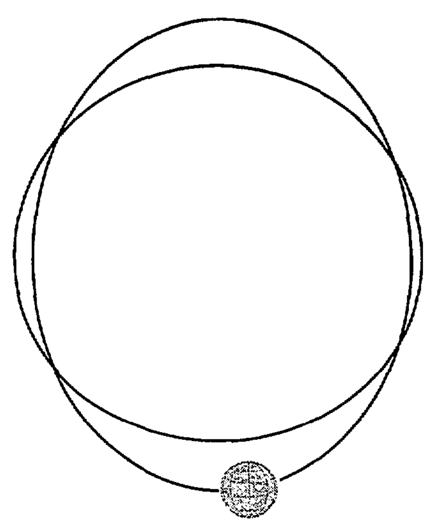


Figure 3. The Earth's orbital patterns - circular to elliptical.

The first cycle is the variability or eccentricity of the Earth's orbit which ranges from nearly circular to more elliptical (Figure 3.) and back every 90,000 to 100,000 years.

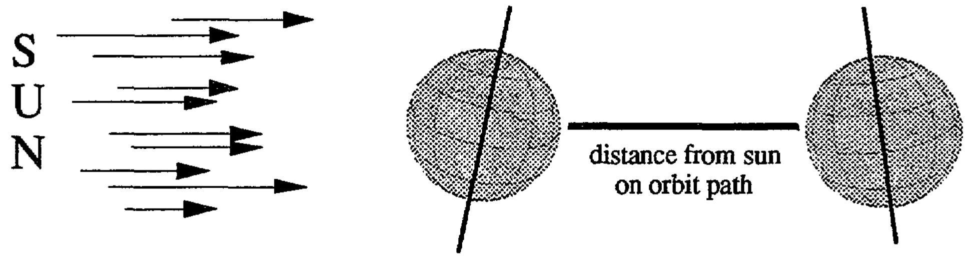


Figure 4. Longitude of Perihelion - present situation.

The second cycle refers to the position of the Earth when it is closest to the sun referred to as the *longitude of perihelion* (Figure 4.) At the present time, the Earth is closest to the sun in its orbit during the southern hemisphere's summer and furthest away from the sun during the northern hemisphere summer (our winter). This changes every 10,000 or so years, making the complete cycle around 21,000 years.

The third cycle refers to the "lean" or *obliquity* of the Earth on its axis (Figure 5.). This lean changes the Earth's tilt from 21.8° (closest to upright) to 24.4° (most inclined). The full cycle from 21.8° back to 21.8 ° takes about 40,000 years.

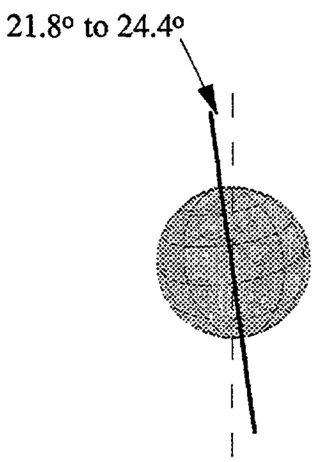


Figure 5. Earth's axial tilt

At the present time the earth's orbit is nearly circular and becoming more circular, the longitude of perihelion gives the southern hemisphere warmer summers (and cooler winters) than the northern hemisphere and the obliquity is decreasing tending to decrease the differences between the seasons.

2.3 Carbon dioxide

The atmosphere presently contains around 2.3 X 10^{12} tonnes of carbon dioxide which is about 353 parts per million in volume. This gas is important in the atmosphere (along with other minor gases such as methane and nitrous oxide) as it absorbs the radiation reflected from the Earth's surface. This "traps" some of the heat which would normally escape back into space.

Carbon dioxide in the atmosphere is normally in equilibrium with dissolved carbon dioxide in the oceans and organic compounds derived from atmospheric carbon dioxide through the photosynthesis process in plants.

Volcanic activity releases carbon dioxide, as well as other gases, into the atmosphere. It is estimated that on average 90,000 million kilograms of carbon is released as carbon dioxide by volcanoes every year.

Recent measurements suggest that the current day concentration of carbon dioxide is around 25% greater than in the atmosphere before the Industrial Revolution (1750-1800). This increase is caused mainly by the release of carbon dioxide through the burning of fossil fuels and the removal of vast tracts of the Earth's forests (deforestation) greatly reducing the Earth's photosynthesis machine.

2.4 Volcanic Aerosols

Of all the gases released by volcanic eruptions, sulphur dioxide is particularly important. During an eruption vast amounts of sulphur dioxide are injected into the atmosphere where, over a period of hours to weeks, it reacts with water to form liquid aerosol particles of sulphuric acid.

Aerosol particles are a natural phenomenon and are normally only a few microns (thousandths of a millimetre) in diameter. The larger aerosol particles may settle out of the atmosphere in a few weeks, but the smaller aerosol particles can remain in the stratosphere for two or three years - long after the ash and pumice of the same eruption have settled onto the Earth's surface.

Volcanic aerosols produce a number of effects on the Earth. The most visible of these are the post-eruptional optical effects such as vividly coloured sunsets, altered colours of celestial bodies (stars and planets), dulled starlight, rings around the sun (known as "bishop's rings after Sereno Bishop who first reported them from Hawaii) and coloured twilight afterglows. These effects were once attributed to the volcanic "dust" but are now known to be caused not by solid particles, but by the tiny acid aerosol droplets.

The existence of volcanic aerosols forming layers in the upper atmosphere was first pointed out by an American atmospheric scientist, Christian Junge, in 1961. The aerosol layer - sometimes called the Junge layer - is not a permanent feature but exists only after periods of volcanic activity. During volcanically "quiet" periods the stratosphere may become clear of the volcanic acid droplets.

Not all volcanic aerosols end up in the stratosphere. Those which form from non-explosive volcanism can also form dry volcanic fogs close to the Earth's surface.

2.5 Continental positions

Continentality refers to the affect on the climate due to the amount of land mass surrounding, or the distance from the ocean, of any given area. Areas of large landmass are characterised by very large annual temperature ranges. Areas close to the oceans have their temperatures moderated by the oceans.

Figure 6. Present positions of the Earth's continents (excludes Antarctica)

The current position of the majority of the Earth's landmass is in the northern hemisphere (Figure 6.). In this configuration the area most affected by continentality is the large Asian landmass.

2.6 Astronomical Collisions

The collision of an object, such as an asteroid or comet, with the Earth can cause rapid changes to the Earth's climate. While the chances of these are small, there is evidence on almost all continents of impacts.

The Wolfe Creek Crater, located near Halls Creek in Western Australia, is the result of the impact of an iron meteorite with Earth about 300,000 years ago (Figure 7.). The structure is 853m in diameter and 61m deep. This crater is the second largest authenticated meteorite crater in the world. Meteorites moving at 75,000 kilometres per hour have been observed by astronomers.

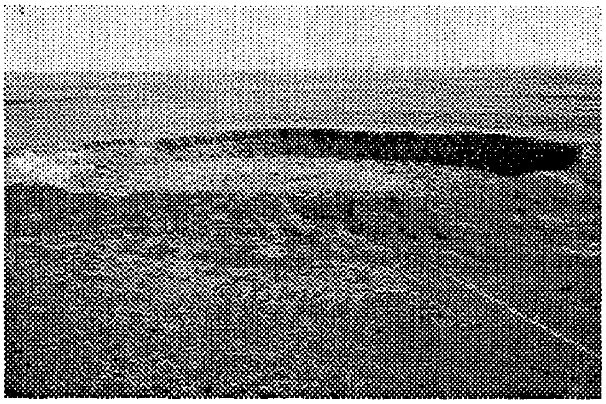


Figure 7. Wolfe Creek Crater, WA

While rare, when these meteorites impact with the Earth they throw vast amounts of dust into the atmosphere and send destructive seismic waves around the Earth. Evidence exists that ancient meteorite strikes have catastrophically altered the Earth's climate causing animals and plants to become extinct.

3. The Earth's Climate Systems

The Earth's climate is a system in which the atmosphere, hydrosphere (oceans, rivers lakes), cryosphere (icesheets and glaciers), biosphere (plants and animals) and lithosphere (Earth's crust) interact. The main cycles which occur in the system are :

The Hydrological (water) Cycle
The Carbon Cycle
The Plate Tectonic Cycle

3.1 The Hydrological Cycle

The Hydrological Cycle refers to the movement of water between the hydrosphere (oceans, river and lakes), biosphere (plants and animals), lithosphere (rocks, groundwater), cryosphere (icecaps, icesheets and glaciers) and the atmosphere. In its simplest form, the cycle involves the evaporation of water from the oceans, or transpired by plants, into the atmosphere where it is transported by atmospheric circulation until it condenses to form cloud droplets. When the droplets become too heavy to be held in the clouds they precipitate, as either a liquid (rain) or solid (hail, snow) on to the Earth's surface. If the precipitation occurs on land, the water either infiltrates into the soil and rocks or runs-off into the rivers and back into the ocean to complete the cycle. The whole process is driven by energy from the sun (solar radiation). The cycle is shown in Figure (8).

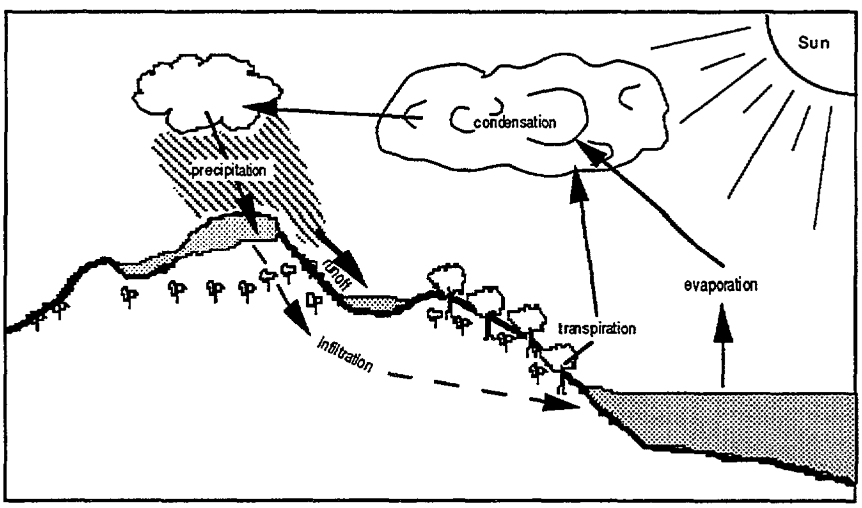


Figure 8. The Hydrological Cycle

The processes in the cycle are affected by any changes in the hydrosphere (i.e. temperature, ocean currents), biosphere (i.e. removal of large tracts of vegetation), lithosphere (i.e. the location of continents, height of mountains) and the atmosphere (i.e. temperature).

3.2 The Carbon Cycle

The Carbon Cycle refers to the movement of carbon between the hydrosphere, biosphere, the lithosphere and the atmosphere (Figure 9). The cycle involves two sub-systems - the organic carbon cycle and the carbonate cycle.

The organic carbon cycle refers to the cycle of carbon within life processes. Carbon dioxide is taken from the atmosphere by plants in photosynthesis and converted to carbon compounds (simple sugars). The plant, or animal which consumes the plant, will either convert these simple carbon compounds to more complex carbon compounds or consume them in cellular processes and release carbon dioxide back to the atmosphere through respiration.
Sometimes, in special geological conditions, plant and animal carbon-bearing material is preserved in the rocks and large accumulations may become coal or oil reserves. In these cases the carbon in removed from the cycle for millions of years.

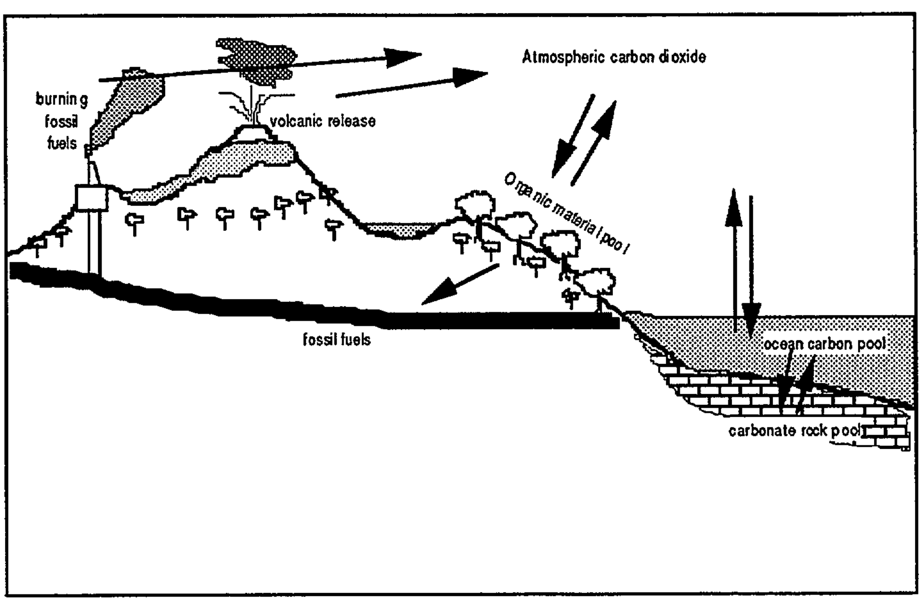


Figure 9. The Carbon Cycle

The carbonate cycle refers to the cycle of carbon in non-cellular (ie not carbon-hydrogen-oxygen) processes. Carbon dioxide in the atmosphere is in equilibrium with carbon dioxide in the oceans. The carbon dioxide in the oceans combines with dissolved calcium, to form calcium carbonate minerals. This mainly involves a plant or animal producing shell materials (less common is straight chemical precipitation). This material "rains" down onto the sea floor eventually becoming locked up in sedimentary rocks. The oceans hold vast amounts of dissolved carbon dioxide and act as a carbon dioxide "bank". In comparison, the atmosphere holds only a small amount of carbon dioxide.

