WHAT WILL YOU FIND HERE

PALEOCLIMATOLOGY IN A NUTSHELL

BACKGROUND MATERIAL FOR TEACHERS

ARCTIC ISSUES:
STUDYING PAST ENVIRONMENTS

BASIC FACTS

What is paleoclimatology, archives and proxies

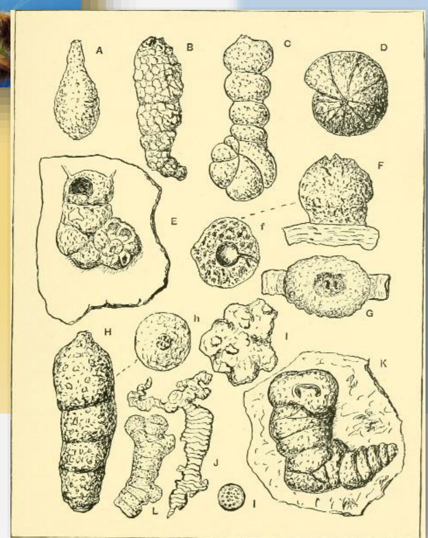
Climate change in the past: when and why

Peatlands: what are they, what's the issue and why is it important.

RESEARCH METHODS

How do scientists interpret natural records?

- Ice caps and glaciers – see EDUCATIONAL TOOl-KIT GLACIER
- Peatlands
- Tree rings
- Coral reefs
- Pollen
- Foraminifera



ADVANCED MATERIALS

Environmental history

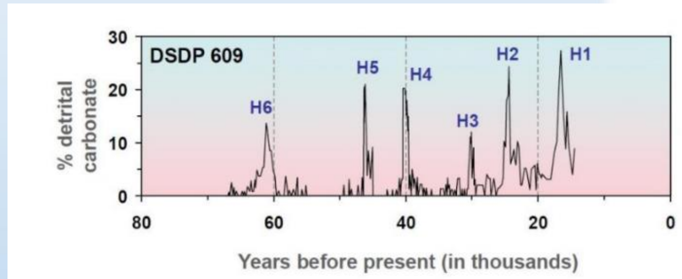
Cosmogenic isotopes

5 FUN FACTS

Peatland Cinderella

The Challenger Mission

Death of a Bishop written in ice cores



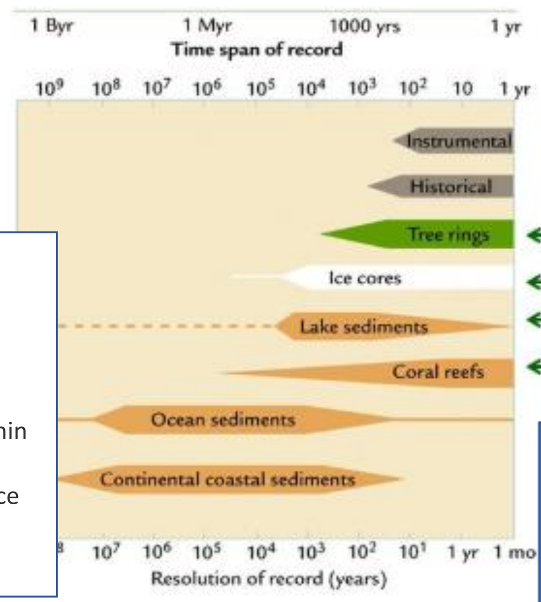
Pack rats time capsules

The oldest tree records

Paleoclimatologists seek to explain climate variations for all parts of the Earth during any given geologic period, beginning with the time of the Earth's formation. Many related fields contribute to the field of paleoclimatology, but the basic research data mainly from geology and paleobotany; speculative attempts at explanation have come largely from astronomy, a physics, meteorology, and geophysics. Since modern records do not outline most of Earth's climatic past, scientists n data preserved in nature over the millennia in paleological remains referred to as proxy records.

How do we know the time period represented by a paleoclimate record?

A variety of analytical techniques are used to determine the ages of the archives and proxies. Typically, dating is used to establish the time of onset, termination, and rate of change of climate events. Many of the dating techniques employed are based on analysing the nature of radioactive isotopes (e.g., radiocarbon, uranium-thorium) present in sample material. These dating techniques are used in conjunction with other methods such as biostratigraphy (which uses the fossil assemblages contained within a sample to estimate its age) and counting tree rings or annual sediment layers deposited ice and lakes. Other techniques such as surface exposure dating methods are used to estimate the amount of time a sample material such as a boulder deposited by an ice sheet or shoreline has been exposed on the Earth's surface to cosmic rays. Whenever possible, scientists utilize more than one dating method in order to maximize the accuracy and precision of their findings.



• Proxies that record annual growth patterns can indicate year to year variations in climate

← -tree rings
← -ice cores
← -deep lake sediments
← -coral reefs

ARCHIVES vs PROXIES
Archives are geological (e.g. sediments) or biological (e.g. tree rings) materials that preserve PROXIES (e.g. pollen)

Proxies are found in different ***archives*** such as tree-rings, ice-cores, corals, ocean or lake sediment cores that cover different time periods at a range of t can be quantified as the **time difference $\Delta t = t_2 - t_1$ between two adjacent samples t_1 and t_2.** The smaller Δt the higher the resolution. Written historical accounts can be used to reconstruct past climatic conditions at very high temporal resolution – **some ancient documents contain daily weather entries – back to about 1,000 years, but there are only a limited number of such records available.**

WHAT DO WE TRACE?
Temperature
Precipitation
Salinity

WHY HAS CLIMATE CHANGED IN THE PAST?

