CLIMATE CHANGE OVER GEOLOGICAL TIME

WHAT IS CLIMATE?

The weather a place experiences can be caused by many factors.

These could be as **simple as being closer to the poles** and receiving less of the sun's heat, or more complex like the benefits felt in the UK due to the consistent flow of warm air from the **Gulf Stream**. The combination of all these factors over a number of decades gives every place on Earth its own average temperature, precipitation and amount of sunshine. This is the climate.

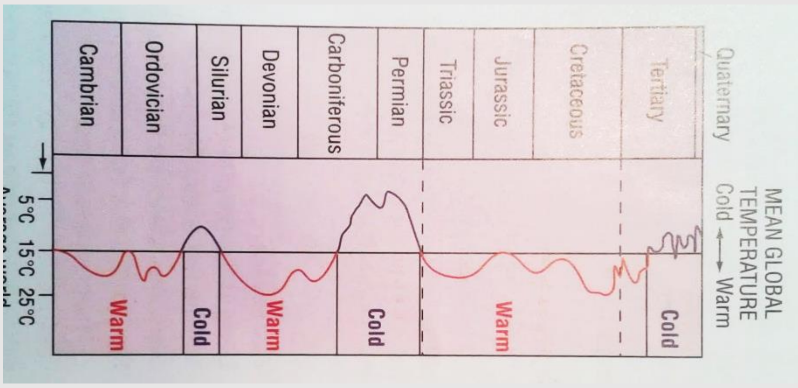
Climate of a location can be affected by:

- Latitude
- Terrain
- Altitude
- Nearby bodies of water and their currents

- **Weather** is the state of the a**tmosphere** at a given **time and place**, with respect to variables such as **temperature, moisture**, **wind velocity** and **barometric pressure**.
- **Climate** is the **long-term weather** pattern of an area, including **temperature, precipitation,** humidity, atmospheric pressure and **wind**. Climate is how weather acts **over many years**.

ICEHOUSE AND GREENHOUSE

Throughout Earth's history, the planet's climate has fluctuated between two dominant climate states (Greenhouse and Icehouse Earth). These climate states last for millions of years and should not be confused with glacial and interglacial periods, which occur during and icehouse period and tend to last less than one million years.



There are **five major global factors** of the palaeoclimate that are believed to be:

1. *The concentration of atmospheric* ***carbon dioxide***
2. *Changes in the* ***Earth's orbit***
3. ***Oceanic changes***
4. ***Orogenic changes*** *due to* ***tectonic plate*** *dynamics*

During a Greenhouse period:

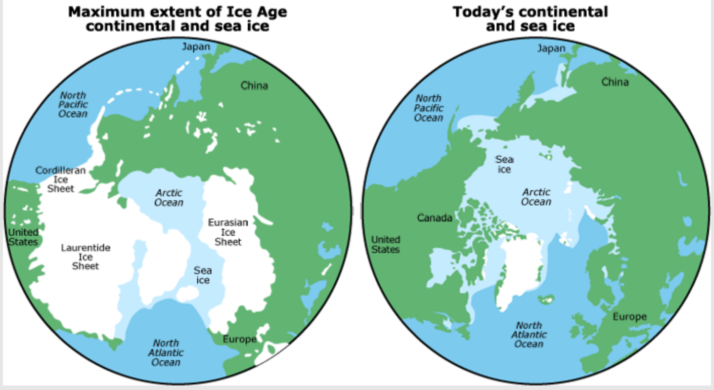
- The Earth has **no continental glaciers or polar icecaps** whatsoever.
- The levels of **carbon dioxide** and other greenhouse gases (such as **water vapor** and **methane**) are high.
- **Sea levels are higher** due to **thermal expan**sion of water and the added water from icecaps that have **melted**.
- **Sea surface temperatures** (SSTs) are **high,** ranging from 28^0C in the tropics and 0^0C in the polar regions.

The geological record shows that CO_2 and other greenhouse gases are abundant during this time. Tectonic movements were extremely active during the more well-known Greenhouse ages (such as 368 million years ago in the Palaeozoic Era). Continental rifting and other volcanic activity becomes more prominent, producing more CO_2 and heating up the Earth's atmosphere.