Human activity since the Industrial Revolution has added another factor to the carbon cycle through the release of carbon into the atmosphere by the burning of fossil fuels.

3.3 The Plate Tectonic Cycle

The Plate Tectonic theory states that the Earth's crust is broken into about 12 rigid plates which slide over a semi-molten or plastic layer of the mantle. There are three main types of plate boundaries :

1. Spreading or divergent boundaries - where plates are moving apart
2. Transform fault boundaries - where plates are moving past each other
3. Subduction or convergent boundaries - where one plate overrides another plate

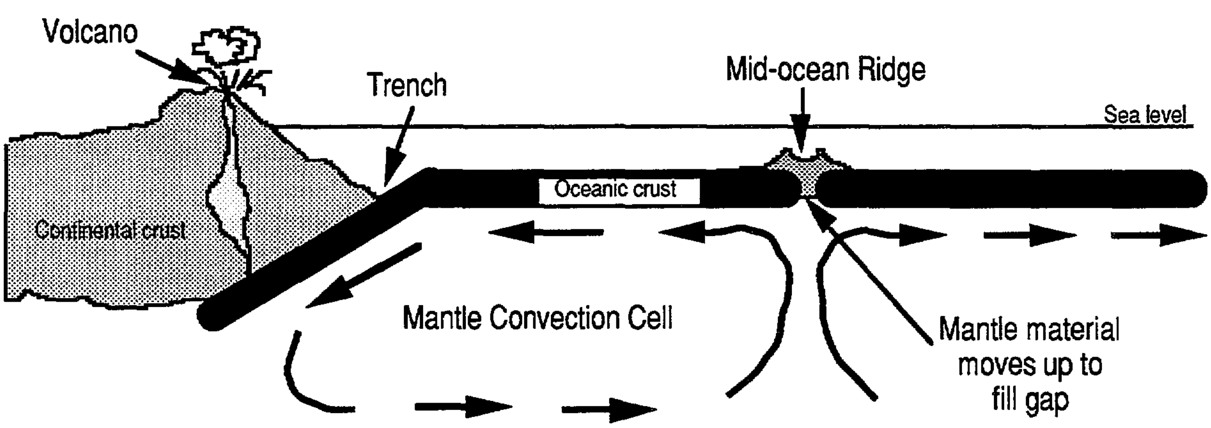


Figure 10. Plate Tectonic Model

Each plate is bounded by some combination of these three plate boundary types. The driving force for plate tectonics is thought to be slow moving convection currents in the underlying plastic mantle material. (Figure 10)

The cycling of the Earth's crust over millions of years has changed the shape and size of the ocean basins as well as changing the location and shape of major mountain ranges. Over time, the Earth's continents have clumped together then been dragged apart. These changes, while taking millions of years, have had a profound effect on climate through the direct changes to the atmosphere caused by volcanic eruptions, through the changes in ocean circulation and through changes in sea-level linked to the sea-floor spreading process.

4. The Role of the Oceans in Climate

The oceans currently make up about 71% of the Earth's surface and play an enormous role in influencing the Earth's climate.

4.1 Oceans as a heat bank

The oceans act as an energy sink, in which solar energy is stored as heat and transported by currents around the planet. Ocean's are however slow to respond to external changes and it may take months or years for surface waters to respond and centuries for water in the deep oceans.

The oceans heat up in the topics due to the intensity of the sun and transport this heat towards the poles as surface currents. At the poles this water cools, sinks and moves back towards the equator to complete the cycle. This transportation of heat is complicated by the blocking of the ocean currents by continental masses and the interactions between converging currents.

Off the east coast of Australia two main ocean currents, one made up of warm water from the mid-Pacific and one made up of colder water from the Tasman Sea, meet and move towards the east. This zone in which the two currents are moving in the same direction is referred to as the Tasman Front (Figure 11.).

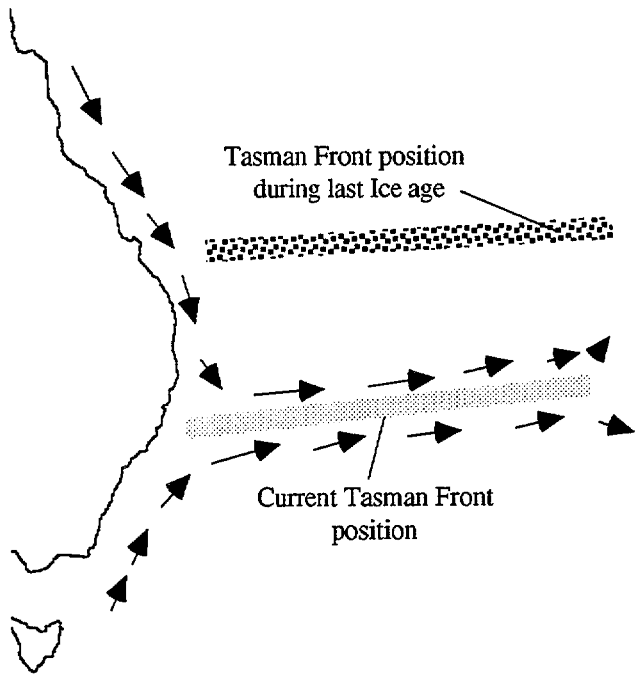


Figure 11. Position of Tasman Front - East Coast Currents

During the last ice age, usually refered to as the Last Glacial Maximum (LGM), the position of the currents, and therefore the Tasman Front, was much further to the north. This climatic driven change in the ocean currents would have produced a cooling effect on the NSW Coast where the warm waters normally would have reached, but which were now under the influence of colder waters from the Tasman Sea.

The intensity of ocean circulation is directly related to the world wide climatic conditions of the period. During cold phases the gradient in temperatures from the equator to the poles is greater and therefore the circulation is intense. During warm periods the difference in temperatures between the equator and the poles is less and the ocean circulation is weaker.

4.2 Moving continents and Ocean circulation

Changes to the way the ocean currents move around the Earth's surface, mainly because of the location of the continents, can greatly affect climate.

Currently the oceans are most extensive in the southern hemisphere while land mass dominates the northern hemisphere. This has not always been the case. The Earth's continents are continually being divided and rejoined through the Plate Tectonic Cycle. As a result, massive changes in the circulation of the oceans take place as ocean basins are joined or isolated from each other.

Up to the Jurassic (170 million years ago), when dinosaurs roamed the planet, the Earth had one major landmass or supercontinent which geoscientists refer to as Pangaea. Pangaea started to break up during the Jurassic because of underlying mantle currents and by the middle of the Cretaceous (100 million years ago) it had formed two main land masses, with what we now call Australia, Antarctica, India Africa and South America joined together to form a massive southern land mass called Gondwana. The continuing break-up of Gondwana in the Tertiary (50 million years ago) led to the present positions of the continents.

For Australia, this movement had two effects on the climatic factors. Firstly the continent moved northwards towards the equator, and continues to move northwards at around 6cm a year. Secondly, the movement separated Australia from Antarctica, opening up the Southern Ocean and allowing ocean currents to flow completely around Antarctica.

The isolation of Antarctica by the movement of all the other Gondwana landmasses northwards allowed a circum-polar current to develop. This current of cold water blocked the movement of warmer waters moving southwards from the pole to reach Antarctica and cold waters moving northwards. With Antarctica isolated from the warmer waters, the landmass started to develop a thick icecap which dominates the current landscape.

4.3 Carbon sink

The oceans also play a role in the chemical balance of the atmosphere. Because of the vast amounts of carbon dioxide contained in the oceans in solution, small changes in the balance between the ocean's carbon dioxide and the atmosphere may play an important role in the Earth's natural buffer to changes in atmospheric chemistry. Again, the ocean response to changes in atmospheric carbon dioxide is very slo; however in the short term, they take up far more carbon dioxide than they release.

4.4 Sea Level Changes

Sea level changes have taken place throughout geological time. These changes are known because of the remains of coastal features, such as beaches, sand dunes etc., either well above or below the current level of the oceans.

Measuring the height of past sea level can be done in two ways - *gauge sea level* and *relative sea level.* Gauge sea level refers to absolute level of the oceans relative to a fixed point, such as the centre of the Earth, which is not affected by surface processes. Relative sea level refers to the "relative" level of the ocean compared to a point on land. Most discussion of sea level changes, especially recent changes, refers to relative sea level.

The absolute amount of water in the oceans can be affected in a number of ways. The largest change is due to the holding capacity of the ocean basins. Mid ocean ridges occur in almost all of the Earth's ocean basins. These volcanic ridges represent places where two tectonic crustal plates are moving apart, the gap between them being filled with hot mantle material. The new ocean floor at these zones is relatively higher than the surrounding ocean floor due to heat expansion of the crust. As the zone spreads the rocks cool and contract therefore sinking back to the lower ocean floor depths. The rate of the spreading of the two plates determines the size of the ridge. An increase in the rate will widen the ridge as hot rocks are moved away from the spreading zone before having time to contract. This acceleration can lead to the holding capacity of the ocean basin decreasing and therefore a rise in sea level. Conversely, if the spreading rate decreases, the ridge narrows and the holding capacity of the ocean basin increases and sea level drops. These changes in ocean basins takes place over many hundreds of millions of years. A major episode of sea-floor spreading took place in the Cretaceous Period causing many areas of Australia to be covered in ocean. These ocean sediments now form the aquifers in the major Australian groundwater basins.

Figure 12 . Changes in sea level over the last 140,000 years (adapted from Beckman 1994)

Another major contributor to the absolute amount of water in the oceans is the growth and melting of land ice. Evaporation of water from the warm oceans in the tropics which is later deposited as ice and snow on land in the polar regions can cause world-wide sea level changes. This ice and snow traps water for thousands of years. As the temperature of the Earth falls as it goes into an ice age, the amount of precipitation at the poles increases causing a slow fall in sea level at around 1m every 1,000 years. Rapid cooling and associated expansion of land ice can cause rapid sea level changes of up to 10m every 1,000 years. The last ice age saw sea levels drop to between 120-150m. The end of glacial periods are more rapid with the associated rises in sea level taking place at even greater rates.

Global warming may increase the melt of land ice and therefore cause a sea level rise. However, initial warming would increase evaporation and precipitation and thus increase global ice reserves.

The melting of sea ice does not have the same effect as the melting of land ice. Sea ice floats on the ocean surface with approximately two thirds submerged and one third above sea level. Because water expands when it freezes, the amount of water displaced by the two thirds under water is equivalent to the volume of "water" in the entire piece of ice. The melting of sea ice would therefore have no effect on sea level.

Place an ice cube in a glass of water then mark with an overhead pen the water level. As the ice melts, check the water level - it will stay the same!

During an ice age, the weight of the ice on land is so great that it causes the continental crust to be pushed down into the underlying mantle. At the same time the ocean basins which are holding less water rise up. This change in the relative positions of the continents due to the weight of ice is known as *glacio-isostatic* adjustment. The effect of the adjustment is that the sea level, in relation to the "sinking continent", appears to rise. At the end of the ice age, the ice mass melts and the continents undergo *glacio-isostatic rebound* where the continents rise and the relative sea level falls. These glacio-isostatic changes make study of sea level changes complex, especially in areas which were under ice sheets during the ice ages.

During the Quaternary Period ice ages, the Earth's geography was altered due to the lowering of sea level to around 150m below current sea level (Figure 12). This caused the development of land bridges. The Australian mainland was connected via these land bridges with Papua New Guinea and Tasmania. These bridges allowed the free movement of people between these previously isolated regions. Also during this time The Great Barrier Reef was exposed. The top of the reef became pitted with caves which collapsed in. These caves filled with water as the sea levels rose and are now seen as "Blue Holes" in the reef from the air.

4.5 Atmosphere-Ocean interaction
El Nino - Southern Oscillation (ENSO)

ENSO is a climatic phenomenon which effects Australia and much of Southern Asia. For the majority of the time atmospheric circulation occurs in a regular pattern over the Pacific Ocean. Hot moist air rises to around 12km over the tropical region around Indonesia/North Australia and moves eastwards. At this height it cools losing most of its moisture. The now cool dry air descends on the eastern side of the Pacific near the coast of Peru. The air then moves back over the surface of the ocean, gathering moisture and increasing in temperature until it reaches the Indonesian/North Australia region where it begins to rise again to complete the circulation cell. (Figure 13)

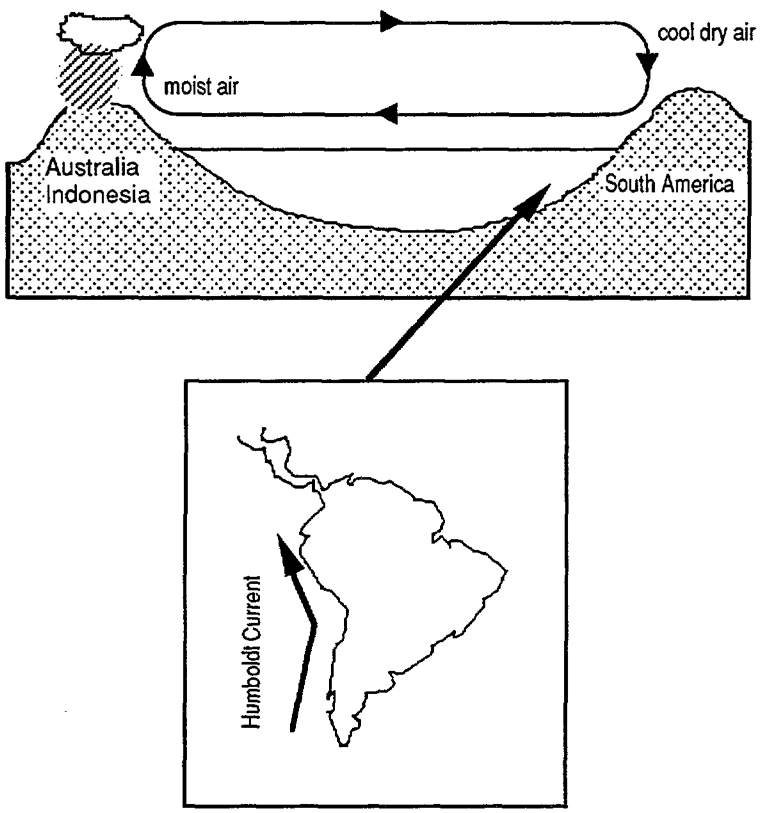


Figure 13. "Normal" Pacific Ocean atmospheric circulation and Humboldt Current flow

This atmospheric circulation means that the Indonesian/North Australia region receives rainfall associated with the rising moist air, while the Peru coastline is usually dry because of the descending cold dry air. Also, the cool air falling over Peru keeps the temperature of the ocean cool. The air moving between Peru and Indonesia across the ocean surface pushes the ocean surface causing surface currents to move in the same direction.