The major climate changes of the past, before humans started influencing environment on large scale, occurred because the climate was driven to change by some external change, which is typically called a climate forcing. These forcings include changes in the intensity of the sun's radiation, volcanic eruptions (which generally cause a short-term cooling), rapid releases of greenhouse gases, and changes in Earth's orbit. At the boundary of the Paleocene and Eocene epochs, 55 million years ago, there was a rapid peak in the Earth's temperature, a sudden global warming that resulted in the Paleocene-Eocene Thermal Maximum (PETM). It is thought that it may have been caused by a sudden release of greenhouse gases into the atmosphere. The sea temperature rose between 5–8 degrees Celsius in just a few thousand years. This sudden change in climate is associated with an extinction event of marine species and changes in the circulation of both the atmosphere and the oceans. The rapid rise in temperature, linked with an increase in atmospheric greenhouse gases can be compared to our climate today and for this reason it is of great interest to researchers.

One of the warmest periods in the Earth's history was the Cretaceous, from 140 to 65 million years ago. The Earth was then several degrees warmer than today and is described as having a 'greenhouse' climate. The poles were warm and at times there may have been no ice on them at all. There is even evidence of temperate forests growing in the Arctic and Antarctic. As 'greenhouse' temperatures were reached, the world's ice melted, which caused significant sea level rise. The Quaternary (the past 2.6 million years) has seen great changes in the climate that caused ice sheets to advance from the poles into usually temper.

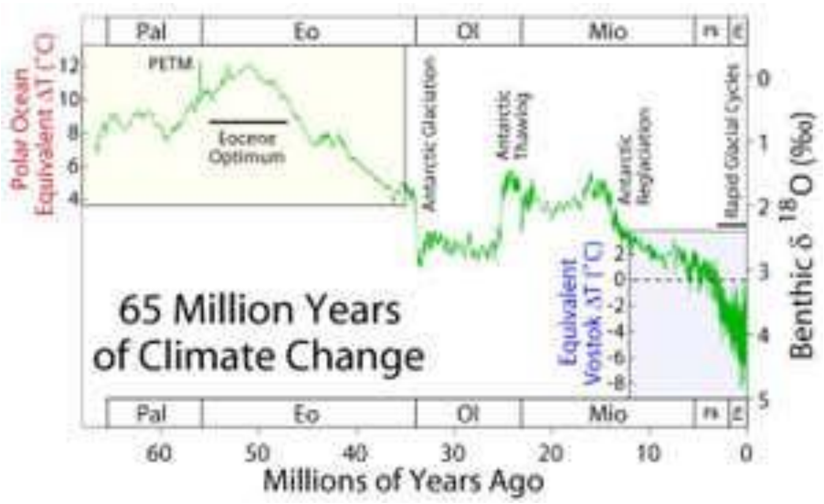


Image: www.newscientist.com

Image: www.universetoday.com

Era	Period	Epoch	Age
Cenozoic	Quaternary	Holocene	0.01 Ma
		Pleistocene	1.8 Ma
	Tertiary	Pliocene	5 Ma
		Miocene	24 Ma
		Oligocene	34 Ma
		Eocene	55 Ma
		Paleocene	65 Ma
Mesozoic	Cretaceous	Late	99 Ma
		Early	144 Ma
	Jurassic	Late	159 Ma
		Middle	180 Ma
		Early	206 Ma

Ma: Million years before present

Peatlands are the largest natural terrestrial carbon store; the area covered by near natural peatland worldwide (>3 million km^2) sequesters 0.37 gigatonnes of carbon dioxide (CO_2) a year – storing more carbon than all other vegetation types in the world combined. **Degraded peatlands, however, contribute disproportionally to global greenhouse gas (GHG) emissions, with approximately 25% of all CO_2 emissions from the land use sector.** Peatlands only account for ~3% of the terrestrial surface. Nevertheless, they may store ~644 Gt of carbon - 21% of the global total soil organic C stock

The overuse, exploitation and drainage of peatland habitats have a host of environmental implications such as land subsidence, wildfires and disruption of the global carbon balance.

THREATS TO PEATLANDS: Afforestation, Agricultural Reclamation, , Burning, Dumping, Erosion, Overgrazing, Tourism etc.

WHERE CAN WE FIND PEATLANDS?

Peatlands are most common across the boreal and subarctic zones of the Northern Hemipshere. Their surface is estimated at ca. 4 mln km ^{2} making them 70% of natural freshwater wetland or 3% of Earth's land surface. Peatlands are strongly influenced by hydrology, chemistry, and associated flora and vegetation. Six countries (boreal Russia, Canada, USA, Finland, Sweden, and tropical Indonesia) together account for 93% of all known peatland area (Joosten and Clarke, 2002; Wieder et al., 2006). Southern hemisphere peatlands are far less abundant, perhaps owing to limited land with appropriate conditions for peatland initiation and development.