Earth is more commonly placed in a Greenhouse state throughout the epochs, and the Earth has been in this Greenhouse state for **80% of the past 500 million years**, which makes understanding the direct causes very difficult.

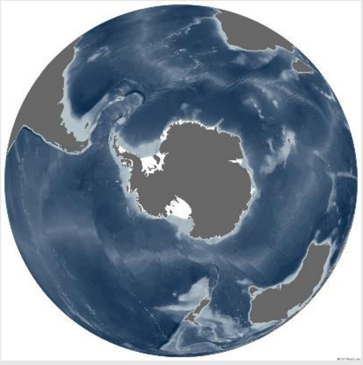
During an icehouse period:

- An icehouse Earth has **ice sheets present**, and these sheets **wax and wane** throughout times known as **glacial and interglacial periods**.
  - **Glacial era** = larger ice sheets
  - **Interglacial era** = smaller ice sheets (but ice sheets are always present)
- Greenhouse gases tend to be **less abundant**.
- Temperatures tend to be **cooler globally**.
- **Sea level is lower**
- **Sea surface temperatures** (SSTs) **are lower.**



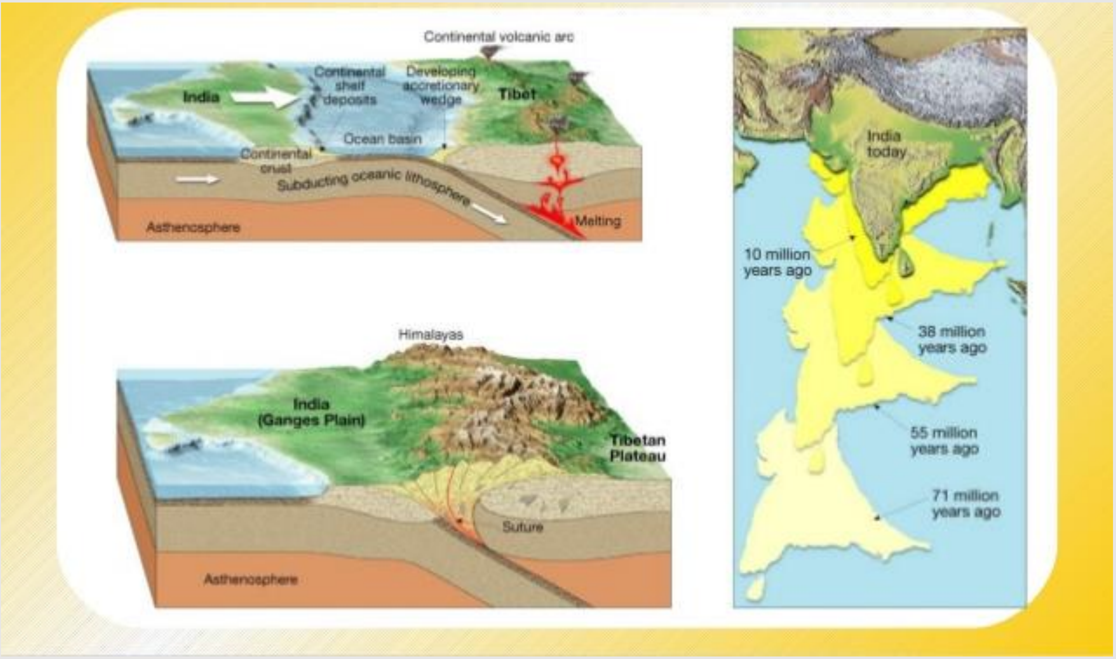
The causes of Icehouse climates are much debated and **less is known about the transition** periods between greenhouse and icehouse climates. One important aspect is clearly that the **decline of CO_2 in the atmosphere**, possibly due to **low volcanic activity** and the **removal by weathering.**

Other important issues are the **movement of the tectonic plates** and the opening and closing of **oceanic gateways.** These seem to play a crucial part in **Icehouse Earths** because they can bring forth **cool waters from very deep-water circulations** that could assist in creating **ice sheets or thermal isolation of areas**.