Also, a cold nutrient-rich deep ocean current, known as the Humboldt Current, upwells and flows up the coast of South America until it reaches northern South America where it mixes with warmer waters. This cold current provides the South American fishing industry with abundant catches.

For reasons not yet understood, every few years the temperature of surface waters of the Pacific ocean around the Indonesian/North Australia region decreases by a few degrees. At the same time the surface waters near Peru increase a few degrees. This temperature change is enough to interrupt the normal atmospheric circulation and cause smaller circulation cells to develop in an opposite direction (Figure 14). The result of this is to cause the Indonesia/North Australian region to become dry (drought), while the Peru coast to become wet - sometimes over 300 times their normal rainfall!.

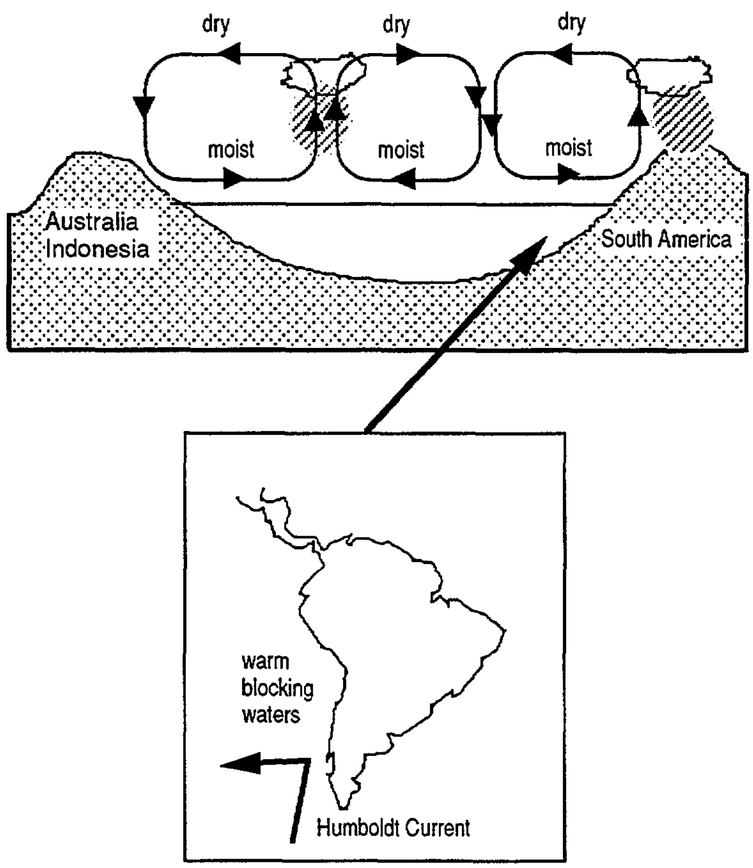


Figure 14. El Nino Effect Pacific Ocean atmospheric circulation and Humboldt Current flow

This has a huge effect on agriculture in both regions. At the same time, the warm water off Peru diverts the Humboldt Current, reducing the fish catches on the Peru coast.

This phenomenon occurs every 2-7 years.

5. Climatic Evidence

Scientists use a range of evidence to find out about past climates and factors that may have influenced climate. The evidence can be placed into the following groups :

- Stable Isotope studies
- Fossils
- Palaeomagnetism
- Ice cores
- Glaciers
- Speleothems
- Tree rings
- Written records

5.1 Stable Isotope evidence

The nucleii of atoms are made up of protons and neutrons. The *atomic number* of the atom refers to the number of protons, while the term *atomic weight* refers to the average number of protons and neutrons. The atomic weight is an average because some atoms of the one element can be found with a differing numbers of neutrons. These are known as isotopes of the element. Isotopes can be stable or unstable, that is they break down releasing or gaining a neutrone. In palaeoclimate studies, stable isotopes are an important tool.

The water molecule, the most abundant molecule on the Earth's surface, is made up of the isotopes of oxygen and hydrogen. Oxygen can have eight, nine or ten neutrons giving three stable isotopes of atomic weights 16,17 and 18 (^{16}O, ^{17}O, ^{18}O). In nature these isotopes occur in the following relative proportions:

^{16}O	99.76%
^{17}O	0.04%
^{18}O	0.20%

Hydrogen has two stable isotopes, ^{1}H and ^{2}H (known as deuterium or D). The relative proportions of these isotopes in nature are :

^{1}H	99.984%
^{2}H	0.016%

Water molecules can form from any combination of these atoms. As a result, water molecules can have a molecular weight range from 18 to 22.

$$\text{i.e. molecular weight } 18 = {}^{1}H_2{}^{16}O$$

$$22 = {}^{2}H_2{}^{18}O$$

The proportions of the heavier isotopes of hydrogen and oxygen means that only four heavy isotope water molecules are common, and only two of them are used in palaeoclimate studies. These are :

$${}^{1}H^{2}H^{16}O \text{ (known as HDO) and } {}^{1}H_2{}^{18}O$$

The energy used to evaporate "light" isotope water is less than that used to evaporate "heavy" isotope water. Evaporation therefore tends to produce water vapour which contains proportionally lighter isotopic water molecules than the original liquid water. The remaining liquid water after evaporation is therefore more concentrated in the heavier water molecules. (Figure 15.)

So, when water evaporates from the surface of the oceans, the atmospheric water vapour is "light" and the remaining oceanic water is "heavy" (in relative terms).

Evaporation, as well as condensation, is reliant on temperature. At any given temperature, the amount of evaporation (and condensation) of water from (and to) the oceans will be different.

In a stable regime, the evaporated "light" water will eventually condense, precipitate and runoff back to the oceans. This maintains an equilibrium in the amount of heavy and light water molecules between the atmosphere and the oceans. However, if the temperature changes the amount of evaporation (or condensation) will change and effect the equilibrium, changing the overall isotopic composition of sea water and of water in the atmosphere.

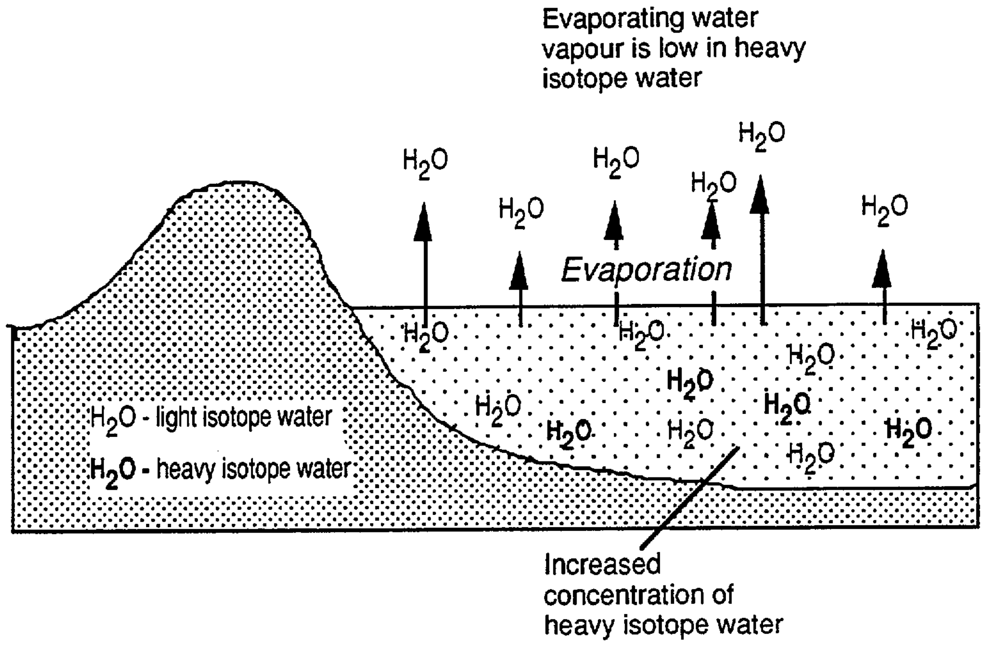


Figure 15. Evaporation from oceans leaving isotopically heavy waters

A cooling period will for example, result in an increase in condensation. This condensation will eventually precipitate, and because of the lower temperature, much of the precipitation will be as snow which will be trapped in ice caps and in continental glaciers. The overall effect of this is that the oceans are not being replenished with the lighter isotope water by runoff, and they remain relatively concentrated in the heavy isotope water. By knowing the relative concentration of the heavy isotope water, a temperature can be calculated.

Any water that has been "trapped" during geological or glacial processes can provide scientists with a time-capsule of information about the ocean temperatures at the time of the rock or ice formation. Rather than look at the entire water molecule, scientists study the proportion of ^{18}O in the "fossil waters" to determine the temperature at the time of formation.

5.2 Fossil evidence

Fossils of plants and animals can provide precise information about the climate at the time those plants and animals lived. This can be inferred information, based on the known conditions in which the organism can live, or information extracted from their living material or shell, such as isotopic data.

The majority of all ocean sediments contain assemblages of dead animal and plant material - mainly their living chambers (called tests) or shells made up of either calcium carbonate minerals (calcareous) or silicon dioxide minerals (siliceous). For example two microscopic oceanic fossils, the foraminifera and the coccoliths, can provide information on both water depth and temperature at the time the animals were living.

Foraminifera

The foraminifera, often refered to as "forams", are single celled animals that exist in both planktonic (floating) and benthic (bottom dwelling) environments. They form calcium carbonate tests. Foram fossils have had rapid evolutionary changes over very short time spans. The benthic forms are important as environment marker fossils as each species lives only at a given depth (see Figure 16.).

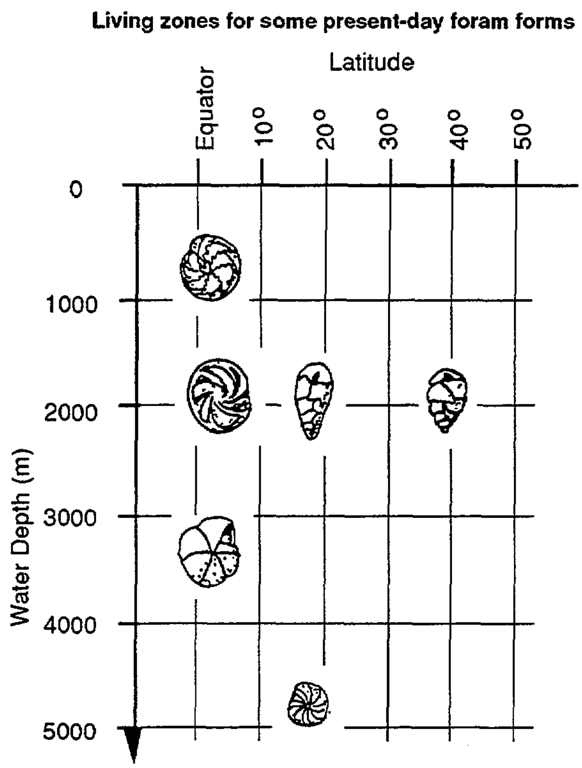


Figure 16. Modern foram species - depth and latitude ranges. (Adapted from Brasier 1980)

Coccoliths

Coccoliths are small circular plates of calcium carbonate which are embedded in the cell walls of the single celled marine algae known as coccolithophores (Figure 17.).

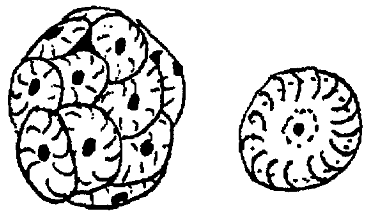


Figure 17. Coccolithophore and Coccolith

Oxygen isotope studies of the oxygen contained in both calcareous and siliceous shell material can be used as a temperature measure of the waters in which the animal lived. Some animals and plants will take in the oxygen and combine it in its shell in the same isotopic proportions as the surrounding water.

Spores and Pollen

Pollen and spores from plants, which are extremely resistant to decay, are also useful in finding our about past climates. These plant microfossils provide information on the types of plants which existed in an area and the changes to the types of plants over time. For example, the pollen record shows how the great forests of the Northern Hemisphere contracted towards the equator in times of advancing glaciers.

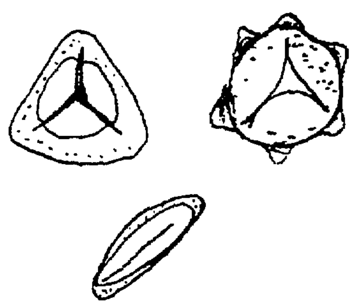


Figure 18. Spores and Pollen

Pollen grains, the most common plant fossil used in these palaeoclimatic studies, range in size from 10 to 150Êm (1Êm or micron is 1,000th of a mm). Their outer coat is chemically resistant to weathering. Pollen grains are distinctive for each plant family and are recognised by their size, shape and number of openings (Figure 18).

5.3 Palaeomagnetism

The Earth has a natural magnetic field with a north and south pole, like a magnet. It is this field to which the north arrow of a compass needle aligns to point northwards. When rock is molten (such as lava) any magnetic minerals also align to this natural magnetic field. When the rock cools, these miniature "compasses" are frozen in that direction. Geoscientists can measure the direction that these minerals point using a device called a magnetometer.