HOW ARE PEATLANDS FORMED?

Peat is the accumulation of organic material (e.g., plants or mosses) that has been formed on the spot and has not been transported after its formation. the production of organic matter exceeds its decomposition and a net accumulation of peat results. Bogs or peatlands are wetlands containing 90% water and 10% dead plants. Peat is the result of the accumulation of partially decayed plants over thousands of years. The dead plants don't rot because they grow in waterlogged conditions where there is little oxygen. Bacteria and fungi - the agents of decay are prevented from working in these conditions. Where the water level is stable near the peat surface (just below, at, or just above), the remains of dead plants and mosses do not fully decompose due to the absence of oxygen, and therefore a layer of organic material accumulates over time where litter deposition exceeds anaerobic decomposition (i.e., in the absence of oxygen). Peat has been on our planet for around 360 million years. **Some peatlands in existence today took more than 10,000 years to develop.**

ECOSYSTEM SERVICES

Peatlands perform an array of ecological functions that we have only recently begun to fully document. There are numerous environmental benefits that peatlands provide, including:

Climate mitigation

They hold a vast stock of carbon in their soils and can add more by sequestering carbon from the atmosphere. But this natural carbon capture and storage ability can only happen if peatland habitats are healthy and functioning. Peatlands (lands with peat at the surface) are highly space-effective carbon stocks: they cover only 3% of the land, but contain more carbon than the entire forest biomass of the world. When peatlands are drained, the preserved carbon and nitrogen are released as greenhouse gases to the atmosphere and as nitrate to the surface water

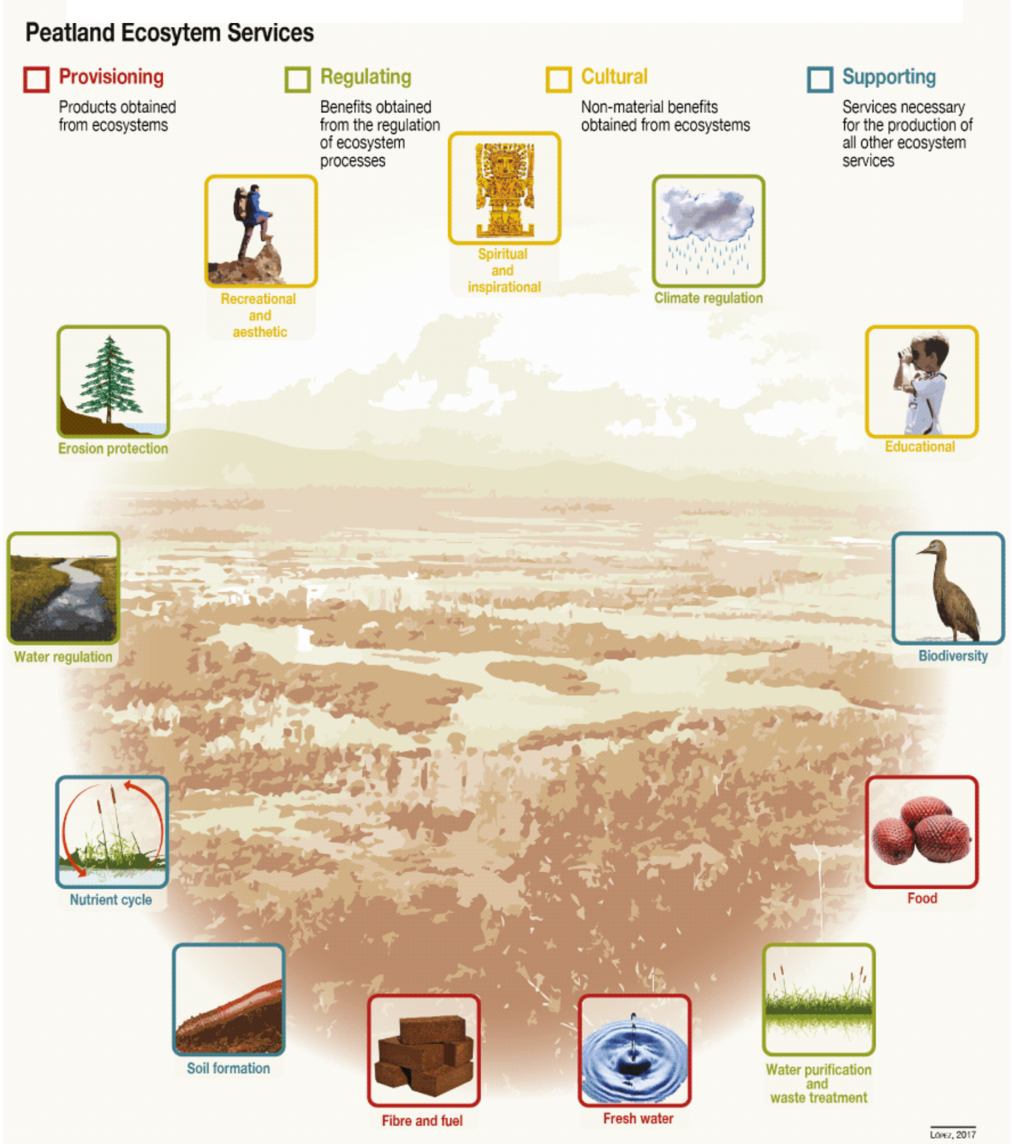
Flood management

Near-natural peatlands can store large quantities of water thanks to the sponginess of peat and the buoyancy of the vegetation. The absorbancy of Sphagnum moss which is common in European peatlands was so good, that it was used in bandages during First World War!