An example of this occurring is the **opening of the Tasmanian gateway**, 36.5 million years ago that **separated Australia and Antarc**tica and which is believed to have set off the **Cenozoic icehouse**.

Tectonic activity forms **mountain belts during the collision** of two plates. The revealed **fresh soils act as 'scrubbers' removing carbon dioxide**, which can significantly affect the greenhouse effect in the atmosphere. An example of this being the collision between the Indian subcontinent and the Asian continent, which created the **Himalayan Mountains about 50 Ma**. This led to an estimated order of magnitude **increase in the rates of weathering** and **erosion,** which consequently **removed** much of the **CO_2** from the atmosphere, therefore acting as a driver of climate change.



Runaway effects

Runaway effects occur when the delicate equilibrium between solar radiation being absorbed by the earth and solar radiation being reflected back out to space is disturbed.

1. The huge increase in ice/snow coverage during an **icehouse period** increases the reflection of solar radiation back into space due to the **high albedo** – so then the temperature drops and there is more snowfall/ice formation **exacerbating** the **albedo effect**. This could result in the entire Earth becoming iced over – '**Snowball Earth'**
   If the albedo is higher, and the Earth is more reflective, more of the radiation is returned to space, and the planet cools.
2. A **small increase in temperature** allows **oceans to release more CO_2 than they absorb** (solubility of CO_2 falls as temperature rises) and so **atmospheric CO_2 increases** resulting in the absorption of more IR radiation produced by the reflection of the sun's radiation from the Earth's surface. This trapping of IR radiation heats up the atmosphere/Earth further so that more CO_2 is released **exacerbating the greenhouse effect.**

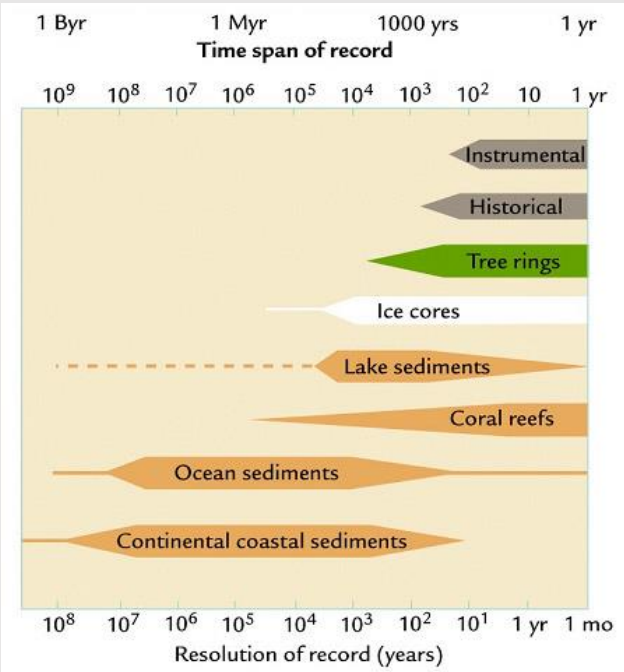
   Moreover, as temperatures rise, more water vapour is present in the atmosphere due to increased evaporation and water vapour is the single largest greenhouse gas in the atmosphere.

CLIMATE PROXIES

- **Climate proxies**: are **preserved characteristics**, which were **dependent on** a given **metrological variable** when they formed, and therefore, act as an **indirect of past climate**.

Reliable modern records of climate only began in the 1880s, proxies provide a means for scientists to determine climatic patterns before record-keeping began.

- Ice cores – isotopes
- Tree rings & fossilized leaves
- Glacial varves/lake sediment with spores and pollen present
- Boreholes
- Corals
- Carbonate skeletons
- Calcite chemistry from microfossils (like foraminifera), bivalves, gastropods, belemnites etc.
- Volcanic ash layers
- Lichen



OXYGEN ISOTOPES

Water is a substance with the chemical formula H_2O. It has 2 hydrogen atoms covalently bonded to a single **oxygen atom in every molecule**. Oxygen has two main (**stable) isotopes** (^{16}**O &** ^{18}**O**).