When geoscientists look at igneous rocks, they find that some show that the Earth's magnetic field is opposite to what it is today. In these rocks the minerals show that the north magnetic pole was once at the south magnetic pole, and the south magnetic pole at the north magneticc pole. (Presently and north and south magnetic poles are located near the north and south geographic poles). This change in poles is known as Polar Reversal and has taken place many times over the age of the earth. The ages of many Polar Reversals are well known through studies of basalts making up the ocean floors (Figure 19).

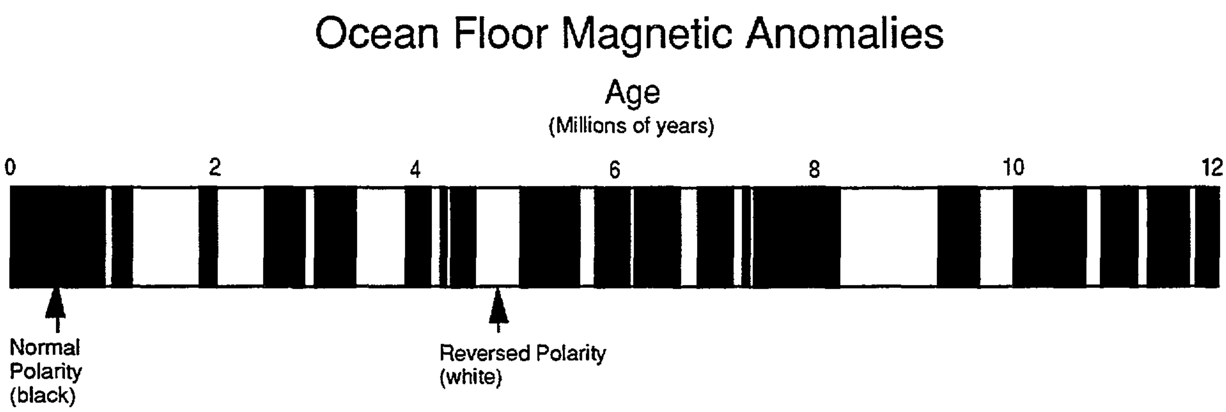


Figure 19. Ocean Floor Magnetic Anomalies

While Polar Reversals have not seemed alone to have caused massive climatic change, they may allow brief periods of increased solar radiation to reach the Earth's surface as the Earth's magnetic shield are weakened or removed during a reversal.

The same method can be used on baked clay items which contain iron minerals and some sediments, although many sedimentary processes tend to complicate the magnetic signature.

More importantly palaeomagnetic methods allow an understanding of changing continental positions, through the process of Plate tectonics, over time.
Geoscientists can use this magnetic information to locate the position of the Earth's magnetic pole at the time the lava cooled. When the pole is plotted relative to a continent over time, it appears that the pole has moved. This phenomena is known as "polar wander". Geoscientists assume that the pole has been reasonably fixed, and that polar wander is really the continent moving by plate tectonics.
Plate tectonics has moved continents around the Earth's surface. Any one continent may have been in a number of latitudes over a few hundred million years. Evidence of glaciation in rocks which now are on the equator may be explained if the palaeomagnetic data show that the continent was much closer to the south pole when the glaciation took place.

5.4 Ice cores

The accumulation of layers of snow, later being turned to ice due to the weight of overlying snow, at the polar ice caps provides valuable information about palaeoclimates. In some places, snow has been able to accumulate for hundreds of thousands of years because melting, evaporation and sublimation are almost non existent. These accumulations of ice provide information on the amount of precipitation as well as temperature, atmospheric composition and volcanic eruptions.

These ice accumulations are drilled, with a hollow drill, and an ice core is recovered. Some of these cores are over 700m long and represent thousands of years of precipitation.

Ice cores have layers, or ice glands, designated by the existence or lack of air bubbles. Normal compaction of snow into ice will trap air bubbles (Figure 20.). These air bubbles contain air from the atmosphere at the time of the snow fall, and scientists can extract the air and look at the composition of the atmosphere at that time. Carbon dioxide, for example, was only 60% of current day levels during the last Ice Age. If however, a warmer period occurs - possibly only for a season - the slight melting of the snow will allow the air to escape from the ice gland as it is compacted. Stable isotope analysis can also be undertaken on the water in the ice as well as on the trapped air. These studies reveal changes in atmospheric temperatures.

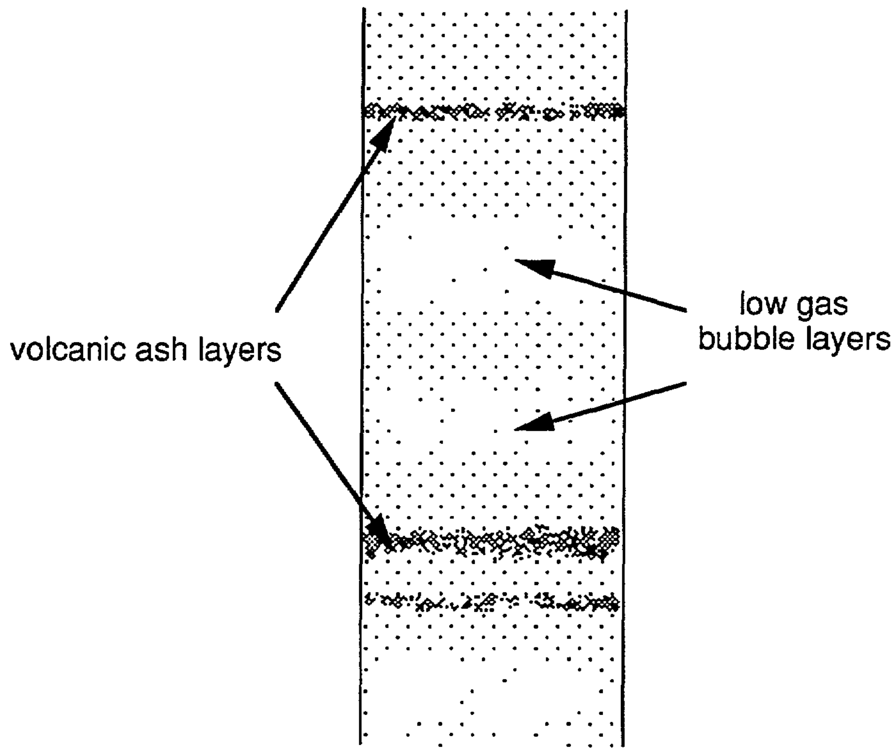


Figure 20. Idealised section of an ice core

As well as air bubbles and ice, ice cores contain layers of dust. Volcanic eruptions can produce vast amounts of fine dust which can be transported around the Earth in the upper atmosphere and settle down on the ice caps. This dust provides a marker bed in the ice which can be dated using radiometric decay methods (see below). Other non-volcanic dust can give evidence for changes in wind directions and strengths.

Dust layers have also been used as evidence for world-wide atmospheric dust "clouds" which may have reduced the amount of incoming solar radiation, which in turn, caused the Earth to cool.

5.5 Glaciers

Glaciers fluctuate in size as a result of the amount of precipitation at the glacial head and the amount of melting at the foot of the glacier. Evidence of past glacial maxima is easily identifiable as glaciers produce dramatic erosional and depositional features, such as striations and terminal moraines.

One important depositional feature is produced in lakes below glaciers into which glacial melt waters drain. The melt waters carry ground up rock material which settle in the lakes to form thin sediment laminations called *varves*. During summer months, glacial melt waters increase, so the varves are thicker. During winter little or no melt water enters the lakes so there is almost no deposition. The resultant sediments show laminations which correspond to each warm season, with the thickness of the varves indicating the temperature and/or length of the warm season. These varved shales are found in many places on Earth and throughout the geological record.

5.6 Speleothems

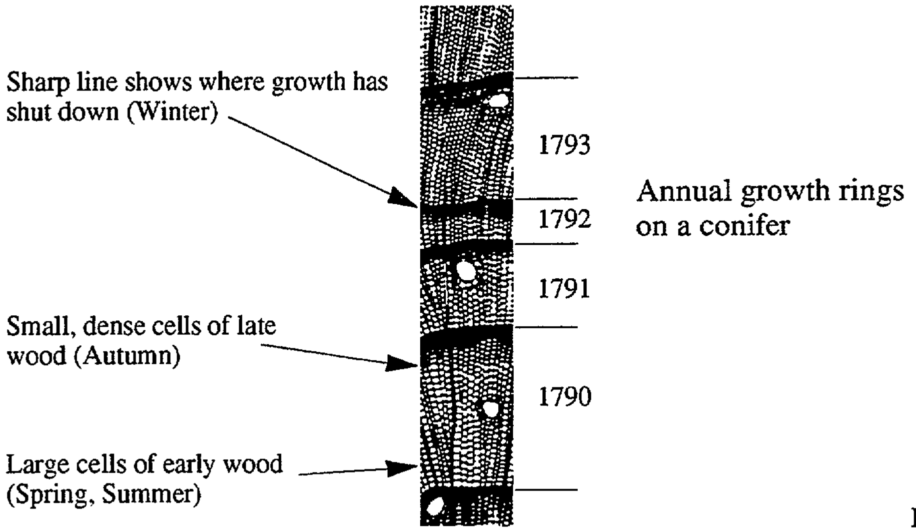
Speleothems is the collective name for limestone cave formations, including stalactites and stalagmites. These formations are made of calcium carbonate precipitated from groundwater which has percolated through the limestone. Sometimes, radioactive minerals are also precipitated, allowing the formations to be dated. As caves are normally almost isolated from the external atmospheric conditions, they provide a constant environment for speleothem growth, the rate of which is determined by other factors such as available groundwater. Changes in precipitation can therefore affect the growth rate of the speleothems which can be measured using growth rings.

While this may seem an unusual way to gather information on past precipitation rates, in some locations, such as the caverns now under an ice field in Alberta, cave formations have provided data for up to 350,000 years.

Speleothems can only be formed in air. Some caves found close to sea level can provide information about sea level changes as during times when the speleothem is cover by sea water marine organisms grow on the formations. When the sea level drops, speleothem growth restarts and covers the remains of the marine organisms. In this way, a number of sea level changes are recorded and can be dated using radiometric dating (see below).

5.7 Tree rings

Studies of tree rings as a method of finding out about palaeoclimates started in the 1830s although it had been recognised that tree rings were affected by the climate back in the 18th century. Tree rings represent seasonal growth cycles so ages of trees can be determined as well as the rates of growth during each season (Figure 21). This study is known as dendroclimatology and dendrochronology



Conifer tree rings

Figure 21.

Two trees of the same tree species growing in the same area may show different growth rates in their tree rings. This occurs due to conditions at the site where the tree is growing. Trees growing on slopes, for example, will have their growth influenced by the amount of precipitation as any groundwater will quickly move down slope. Periods of drought will therefore limit growth. These trees are in a growing position that is known as precipitation sensitive. A tree growing on flat ground will not be as strongly influenced by drought. Other growing sites can be sensitive to other factors, such as amount of sunlight (aspect), snow line (altitude) etc. Dendroclimatologists can select trees to provide them with the paleoclimatic information required.

5.8 Written records

When studying changes in climate over the last few thousand years, some locations in which human civilisation flourished provide human written records related to climatic conditions. These records can be divided into four different types :

1. Direct weather observations - i.e. frequency of frosts and snow etc.
2. Recording of weather-dependent events - i.e. floods, drought, rivers freezing etc.
3. Recording of weather-dependent biological events - i.e. dates of plants going to flower or arrival of migratory birds etc.

4. Records of crop growth or failure

Area	Earliest Written records
Egypt	3000 BC
China	1750 BC
Europe	500 BC
Japan	AD 500
Iceland	AD 1000
America	AD 1550
Australia	AD 1770 (English) Dutch and French slighty earier but non continuous

Historical written records are normally discontinuous observations which emphasise extreme weather events and catastrophes. Most commonly these records were written to record not the climatic event but rather the human suffering which it caused. "Normal" weather is normally not impressive enough to have warranted recorded.

> *Among events of divine ordering there, after Caesar's murder* [44B.C.] *the obscuration of the sun's rays. For during all that year its orb rose pale and without radiance, while the heat that came down from it was slight and ineffectual, so that the air in its circulation was dark and heavy owing to the feebleness of the warmth that penetrated it, and the fruits, imperfect and half ripe, withered away and shrivelled up on account of the coldness of the atmosphere."* Plutarch -Roman historian.

In some cases evidence is not found in writings but rather in art. A study of 12,000 landscape paintings made between 1400 and 1967 shows that artists emphasised the cloud type and amount that they were experiencing and that distinctive changes in the climate of Europe, discovered through other records, is reflected in the paintings.

5.9 Dating methods

As well as collecting climatic data, it is essential that the scientists know which period of time in the Earth's history the data represent. To do this they use a variety of dating methods. Relative dating is obtained by the study of fossils. The study of fossils over the last few hundred years has allowe scientists to produce an time scale

in which each fossil group has a distinctive range. By recognising fossils in a sample, a timeperiod for the sample can be found.
For a more absolute (numerical) age radiometric dating is used.

Radiometric Dating
Radiometric dating is based on the natural radioactive decay of an unstable element (parent) to a more stable element (daughter). In the process radiation is released. The time taken for one half of the parent atoms to decay to the daughter atoms is known as the half life of the element.

Knowing the half-life of radioactive atoms which are found in some rock forming minerals enables geoscientists to find the age of the mineral. The geoscientists need to work out the percentage of parent atoms to daughter atoms and work backwards to calculate an age.

The most common radioactive atoms used are :

Parent	Daughter	Half-life (years)
Carbon - 14	Carbon - 12	5,740
Uranium-238	Lead-206	4,510 million
Uranium - 235	Lead-207	713 million
Potassium-40	Argon-40	1,300 million
Rubidium-87	Strontium-87	47,000 million

As it is easier to measure the daughter atoms, especially in Uranium-lead dating, geoscientists use decay product curves to calculate ages.

The radioactive decay and product curves for some of these radioactive atoms and their daughter atoms are shown below in Figure 22.