Nutrient balance and retentions

Biodiversity

http://www.grida.no/resources/12533, author: Nieves Lopez Izquierdo



Why are peatlands interesting from a point of view of studying past environments? Peat bogs can preserve wood, pollen, even bodies for thousands of years. provision of paleo-environmental **archives;** for this reason, they have been called 'Living History Books'.

The growth of plants and animals on the surface is highly sensitive to changes in precipitation and temperature, which cause the position of the water table, at or near the bog surface, to fluctuate over time.

If the climate gets wetter or cooler, the plants change in response. If it gets drier or warmer, they change again. As the bog grows upwards, it preserves a record of all of these changes and we can now stand on the surface and take a core back through all the accumulated layers to reconstruct the history of the climate. Which brings us nicely back to my sinking wellies.

Scientists retrieve cores, and study the plants that make up the peat (mainly mosses of the genus *Sphagnum*) and microscopic, single-celled organisms called testate amoebae. These amoebae grow a shell, or test, that is readily preserved in the peat sediments, and can be used as species identification

Then, samples are taken at regular intervals down the core, stretching further into the past the deeper we go.

We can then examine the fine details of moss leaves, other plants and testate amoebae under a microscope and build up a picture of how conditions on the bog have changed over time. We know this relates to past climate because we study ombrotrophic, or 'rain-fed', bogs, which receive all their water and nutrients from the atmosphere.

Researchers also look at changes in the ratios between different oxygen and carbon isotopes (lighter and heavier versions of these atoms) preserved in the cellulose of the moss leaves.

TREE RINGS

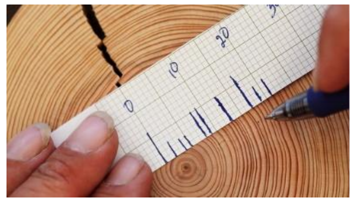
This field of research is known as dendrochronology. Scientists can use tree rings to measure the age of a tree and learn more about the local climatic conditions the tree experienced during its lifetime. More than a century of dendrochronology research has now resulted in a network of tree-ring chronologies covering all the continents except Antarctica. This global tree-ring database is most dense in the mid- and high latitudes in the Northern Hemisphere, due to a mix of the history, location, and scholarly focus of major tree ring laboratories and individual researchers, the location and existence of forest regions with long-lived trees.
The proxy climate record preserved by tree ring data **spans** a period of about 9,000 years. The **resolution** of tree ring data is one year. Tree ring records are amongst the highest resolution proxy climate data types, but they also have one of the shortest time spans over which they apply as compared to other proxies.

The concept that trees produce annual growth, underlying modern dendrochronology, it was presented as early as 322 B.C.E. by Theophrastus. The first mention of a relationship jars with weather conditions were found in the notes Leonardo da Vinci from 1482–1498. to determine the age of the tree.

Dendrochronology has been used since XVIII th century, and has Basic Principles :

- Uniformity - any individual tree ring record may be calibrated against the sum total of the existing record in order that it can be placed in the chronology. When calibrated, we should be able to tell precisely which year a certain ring was created
- Limiting factors - that certain weather and climate conditions have an effect on the tree ring growth in any given year or season
- Aggregation - The strength of the tree ring record is that variations for local conditions are taken into account and any tree ring data set *should* slot nicely into the existing record
- Ecological amplitude - Certain tree species will only grow in certain areas. Some like wet, salty soil and others prefer dry, acidic soil; there are preferences for temperature, humidity and most have an elevation limit. The best records are those taken from the margins of the land that the species prefer because it is here we see the most variations in tree ring growth

You don't have to cut down the tree to study tree ring! Collecting a sample is possible with an instrument called an increment borer. The borer extracts a thin strip of wood that goes all the way to the center of the tree. When you pull the strip out, you can count the rings on the strip of wood and the tree is still healthy. In some cases also wood from old buildings is used (especially in Europe)



Part of the dendrochronological record is also to measure the amount of **carbon in the tree sample**, because of this lengthy record we will know the **exact date that a tree ring was created inside the living organism**. This ongoing record then, is vital to dating organic material through radiocarbon dating. The amount of radiocarbon-14 isotope in the artefact is compared against tree ring data for calibration, and it is always calibrated against organic material of known age.
The comprehensive nature of the tree ring record is the perfect database against which to calibrate when we are trying to date organic materials. Most records will be unique and this should, in theory, give an absolute date for the artefact; if they have an identical level of the isotope, we can safely conclude that they are of the same age . Finding a precise year is rarely so clear-cut so a range of dates is selected, hence that radiocarbon dates always come with an error factor. 4750BP +/-30 years for example.