- ^{16}O is the lighter isotope which is more abundant → 99.7%
- ^{18}O is the heavier isotope which is **less abundant** → 0.25%

The lighter ^{16}O is removed more easily from reservoirs/bodies of water during evaporation than water containing the heavier ^{18}O. ^{18}O is left behind in the ocean/waters and so the ratio of the two isotopes change.

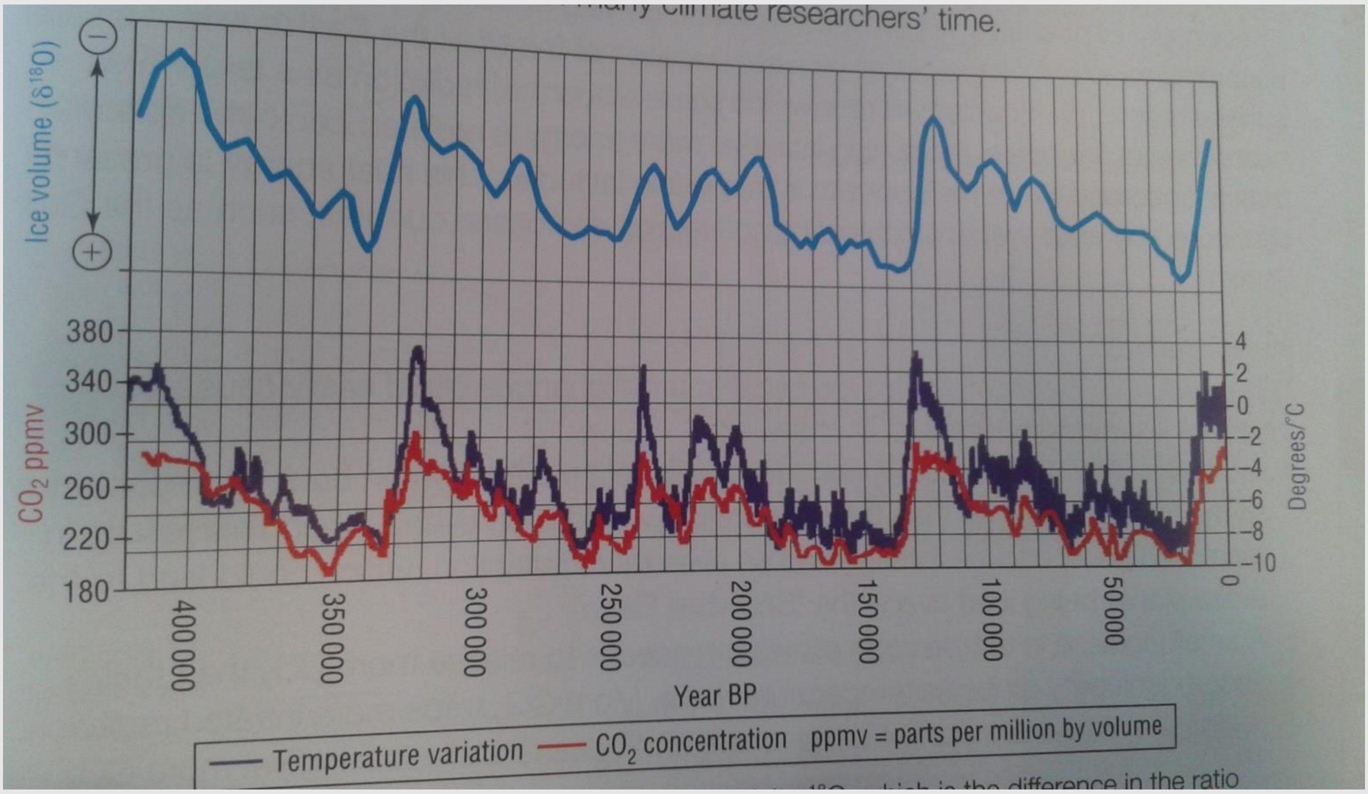
Under normal circumstances, the **evaporated water is returned back to the ocean** in rain, and this ra**tio is 'reset' back to the background level.**
However, during **glaciation periods**, the lighter isotope becomes trapped, as snow falls in the poles and the water freezes so that more **^{16}O is locked in ice sheets, glaciers and icecaps** etc. The ratio of ^{16}O to ^{18}O will decreases.
More ^{18}O is present in cooler temperatures than warmer temperatures.