When using this radiometric dating method, geoscientists make three assumptions.

1. When a mineral forms it has only parent atoms and no daughter atoms.

2. No daughter atoms "escape" the mineral crystal or no parent atoms are added. This is an especially important factor in using K-Ar dating. Argon, being a gas, is more easily removed from a crystal.

3. No geological process has restarted the "clock" - by removing the daughter atoms.

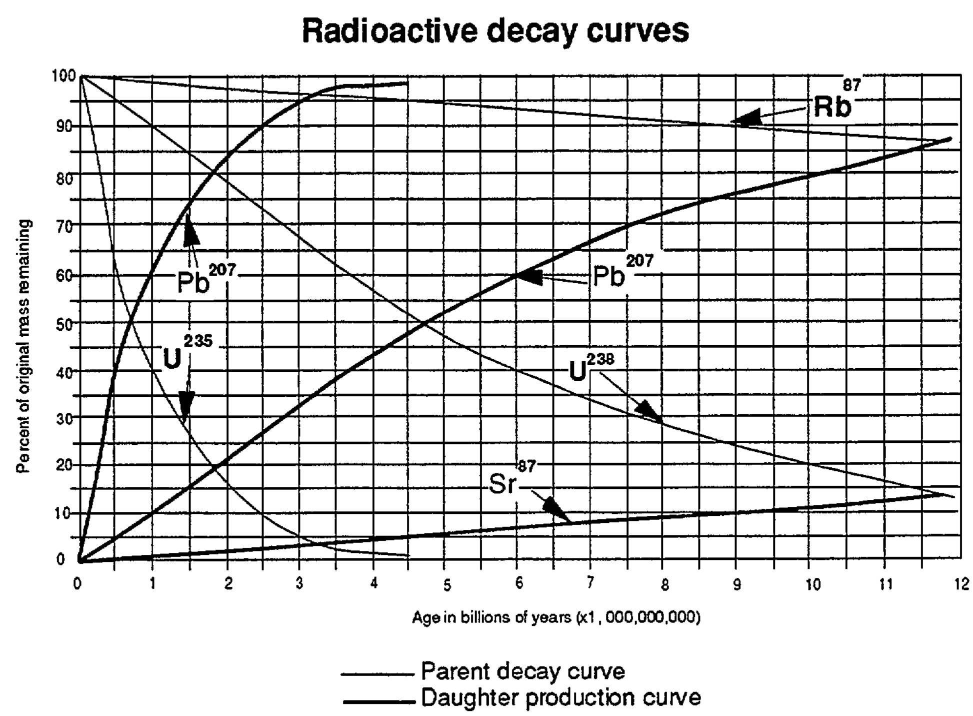


Figure 22.

Carbon -14 Dating

Carbon dating, while having only a short time over which it can be used (around 40,000 years before present) is one of the most used dating tools for recent climate change dating.

Radioactive carbon-14 is being produced continually in the upper atmosphere as the product of a reaction between the suns rays and nitrogen. The amount produced is in equilibrium with the radioactive decay of carbon-14 into carbon-12, so, the ratio of carbon-14 to the far more abundant carbon-12 remains constant in the atmosphere. When a plant removes carbon from the atmosphere, through the process of photosynthesis, and converts it into woody tissue, the carbon-14 continues to decay to carbon-12 without being replenished by atmospheric carbon-14. Hence, the ratio of carbon-14 to carbon-12 changes.

Measurements of the amounts of carbon-14 to carbon-12 can therefore be used to date carbon samples (Figure 23.). These may be woody material, animal material, charcoal or carbon in calcium carbonate materials such as shells.

Since the Industrial Revolution large amounts of "fossil" carbon have been burnt and released to the atmosphere. This fossil carbon is millions of years old and contains no carbon-14. This has diluted the carbon-14 concentration, making dating of woody material less than 150 years old complicated.

Radiocarbon Decay Curve

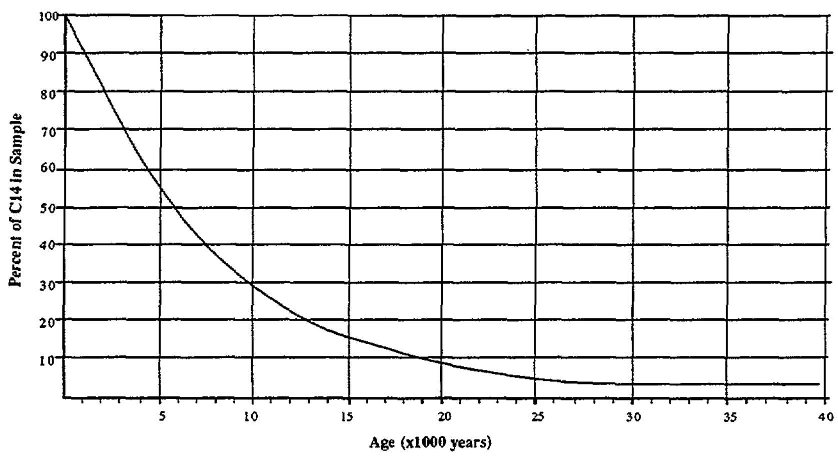


Figure 23.

6. Climatic Outputs - Climates of Pre-History

The Earth's climatic history has been one of warm periods interspersed with ice ages.

6.1 Ancient Ice Ages

An ice age is a period of time in which the Earth experiences colder climatic conditions, normally manifested by an increase in glaciation and/or polar ice caps.

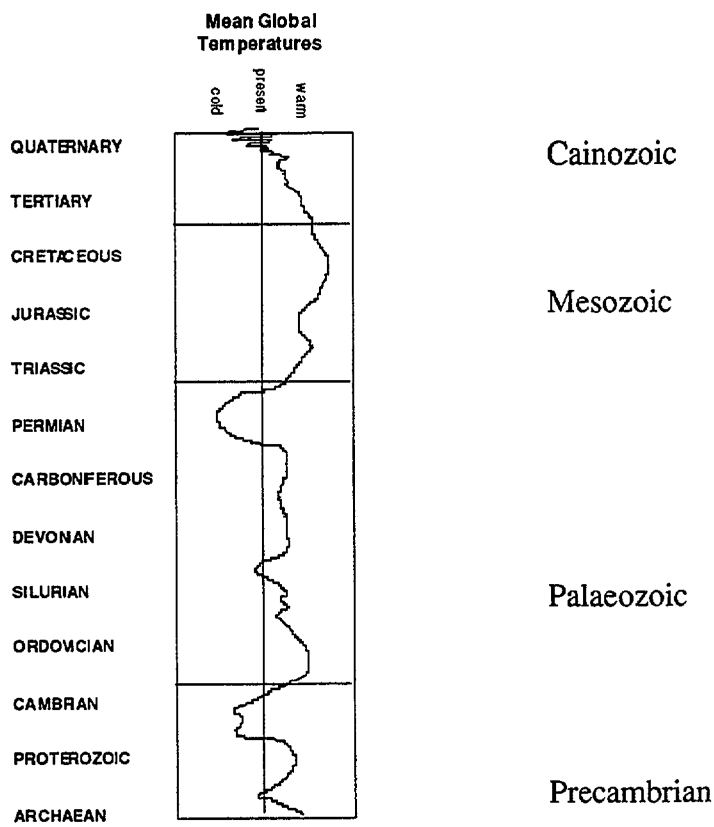


Figure 24. Global Temperatures throughout Geological Time

The Earth has gone through many ice age periods (Figure 24.). The first period known was during the middle Precambrian, around 2,300 million years ago. The evidence for this ice age is the existence of glacially deposited rock layers, known as tillites, in America, South Africa and possibly in Western Australia. The evidence suggests that the ice age lasted several tens of millions of years.

A great deal of evidence exists in Australia for a later ice age in the late Precambrian. Glacial deposits are well developed and exposed in a band across Western Australia, Northern Territory and South Australia. In some locations the glacial material is more than 5,500m thick! This ice age period started around 950 million years ago and lasted for around 400 million years with three glacial peaks at 940, 770 and 615 million years ago (Figure 25.).

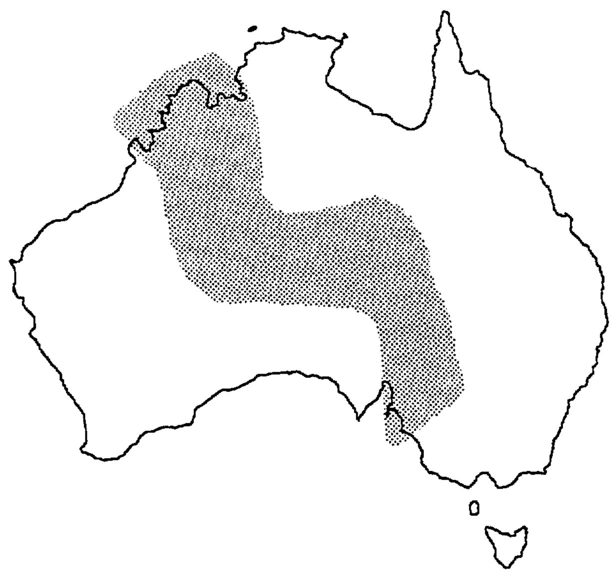


Figure 25. Location of glacial rocks in Australia from the Late Precambrian Ice Age.

Near the end of the Ordovician, around 450 million years ago, another ice age period commenced and lasted about 50 million years. Australia has no rocks providing evidence for this ice age.

The Late Palaeozoic Ice Age period, starting 330 million years ago and lasting 90 million years, left geological evidence on all the continents which once made up the supercontinent of Gondwana. This period probably was characterised by ice caps that waxed and waned over the 90 million years. In Australia there is evidence for six or more ice cap centres.

Late Cainozoic Ice Age

More is known about the last Ice Age than any other. The Late Cainozoic Ice Age was originally referred to as the "Great Ice Age" by Geikie in 1874. It started about 2.6 million years ago and went through at least 10 glacial cycles. These cycles affected the Earth differently in the northern hemisphere to the southern hemisphere.

The existence of large mountainous continental masses in the northern hemisphere provided "seeding" areas for continental ice sheets. As a result, extensive ice sheets formed and reached, in places, as far south as 40^{o}N latitude. These ice sheets covered most of the British Isles and northern North America. In the southern hemisphere the changes were not as dramatic due to the smaller amount of land. The sea-ice around Antarctica doubled its size and mountain glaciers increased. In Australia, an ice cap developed over the central highlands of Tasmania with glaciers forming on the edges such as in the Cradle Mountain area. Mainland Australia had less pronounced affects due to its low altitude. Some small glaciers developed in the Kosciusko region and snow and ice reached 1000m below the current snowline. The major affect of the glacial period on Australia was caused by the resulting sea level drop of around 150m.

The last major glacial period reached its maximum around 19,000 years ago and since then the glaciers and ice sheets have contracted. The temperature during this glacial maximum is estimated to have been 5^{o}C lower in Australia than the present average temperatures.

Little Ice Age

A colder than normal period between AD1500 and AD1900 has been called the Little Ice age. The area most affected was Europe where more severe winters and longer periods of ice and snow reduced the crop growing seasons. Temperatures were around 1^{o}C lower than the average temperatures this century.

6.2 What caused the Ice Ages

Many theories have been put forward for why the Earth has ice ages. These include the movement of the Earth through galactic clouds, increases in Volcanic dust, Milankovitch cycles, changes in the amount of carbon dioxide in the atmosphere, mountain building, isostatic uplift, movement of the continents and changes in the polarity of the Earth's geomagnetic field (Figure 2.). Evidence for any of these causes is always complicated by the strong influence the ice sheets themselves have on the local climate by increasing the reflectivity of the Earth's surface and causing localised atmospheric conditions.

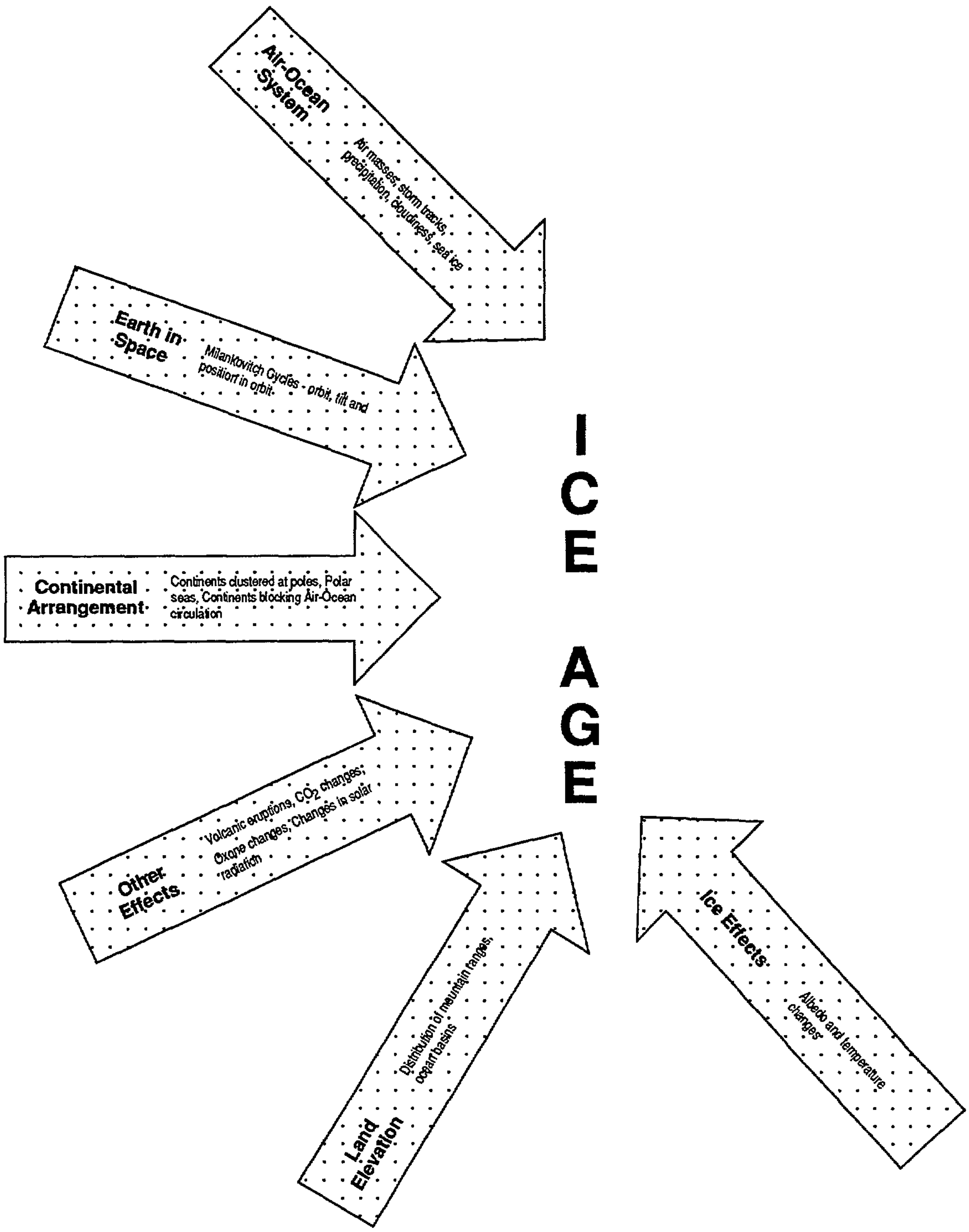


Figure 26 . Causes of the Ice ages (adapted from Embleton & King, 1975)

The real cause may be combinations of all these ideas, or even some unknown mechanism.