Salix Arctica

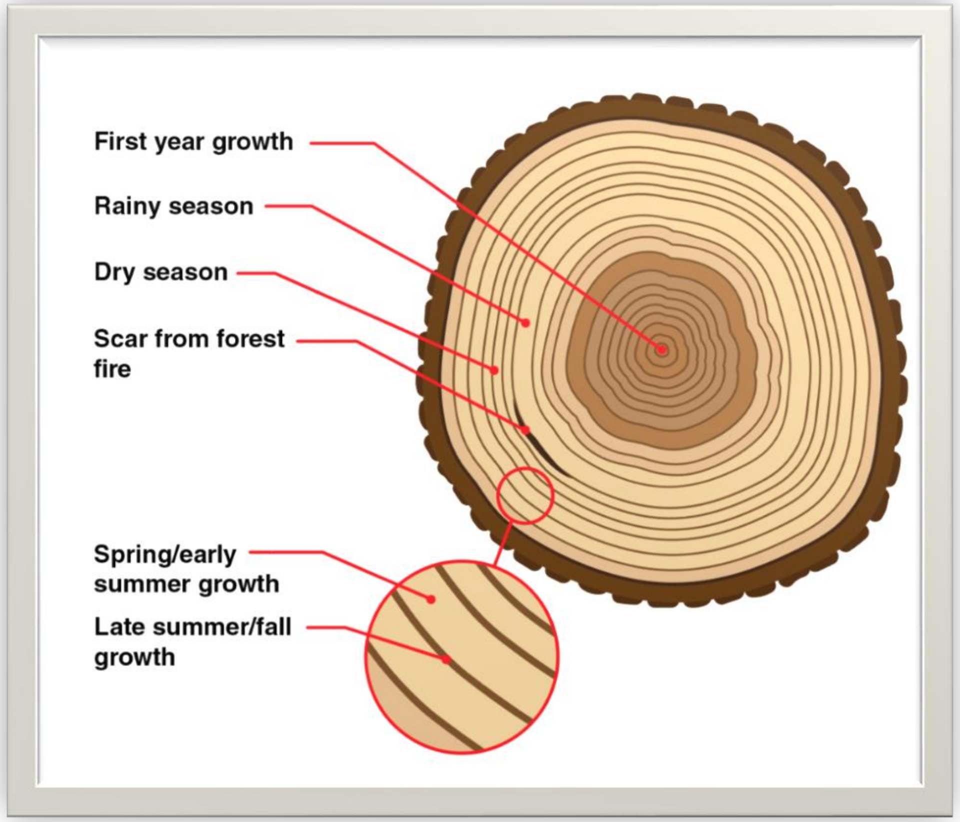


Image: https://climate.nasa.gov/

The rings can tell us how old the tree is, and what the weather was like during each year of the tree's life. The light-colored rings represent wood that grew in the spring and early summer, while the dark rings represent wood that grew in the late summer and fall. **One light ring plus one dark ring equals one year of the tree's life.**

Arctic forest?
There has been a growing interest in recent years in dendroclimatic research in polar and subpolar areas. Despite the lack of trees, woody shrub vegetation occurs in the Arctic.
These small, creeping tundra plants, such like polar willow, or dwarf birch, produce annual growth that can be used in dendrochronological analyzes.
Temporal scale seems smaller compared to the information written in tree rings, because the maximum the age of tundra bushes is about 120 years.
Shrubs allow reconstruction of selected climatic elements, reaching beyond period of available instrumental measurements. Is this is especially important considering the dramatic and very rapid climate change observed in the polar regions.
At the beginning of the 21st century, the shrubs reacted to temperature rise and their annual growth increased; but then they have been dealing with the so-called drought stress, so annual growth became scarce. So the positive influence of temperature rise (greening) turned into browning of tundra.
This current Arctic drying is clearly visible also e.g. in Siberia or the Canadian Arctic, where more frequent fires are observed.

POLLEN

Pollen grains are the sperm-carrying reproductive bodies of seed plants. Each of these grains has its very own unique shape depending on what plant it comes from, and their walls are made of a substance known as *sporopollenin*, which is very chemically stable and strong.

When pollen grains are washed or blown into bodies of water, their tough outer walls allow them to be preserved in sediment layers in the bottoms of ponds, lakes, or oceans. Because of their unique shapes, scientists can then take a core sample of the sediment layers and determine what kinds of plants were growing at the time the sediment was deposited. Knowing what types of plants were growing in the area allows the scientists to make inferences about the climate at that time by using knowledge about modern and historical distributions of plants in relation to climate.

Once they take a core sample, the scientists isolate the pollen and spores from the sediments and rocks using both chemical and physical means. The grains are very small, typically between 10 and 200 micrometers, which requires mounting them on microscope slides for examination.The scientists then count and identify the grains using a compound microscope and generate diagrams of the type and abundance of pollen in their samples.

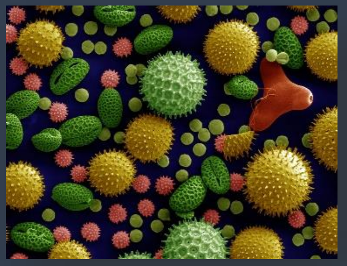
By analyzing pollen from well-dated sediment cores, scientists can obtain records of changes in vegetation going back hundreds of thousands, and even millions of years. Not only can pollen records tell us about the past climate, but they can also tell us how we are impacting our climate. Comparing trends in vegetation from the last few thousand years to recent trends in vegetation can also help scientists determine whether human activities have had significant impacts on ecosystems.