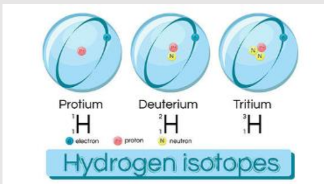
The effect can be measured in two ways:

1. Measure the **isotopic ratios** present in an ice-core from the poles.
2. Measures the **carbonate chemistry of marine organisms** that build their shells from the **carbonate ions present in water**.

Both of these sample sites, preserve the isotopic **ratio of ^{16}O : ^{18}O** (But of course **they record opposite effects**; One is sampling the ice and the other the ocean). These isotopic ratios act as geological proxies for determining the climate of the past.

Carbonate formed in higher, tropical and temperate climates will have a **higher proportion of ^{16}O** but carbonates in cooler, polar temperatures will have a low proportion of ^{16}O and an increased amount of ^{18}O . The oxygen in the **calcium carbonate** of shells of **bivalves, belemnites and microfossils like foraminifera** comes from the **sea water and carbon dioxide**. This is how shells preserve ratios of ^{16}O and ^{18}O.





A similar concept is applied for the heavier isotope of helium – Deuterium. Water molecules containing the Deuterium nuclei are less likely to evaporate than water molecules that have protium nuclei.

The water is locked in ice cores. And hydrogen volatiles become trapped in coal and other organic material that is preserved.

CARBON ISOTOPES

^{12}C = Light Carbon – the common isotope – 98.9%
^{13}C = Heavy Carbon – the rare isotope – 1.1%

^{12}C accounts for the majority of carbon in the global **carbon cycle**. The ratio of the two carbon isotopes is temperature dependent.
The change in **^{13}C values from pelagic and benthic fossils** can be correlated with climate change.

Plants will **preferentially take up ^{12}C** (from the **atmosphere and soils** since a lighter isotope is more energetically favourable). During **glacial periods**, the **terrestrial biomass greatly reduces** so there is **less vegetation** and so **less uptake of ^{12}C**. This causes the ratio of **^{13}C/^{12}C in the ocean to decrease**. There is **more ^{12}C in the ocean** and so relatively less ^{13}C. **Shells contain more ^{12}C than ^{13}C** in the ***calcium carbonate*** (aragonite or calcite) test of marine organisms (microfossils, bivalves, etc.).

Increases in temperature equate favour vegetation growth and photosynthesis so the relative proportion of ^{13}C increases.

Carbon isotopes are more useful than oxygen isotopes for stratigraphic purposes in the **remote past up to 10Ma** because they are **more resistant to diagenetic change**.

CLIMATE CHANGE

In recent years there has been an increased level of debate between scientists and politicians around the world over mankind's influence on global climate. Opinions vary on exactly what changes have occurred and what the future will bring, the majority of scientists believe that the effects we are seeing are too rapid and extreme to be caused by natural climate change.

We currently live in an icehouse period, where large continental ice sheets exist at both poles. The onset of this icehouse began in Antarctica 34 Ma and in the Arctic 2 Ma. The Earth has been in deep freeze, a snowball Earth, at least three times in its history – where ice sheets extend from the poles to the tropics.

The consequences of climate change are not limited to increase and decreases in global temperature, but temperature is always a crucial factor, so finding palaeotemperature is the focus of many climate reaserchers' time.

EXTINCTION OF SPECIES

He extinction of species can be influenced by climate change. Most organisms thrive in a relatively limited range of conditions, and if the conditions in an area change, the type of species there alters. If the change happens on a global scale, then whole species or groups of species can be wiped out.

An example of this is the mass extinction at the Permian-Triassic boundary. 96% of marine life and 70% of terrestrial life became extinct. This followed the glaciation that affected Antarctica, Africa, South America, Australia and India when they were all joined as part of Gondwanaland. It was similar to the current icehouse, with ice sheets in the southern hemisphere and low atmospheric carbon dioxide levels.