6.3 Mass Extinctions

The study of fossil remains of plants and animals (palaeontology), which started in the late 1700's, brought to the world's attention the existence of animals and plants which no longer exist on Earth. While the concept of extinction started with the discovery of felephant fossils in France, the animal group which highlighted this "extinction" idea the most were the dinosaurs. Their apparent rapid extinction at the end of the Cretaceous Period, some 65 million years ago, led many palaeontologists to look for reasons for their demise.

However, the mass extinction at the end of the Cretaceous was not the only extinction period in Earth history. At least eight other world-wide mass extinction episodes (Figure 27). have taken place and the current known evidence points to climatic changes for the majority of these.

Geological event	Probable cause
Late Pleistocene	Post-glacial warming plus predation by man
Eocene to Oligocene	Stepwise extinction associated with severe cooling, glaciation and changes of oceanographic circulation, driven by the development of the circum-Antarctic current.
End Cretaceous	Possible astronomical object impact producing catastrophic environmental disturbance.
Late Triassic	Possibly related to increased rainfall with implied regression
End Permian	Gradual reduction in diversity produced by sustained period of refrigeration, associated with widespread regression and reduction in area of warm, shallow seas.
Late Ordovician	Controlled by the growth and decay of ice sheets following a sustained period of environmental stability associated with high sea level.
Late Cambrian	Habitat reduction, probably in response to a rise in sea level, producing a reduction in number of component communities.

Late Precambrian	Complex, including widespread regression, physical stress (restricted circulation and oxygen deficiency) and biological stress (increased predation, scavenging and bioturbation).

Figure 27 . Major Earth extinction Episodes.

6.4 The Cretaceous Extinction

The boundary between the late Cretaceous Period and the start of the Tertiary Period (which is also the boundary between the Mesozoic and Cainozoic Eras) occurred some 65 million years ago. Known as the K-T Boundary, it is marked by an extinction episode in which most of the Earth's species of the time, including the dinosaurs, became extinct. Recent research has also shown the existence of high levels of the element Iridium in rocks of exactly the same age around the Earth. Iridium is not abundant on Earth, but is found to be rich in some meteorites and asteroids.

It is now thought by some scientists that the Earth was hit by a large (10 km across) asteroid 65 million years ago. The asteroid hit the earth with the force of 100 million million tonnes of TNT instantly vapourising the asteroid and throwing billions of tonnes of rock and water into the atmosphere. The heat from the blast set off huge forest fires which added soot to the atmosphere. Living things within a few hundreds of kilometres would have been killed instantly, and, if the impact took place in the ocean, huge waves would have swept around the Earth.

While the initial impact caused devastation, it was the climatic changes over the next months which caused the mass extinctions. Within a year the entire planet surface was blocked from the Sun because the atmospheric dust and soot. Without sunlight, photosynthesis stopped and the Earth's plants died, animals starved and eventually the food chain collapsed. As a result three quarters of the Earth's species became extinct.

Evidence for this scenario continues to increase, with the discovery of an asteroid impact crater off the coast of the Yucatan Peninsula of Mexico being sited as the collision zone and the discovery of agglomerate deposits formed by huge ocean waves.

7. Rate of Change

The natural rate at which the Earth's climate has changed in the past gives us an appreciation of the possible rate of climatic change which is occuring because of the activities of human.

Generally, the natural rate of climate change throughout earth history has been, in human terms, very slow. Evidence shows that climatic changes have taken many tens of thousands or millions of years to occur. However there are exceptions to this such as the extinction episode at the Cretaceous-Tertiary boundary (see 6.4) and the deglaciation of the last ice age when the change caused land bridges enabling the movement of humans between island, including Tasmanis, and the Australian mainland.

The current predicted change in the Earth's climate, caused through the activities of humans, appears to be at a rate far greater than past climatic change episodes - these could be catastrophic climatic events with global warming and sea level changes of many metres happening over decades rather than millennium.

References

Beckmann, R., 1994, *"Environmental Science"*, Australian Academy of Science

Brasier, M D, 1980, *"Microfossils"*, Allen & Unwin Press, London

Bradley, R.S., 1985, *"Quaternary Paleoclimatology"*, Allen & Unwin Press, London

Budyko, M.I. et al, 1988, *"Global Climatic Catastrophes"*, Springer-Verlag

Clark, I F. (editor) 1983. *"Perspectives of the Earth"*. Australian Academy of Science.

Donovan, S K (Editor), 1989, *"Mass Extinctions - Processes and evidence"*, Belhaven Press, London.

Elliott, D K (Editor), 1986, *"Dynamics of Extinction"*, John Wiley & Sons, New York

Embleton, C & King C A M, 1975, *"Glacial Geomorphology"*, John Wiley & Sons, New York

Frakes, L A, 1979, *"Climates Throughout Geologic Time"*, Elsevier Scientific Publishing Company, New York.

Goody, R M, Walker, J C G, 1972, *"Atmospheres"*, Prentice-Hall,, New Jersey

Gribbin, J., 1978, *"Climate Change"*, Cambridge University Press, London.

Houghton, J T, Jenkins, G J, Ephraums, J J., 1990, *"Climate Change, The IPCC Scientific Assessment"*, Cambridge University Press, London.

McNamara, G , 1995, *"The Cosmic Shooting Gallery"*, ANH, p 52, The Australian Museum Trust.

Muller, R A, Oberlander, T M., 1978, *"Physical Geography Today"*, CRM, Random House

Pickering K T & Owen L A, 1994, *"An introduction to Global Environmental Issues"*, Routledge, London.

Williams M A et al, 1993, *"Quaternary Environments"*, Edward Arnold,- Hodder & Stoughton

AGSO

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

Geoscience Education

Activities

Gary Lewis
1995

Further Information : (06) 249 9570

Iceman

The Polar Ice Cap Expedition made a gruesome discovery yesterday on its return leg of a five week ice-core collection trip. Team leader, Dr Fiona Allen, sent a message to police that her team had come across some human remains while drilling an ice core. "The remains seemed old but well preserved" Dr Allen said. Scientists have been flown into the site to examine the remains. The expedition will continue to collect ice cores to provide the team with more information about past climates.

When Dr Fiona Allen returns to Australia she employs you to study the ice core she and her team extracted from the "Ice Man" site. Your job is to find out about the age of the remains and try to find out why a person would be so far north on the ice cap. She also tells you that she spoke with some of the native people of the area who said that it is common practice for hunters to journey onto the polar ice cap, but not as far as where the remains were found.

You notice that the core contains nine layers of volcanic ash from which you remove a small sample and send away for radiometric dating. The dating team returns you a range of dates for each sample - the youngest age and the oldest age of each volcanic layer You assume that there is always a error of 10 years in their dating, so that a range of less than ten years is probably one volcanic eruption of an age between the two dates (ie. VE1 was an eruption 3 705 years ago).

The information they provided is :

Volcanic Event number	Youngest age (years ago)	Oldest age (years ago)
VE1	3 700	3 710
VE2	4 702	4 710
VE3	5 295	5 300
VE4	8 715	8 722
VE5	8 932	8 935
VE6	13 885	13 891
VE7	19 420	19 427
VE8	19 610	20 343
VE9	20 717	20 726

On the ice core log provided, write the ages of each volcanic event on the right-hand side of the core.

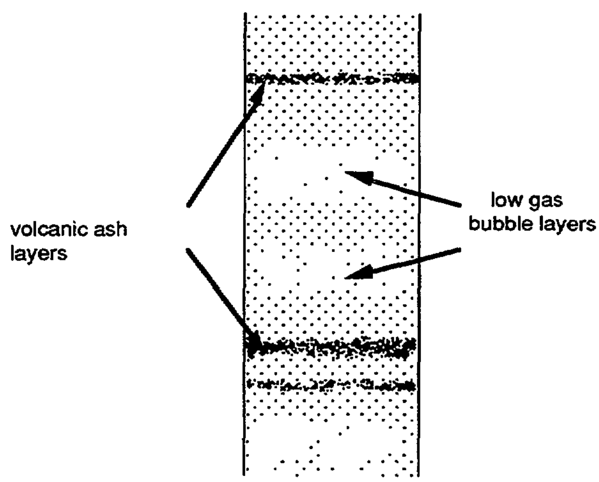
How many years does this core represent? ______________________________

Calculate the time scale of the ice core by measuring its length and dividing it by the total amount of years it represents.

1mm= __________ years

What is the approximate age of the ice in which the Ice Man was found? ____________

You also know that areas in ice cores which are low in gas bubbles represent periods of time when the climate was slightly warmer and the ice melted releasing the gases.



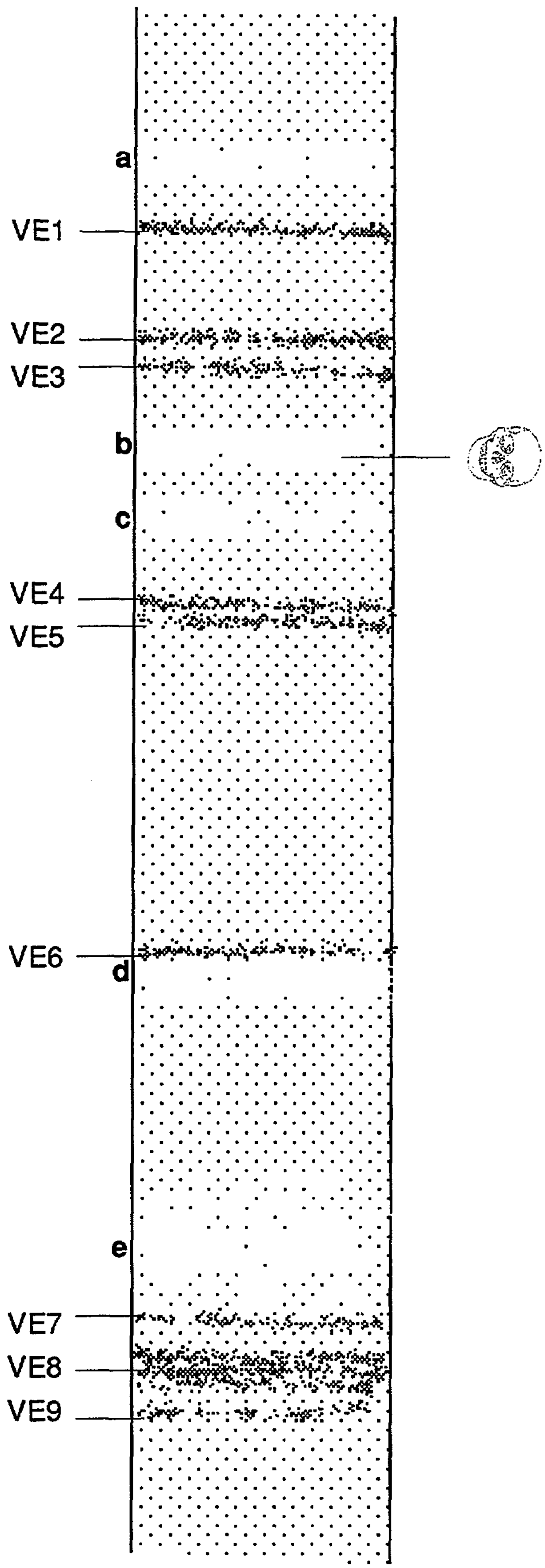
These zones are marked a to e on the left-hand side of the ice core.

? What information does this tell you about the climate at the time the Ice Man lived?

? Write a paragraph on the relationship, or lack of relationship, between the volcanic events and changes in climate.

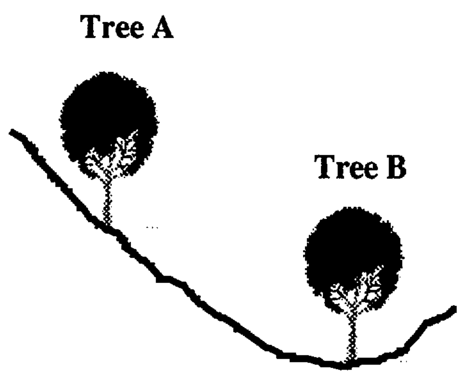
ICE MAN LOCATION
ICE CORE

Ice core log



Tree Ring Climates

Two field hands, Jayne Jones and Bart Smith, recently travelled into Mt Field National Park in central Tasmania to collect cores from some ancient trees for you to use in your study of past Australian climates. Using a special device, they removed small core sections from two living trees, A & B, in a small valley. Jayne recorded the position of the two trees in her field note book.