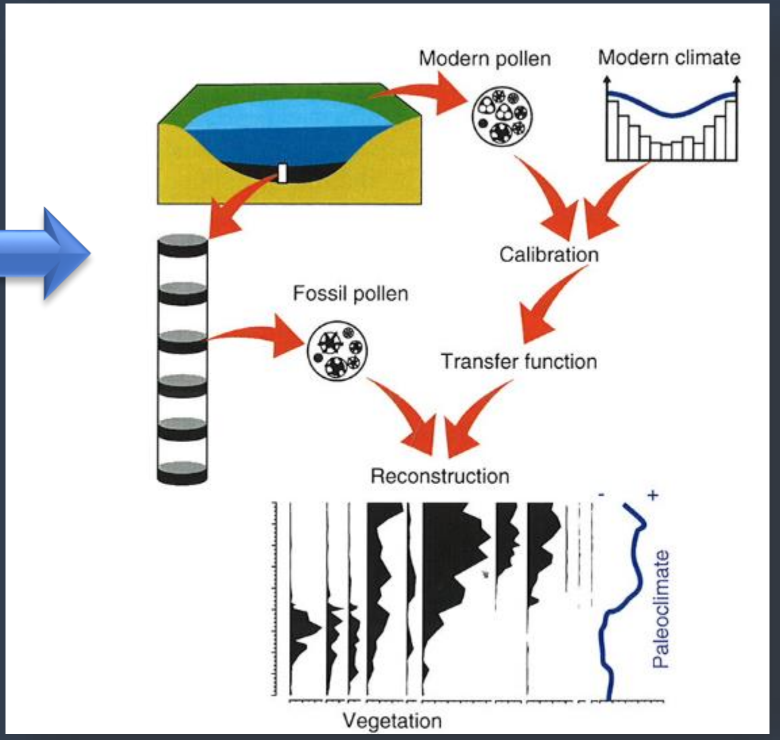
Certain types of pollen occur in very specific areas; for example, the Black Spruce *(Picea mariana)*, an evergreen tree, grows in taiga forests ('boreal' or 'snow forest') in high latitudes. These trees produce a certain type of pollen that is only found in cold, high latitude regions of the world today. So, if we find Black Spruce pollen in old rocks or ocean sediments at lower latitudes (closer to the equator), we can interpret that the Earth may have been colder in the geologic past. By knowing what kinds of pollen occur in each climate belt today, we can then interpret what the climate belts of the past looked like by mapping out where ancient pollen is found in old rocks and sediments.

SOURCE:
POLLEN METHODS AND STUDIES | Use of Pollen as Climate Proxies

December 2013, DOI: 10.1016/B978-0-444-53643-3.00180-1

In book: Encyclopedia of Quaternary Science





Physical Properties of Foraminiferal Shells that can be Used for Paleoproxies

CENSUS Counts of taxa, ecological or functional types
Presence/absence
Semi-quantitative abundance estimates
Absolute abundances
Relative abundances

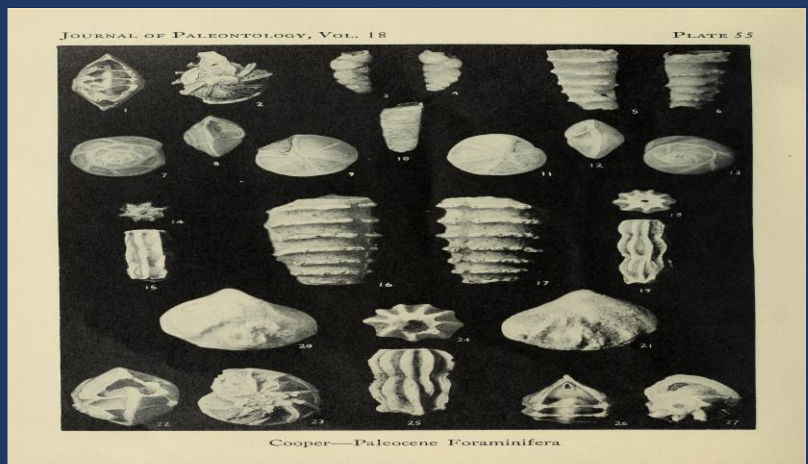
BIOMETRY Measurements made on individual specimens
Morphology — size, shape
Shell ultrastructure
Colour and weight

MODIFICATION Changes to fossils incurred after deposition
Preservation, fragmentation