Back in the laboratory, Bart removed two small samples from each core (A1, A2 & B1, B2) and sent the samples away for radiocarbon dating. The results came back as :

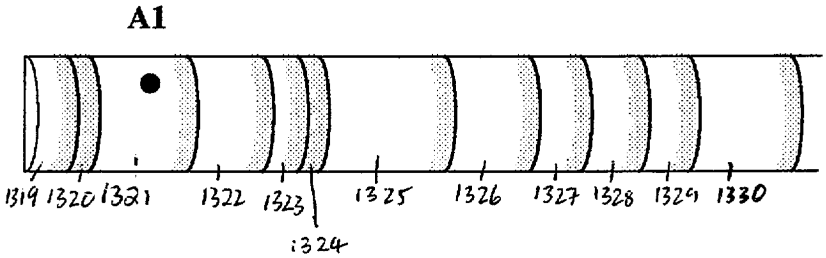
Sample	Age in years*
A1	674
A2	641
B1	653
B2	644

* based on 1995 standard

Calculate the year the tree produced the tree ring from which the four samples were taken by subtracting the age from 1995 (the radiocarbon date standard used) and complete the table below.

Sample	Year of each sample
A1	1995 - 674 = 1321AD
A2	
B1	
B2	

Jayne prepared the core samples for you and marked from which tree rings Bart removed the dating sample. Write the year below these tree rings and fill in the years in between. ie.



The amount that a tree grows during its growing season, normally summer, depends on the amount of water available to the tree and the warmth of the sun. A dry summer may result in a narrow growth ring, while a wet summer a wider growth ring.

? In what year did the two trees grow the least (narrowest growth rings) ?

Tree A : __________ Tree B : __________

? In what year did the two trees grow the most (widest growth rings) ?

Tree A : __________ Tree B : __________

? What climatic feature, typical in Australian climate history, may have happened from 1335 to 1347? ______________________________

? During what other years did this climatic feature occur? ______________

? The growth rings of Tree A and Tree B do not appear to be exactly the same. What environmental factors may differ between the two trees?

____

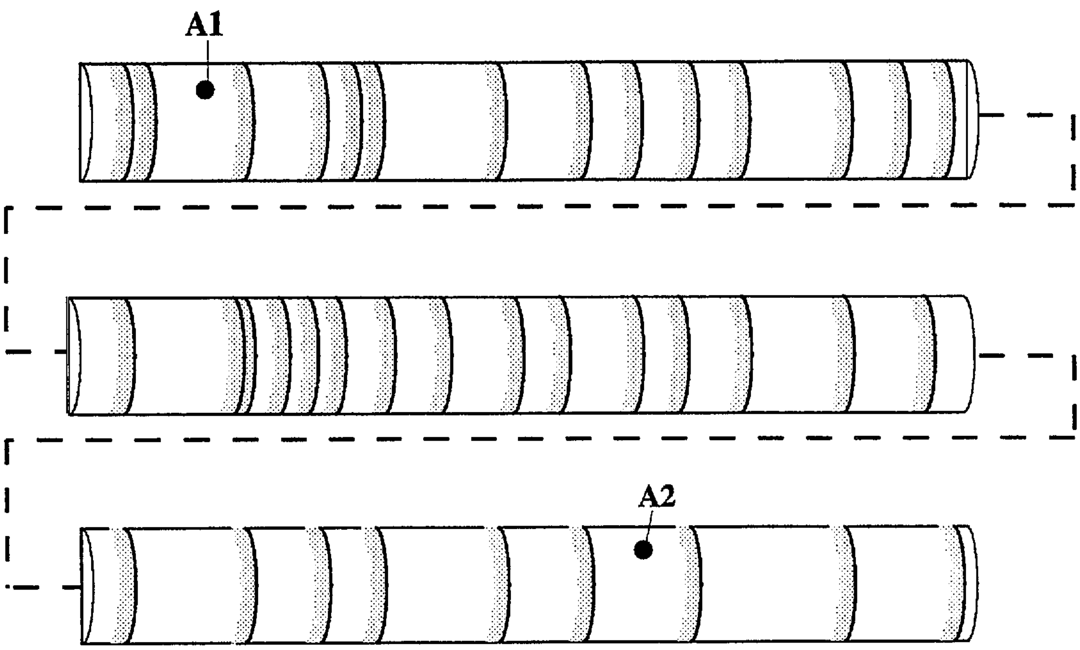
Which of the two trees would you select to provide more detailed climatic information and why?

____

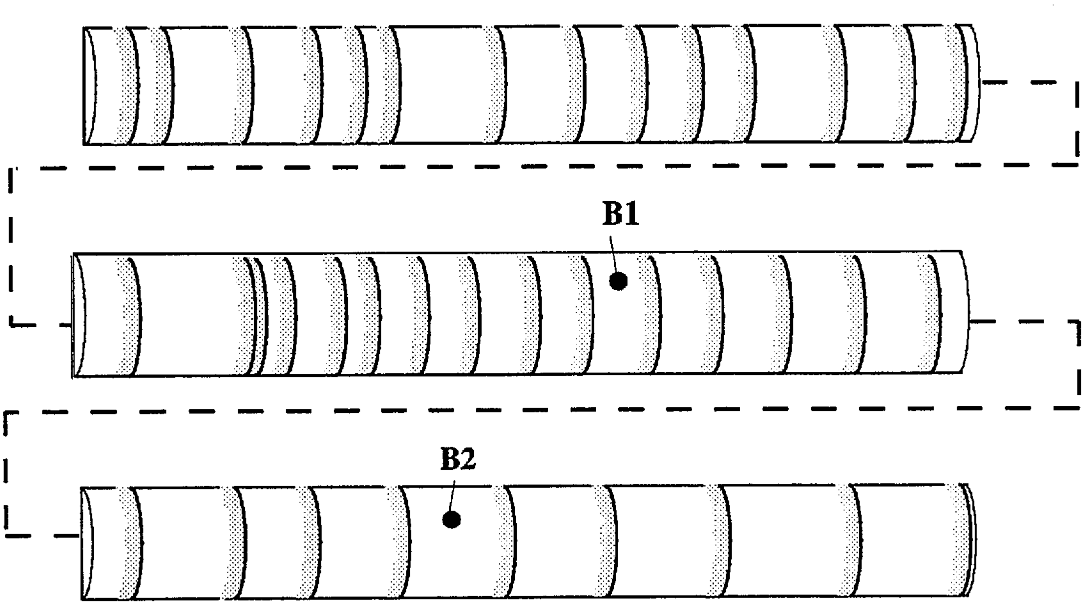
____

____

Core from Tree A

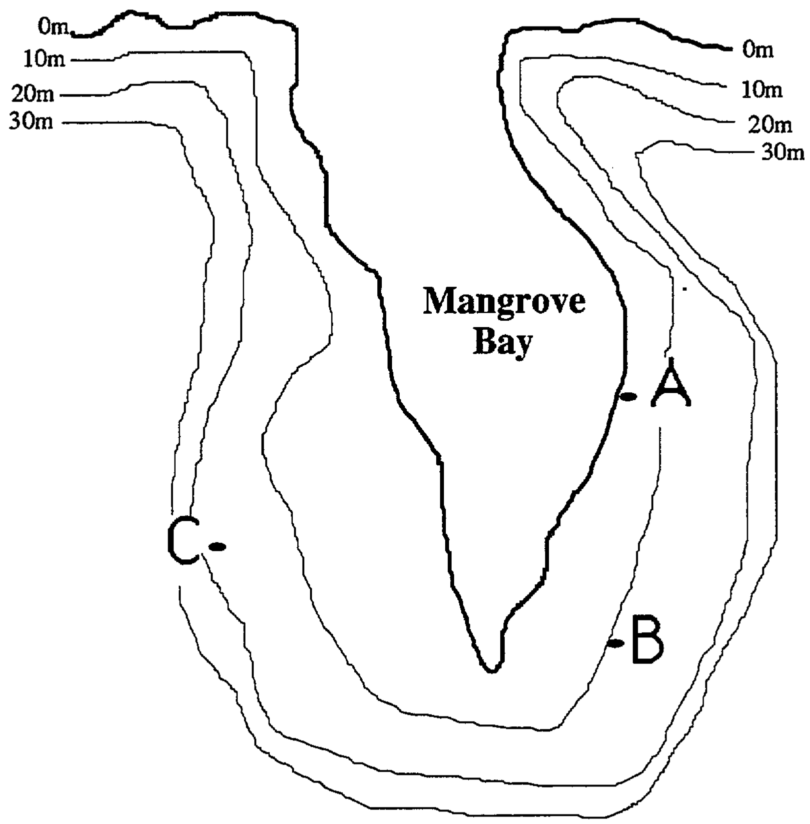


Core from Tree B



Terrace Temperatures

In a small bay in southern Queensland, geologist Abdul Theca discovered sand deposits on "terraces" above the current sea level. Abdul collected a small sand sample from each of the terraces at locations A, B and C and sent them to microfossil expert Sanja Leeverson for fossil identification.



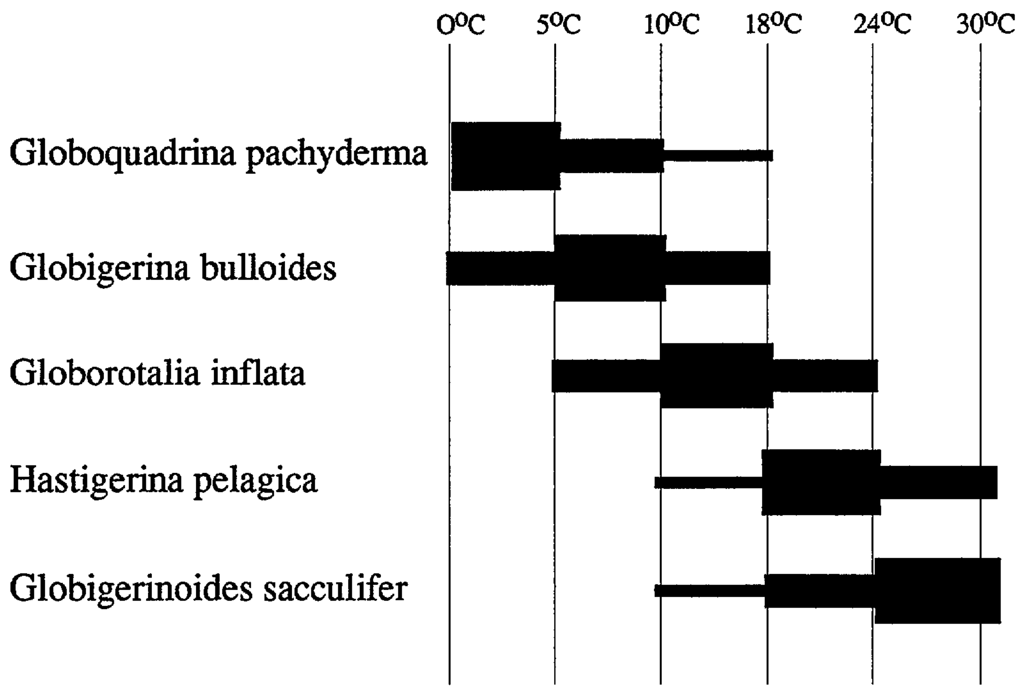
Location of samples taken from Mangrove Bay

Sanja recognised five different fossil foraminifera in the terraces and provided Abdul with the following information about their abundance.

Foram	Sample A	Sample B	Sample C
Globoquadrina pachyderma	10%	0%	0%
Globigerina bulloides	20%	0%	0%
Globorotalia inflata	40%	30%	0%
Hastigerina pelagica	15%	50%	30%
Globerinoides sacculifer	15%	20%	70%

Abdul has contacted you and asked if you could find out what may have caused the changes in sea level, as each of the terraces where deposited when the sea level was higher than present.

You come up with two possible explanations - either the sea level rose because of a period of climate change or the land surface is being uplifted out of the water because of some other factor. You find in a Foram reference book the following diagram which shows the relative abundance of the foram fossils recognised by Sanja plotted against sea water temperatures.



Using this information, at approximately what temperature was the sea when each of the three sand terraces was deposited?

Terrace A (sample A) : __________

Terrace B (sample B) : __________

Terrace C (sample C) : __________

How high are these terraces above current sea level ?

Terrace A (sample A) : __________

Terrace B (sample B) : __________

Terrace C (sample C) : __________

What appears to be the relationship between the sea temperature and the height of the terraces?

____

____

____

What further information could you seek to confirm that the sea level changes are related to the change in sea level temperatures ?

____

____

____

Changes in climate, either warming or cooling, cause changes in ocean currents. As all of these fossils are planktonic (floating) they will have been brought into the bay by the prevailing ocean currents moving along the Queensland coast.

During an ice age, the cold waters from the southern Tasman sea move further up the east coast and may reach Mangrove Bay. If these waters are around 8-12°C, what proportion of foram fossils would be deposited in sands in the Bay and would these "terraces" be higher or lower than the present sea level?

____

____

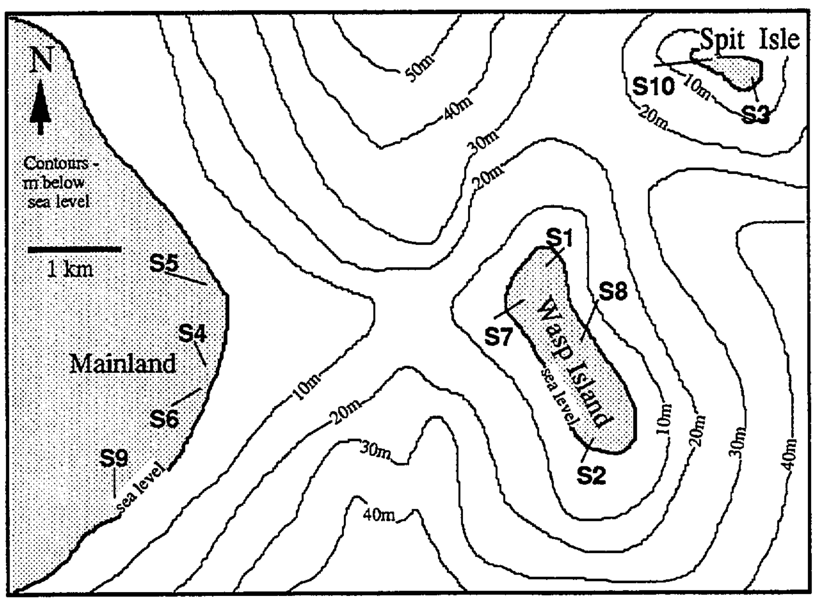
____

____

Occupation Ages

You have been asked to gather evidence for aboriginal occupation of two islands, Wasp Island and Spit Isle, off the coast of northern Australia since the last Ice Age.

You visited the islands and the adjacent mainland with a member of the local Aboriginal community and collected charcoal samples from ancient fireplaces. It is known that the tribe which occupied this area did not build or use boats or rafts. The locations of your samples are marked on the map below.



Sample Locality Map

Each of the samples has been analysed for radioactive carbon 14. Use this information, and the Radiocarbon decay graph, to find the age of each of the samples and complete the table below.

Sample	Remaining C14	Age
S1	62%	___________
S2	15%	___________
S3	38%	___________
S4	10%	___________
S5	40%	___________
S6	6%	___________
S7	16%	___________
S8	70%	___________
S9	80%	___________
S10	18%	___________

? What is the age of the oldest sample from Wasp Island ? ____________________

? What is the age of the oldest sample from Spit Isle ? ______________________

? What is the age of the oldest sample from the Mainland ? ___________________

When does this suggest that Aboriginals were able to walk to the islands? __________________

What must have happened for the tribal people to walk to these islands ?

____

____

____

What evidence can you find to explain why the two islands were not initially occupied at the same time?

____

____

____

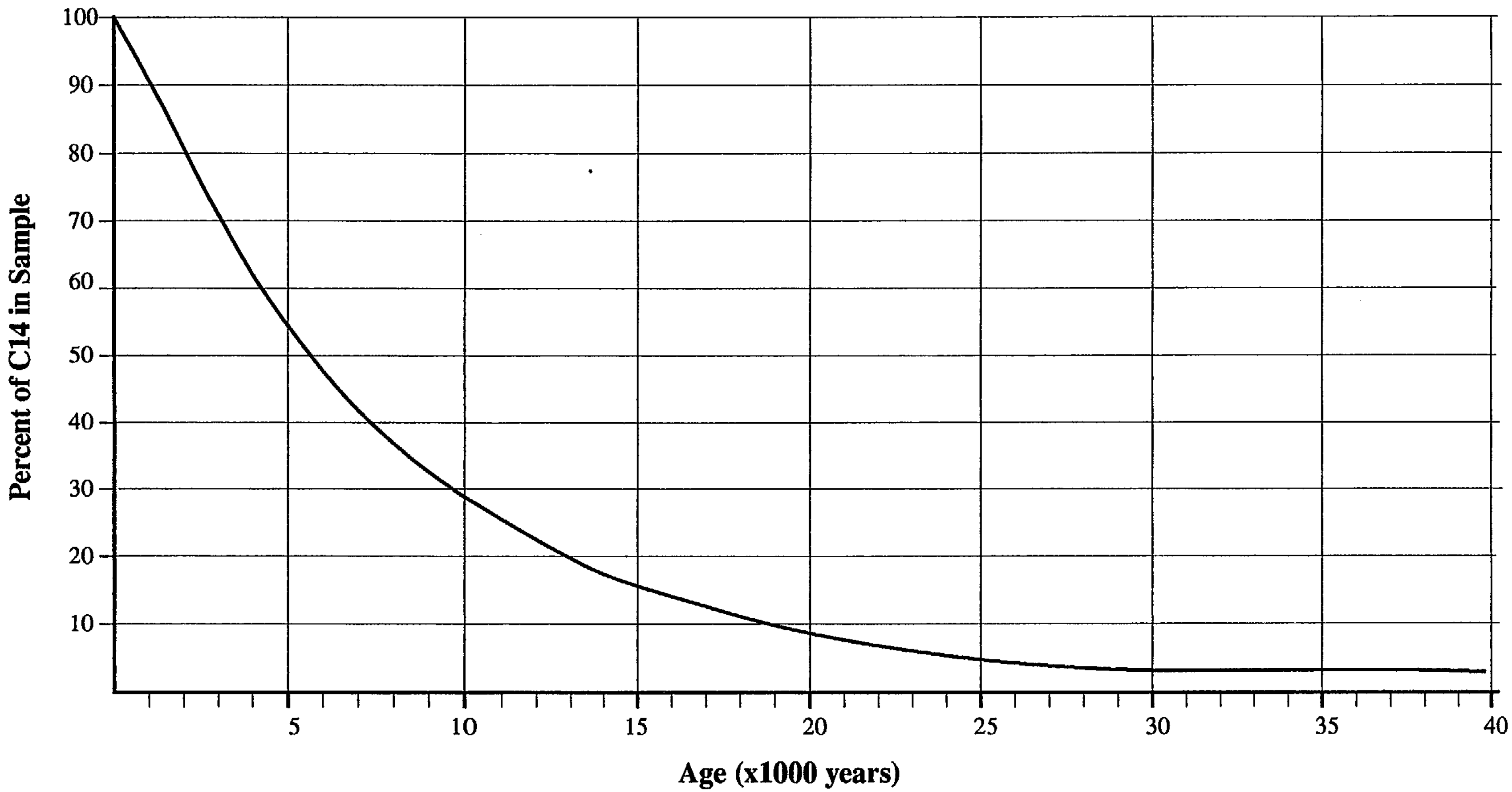
What other evidence might you be able to collect to prove your findings?

____

____

____

Radiocarbon Decay Curve



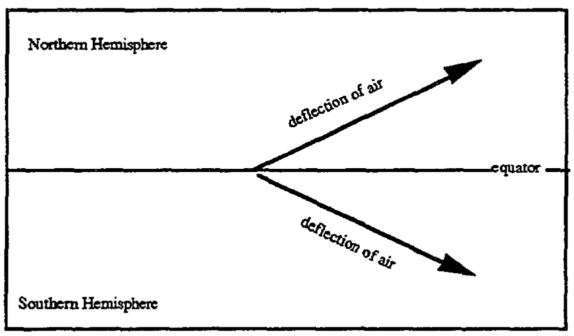
Eruption on Climeworld

It is the year 2025 and you, a trained climatologist, have travelled to the planet Climeworld. You have been asked by the Climeworld government to research the effect of volcanic eruptions on their planet's climate.

You know that every time a volcano erupts it puts many tonnes of volcanic aerosols into the atmosphere which block the solar energy reaching the planet's surface near the eruption. These areas are cooled and during large eruptions, crops fail and local inhabitants suffer famine.

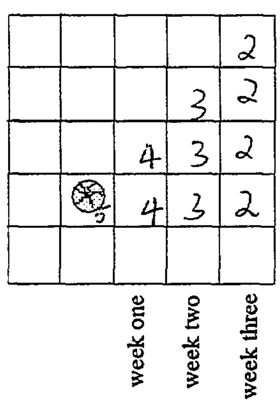
Background information on Climeworld

The atmosphere on Climeworld is very similar to Earth. However, the circulation of the Climeworld atmosphere is very simple. Air at the equator is heated and rises and moves towards the poles. Because of the circulation of the planet, the poleward moving air is deflected.

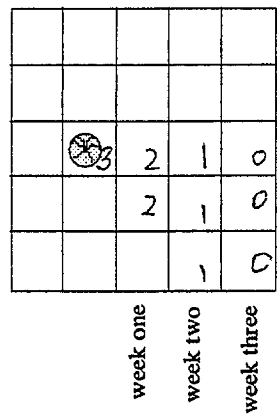


When a volcano erupts on Climeworld it is given an eruption magnitude number. (The largest recorded eruption was a 20). Every week after eruption the aerosol "cloud" spreads out in the atmosphere and decreases in intensity in the following way :

Northern Hemisphere - to the east one distance unit and north-east one unit. For example in an eruption of magnitude 5 -



Southern hemisphere - to the east one distance unit and south-east one unit. For example in an eruption of magnitude 3 -



The cloud continues to spread until it has completely dispersed (intensity=0)

The magnitude number is equivalent to the amount of solar radiation blocked from reaching the surface. Normally 25 units of solar radiation reach the surface of the planet. In an eruption of magnitude 10, directly under the eruption cloud only 15 units or solar radiation will reach the surface.

A magnitude 5 eruption is recorded from a volcano located at 24-06 (the Map of Climeworld has a grid reference system, the first number refers to the columns while the second number refers to the row). Note : this volcano is in the northern hemisphere of Climeworld. Plot the spread of the aerosol cloud until it is completely dispersed.

? How many weeks does it take for the eruption cloud to disperse? ____________________

A magnitude 9 eruption is recorded from a volcano located at 19-21 Plot the spread of the aerosol cloud until it is completely dispersed.

? How many weeks does it take for the eruption cloud to disperse? ____________________

? What is the smallest eruption magnitude which this volcano would need to erupt to cause some solar radiation blocking over the city of Icely (31-24)? ____________________

What would happen if a magnitude 20 eruption took place at the volcano located on the equator (marked V)? Because of the size of the eruption, assume that the four surrounding squares (29-13, 29-14, 30-13, 30-14) all receive the initial intensity 20.

? What cities would affected by this eruption and how long after the eruption would they record the effects? ____

____

The growth of the planet's plants is related directly to the amount of solar radiation reaching the surface. The amount of plant activity against the solar radiation level is :

Solar radiation level	Plant activity
25	normal level
20	most plants survive
18	deciduous trees loose leaves, summer crops fail
16	winter crops fail
14	all crops fail
12 or less	all plants die

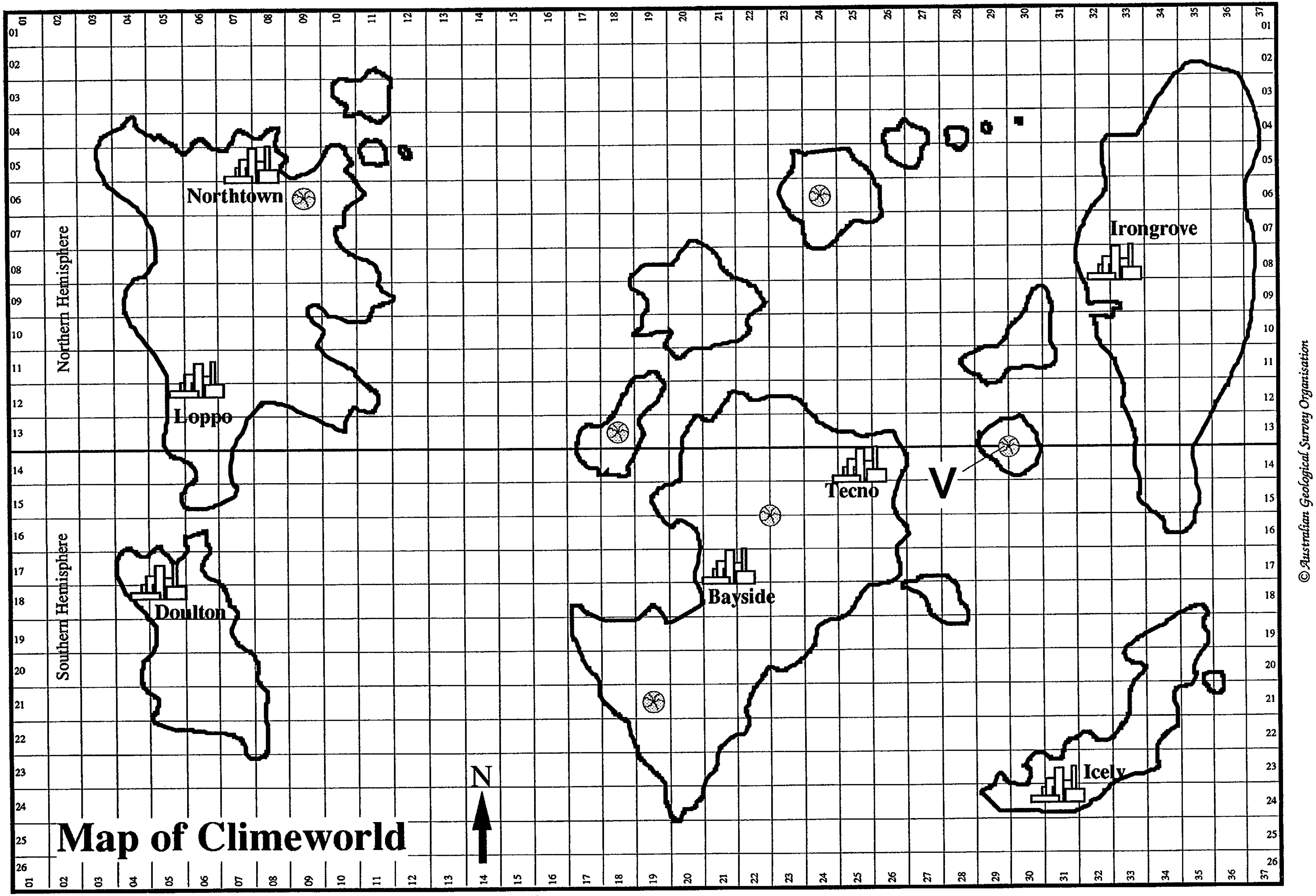
Using a coloured pencil, shade those zones in which all crops fail - which marks the area in which Climeworld inhabitants would be in famine.

? Why does this volcano have the potential to affect the entire planet's climate?

____

? Are there any other volcanoes on the planet which could cause such widespread famine?

____


Map of Climeworld
Northern Hemisphere
Southern Hemisphere
Northtown
Loppo
Doulton
Bayside
Tecno
Irongrove
Icely
V
N
© Australian Geological Survey Organisation