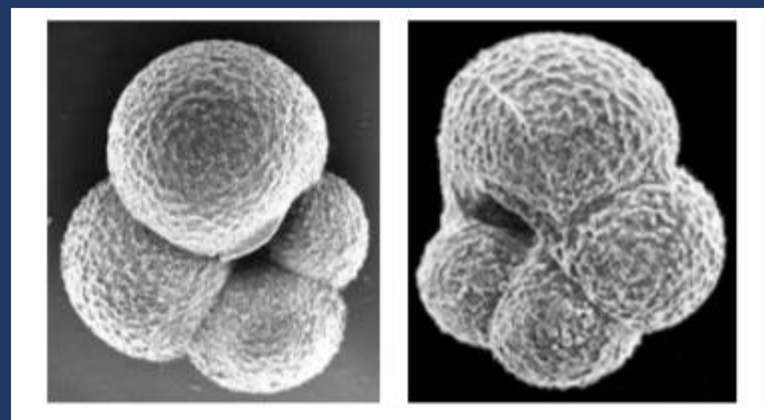
Some species are geologically short-lived and some forms are only found in specific environments. Therefore, a paleontologist can examine the specimens in a small rock sample like those recovered during the drilling of oil wells and determine the geologic age and environment when the rock formed. As a result, since the 1920's the oil industry has been an important employer of paleontologists who specialize in these microscopic fossils. Stratigraphic control using foraminifera is so precise that these fossils are even used to direct sideways drilling within an oil-bearing horizon to increase well productivity.

FORAMNIFERA

Planktonic foramnifera, also called **forams**, are protists with multi-chambered $CaCO_3$ (calcium carbonate) shells, and due to their abundance in the fossil record, are commonly used in reconstructing paleoceanographic records.
They live in the upper zone of the open ocean, and passively incorporate geochemical signatures of their environment during their growth. Planktonic forams are widely used in paleoclimate research, because their high preservation potential, rich fossil record and temporal resolution (that is, how precisely they indicate time in which some conditions were present), in conjunction with their integrated geochemical signatures, can provide valuable information on ocean productivity and temperature. The oldest fossils of benthic foraminifera date back to the Cambrian period (so they are older than **485 million years**)!
How do foramnifera help scientists determine past temperatures?
Oxygen in sea water comes in two important varieties for paleoclimate research: heavy and light. The ratio of these different types of oxygen in the shells can reveal how cold the ocean was and how much ice existed at the time the shell formed. In general, the shells contain more heavy oxygen when ocean waters are cold and ice covers the Earth.



The microscopic foraminifera Neogloboquadrina pachyderma (N. pachyderma) serves as a particularly useful indicator of ocean temperature. These foraminifera are found in two forms. When the ocean water is relatively warm, this organism tends to grow into a right-coiling form. When the water is relatively cold, N. pachyderma grows into a left-coiling form. When these organisms die, they settle to the ocean bottom and their skeletons are incorporated into the accumulating layers of sediment, preserving a record of the ocean temperature at the time each organism was alive.
Scientists study the record preserved in the sediment layers by drilling into the ocean bottom using a variety of coring devices. They obtain undisturbed sediment cores using hollow tubes. The sediment cores are then brought to the surface and analyzed. The age of the layers is determined using radioisotopic dating techniques, and each layer is carefully studied.



On the left- left coiling **N. pachyderma, On the right – right-coiling N. pachyderma (image:** https://store.lab-aids.com/)

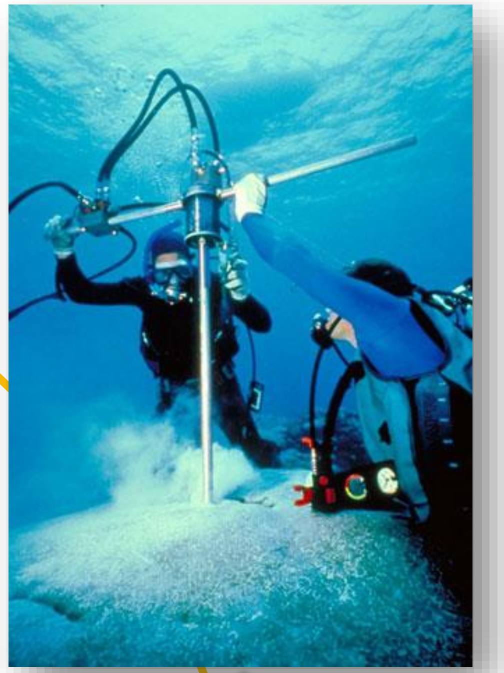
To gather data and information about coral growth bands, scientists I scuba gears dive down among the reefs. Once in position, they use a hollow, diamond-tipped drill bit to gather small core samples from the corals without injuring the animal. Sometimes the banding patterns in these samples are evident by visual inspection alone, but often scientists use x-ray imaging software to get a look at the patterns. The scientists then mark the varying layers by year and season and extract samples from the layers for precise chemical analysis.

CORAL REEFS

Obtaining climate and environmental records from corals can be a costly and time-consuming exercise. The first requirement is to locate suitable large corals and extract, using specialized coral coring equipment and highly qualified scuba divers, long coral cores (typically 5–7 cm in diameter). The core samples are returned to the laboratory, sliced, and X-rayed. There are two main types of records obtained from corals: (1) those associated with coral growth characteristics and (2) those associated with geochemical analysis of materials incorporated into the coral skeleton. The starting point for both is usually an X-ray image of the coral slice which reveals the annual density banding pattern and the growth direction which allows orientation of sampling transects for extracting coral growth variables and geochemical analyses. Computerized tomography, although still expensive, has recently been shown to be a useful and flexible new tool for measuring skeletal growth characteristics. The majority of measurements for tropical paleoclimatic reconstructions are now based on geochemical analyses of the coral skeleton itself. This involves drilling calcium carbonate powder at regular intervals along a major growth axis of the coral skeleton.

Coral reef records are especially sensitive to conditions in the world's oceans and seas.

Coral reefs are the massed skeletons formed by colonies of tiny animals called **coral polyps**. The polyps secrete the solid reef's rock-hard structural material which is composed of the mineral calcite (also called calcium carbonate, $CaCO_3$). Over time, the polyps migrate outward towards the ever-expanding surface of the coral reef, laying down layer upon layer of calcite beneath them. As corals grow, they form skeletons by making calcium carbonate from the ocean waters. The density of these calcium carbonate skeletons changes as the water temperature, light, and nutrient conditions change, giving coral skeletons formed in the summer a different density than those formed in the winter. Coral has a fairly narrow range of tolerance of environmental conditions in which it can grow; it thrives only in warm tropical or subtropical oceans, in clear, shallow water that allows enough sunlight to reach the coral to support the algal symbionts. This sensitivity to environmental factors makes coral a good gage of local climate conditions. Since coral are only prevalent in low-latitude oceans, the climate record they provide complementary data to those from tree rings and ice cores, which comes from intermediate and high latitude regions. Unlike tree ring records, it is not the thickness of the annual layers of coral that serves as the primary climate indicator from this source. Instead, the **composition of the layers** provides scientists with clues about past climates, while the layered structure allows them to precisely date the changes they find. As is the case with water found in ice cores, the relative abundance of the two naturally-occurring isotopes of oxygen (in calcite - $CaCO_3$) tells the climate tale encoded within coral skeletons. Varying ratios of oxygen-16 abundance as compared to oxygen-18 signal changes in the temperature of the ocean. As is so often the case with climate proxies, scientists must be careful in their analyses of the implications of 18O/16O ratios, for changes in salinity also can alter this balance.



Scientists in SCUBA gear use a drill to extract a coral sample from Clipperton Atoll
Source: https://eo.ucar.edu/

ENVIRONMENTAL HISTORY

Environmental history is a rather new discipline that came into being during the 1960's and 1970's. It was a direct consequence of the growing awareness of worldwide environmental problems such as pollution of water and air by pesticides, depletion of the ozone layer and the enhanced greenhouse effect caused by human activity. In this development historians started to look for the origins of the contemporary problems, drawing upon the knowledge of a whole field of scientific disciplines and specialisms which had been developed during the preceding century. For environmental - climate and vegetation history scientists rely on written sources, paintings, photographs and recorded instrumental observations. Historical documents contain a wealth of information about past climates but also descriptions of the landscape used to reconstruct climates and landscape change dating back several hundred years back in time. Observations of weather and climatic conditions as well as the landscape and resources such as forests and peat deposits (for fuel) can be found in farmers, travellers and gamekeepers diaries, newspaper accounts, ships logs and other written records. Landscape paintings or photographs can provide information about woodland cover, use of the land and perceptions of landscapes. When properly evaluated, historical data can yield both qualitative and quantitative information about past climate and landscape change.

Frozen River Thames, December 1676. Painting by Abraham Hondius. Note Old London Bridge in the background 9Source: Wikipedia)

The **Little Ice Age** was a period of regionally cold conditions between roughly AD 1300 and 1850. There were two phases of the Little Ice Age, the first beginning around 1290 and continuing until the late 1400s. There was a slightly warmer period in the 1500s, after which the climate deteriorated substantially, with the coldest period between 1645 and 1715 . During this coldest phase of the Little Ice Age there are indications that average winter temperatures in Europe and North America were as much as 2°C lower than at present.

There is substantial historical evidence for the Little Ice Age. The Baltic Sea froze over, as did many of the rivers and lakes in Europe. Pack ice expanded far south into the Atlantic making shipping to Iceland and Greenland impossible for months. Winters were bitterly cold and summers were often cool and wet. These conditions led to widespread crop failure, famine, and population decline. The tree line and snowline dropped and glaciers advanced, overrunning towns and farms in the process. There were increased levels of social unrest as large portions of the population were reduced to starvation and poverty.

The prices of grain increased and wine became difficult to produce in many areas and commercial vineyards vanished in England. Fishing in northern Europe was also badly affected as cod migrated south to find warmer water. Storminess and flooding increased and in mountainous regions the treeline and snowline dropped. Iceland was one of the hardest hit areas. Sea ice, which today is far to the north, came down around Iceland. In some years, it was difficult to bring a ship ashore anywhere along the coast. Grain became impossible to grow and even hay crops failed. Volcanic eruptions made life even harder. Iceland lost half of its population during the Little Ice Age.

Tax records in Scandinavia show many farms were destroyed by advancing ice of glaciers and by melt water streams. Travellers in Scotland reported permanent snow cover over the Cairngorm Mountains in Scotland at an altitude of about 1200 metres. In the Alps, the glaciers advanced and threatened to bulldozed towns. Ice-dammed lakes burst periodically, destroying hundreds of buildings and killing many people.

What caused the Little Ice Age?

The earth does not have some magical average natural temperature to which it always returns. If it warms, the earth must be receiving more heat or retaining more heat. If it cools, then it must be receiving less heat from the Sun or radiating more into space, or both. The exact cause of the Little Ice Age is unknown, but there is a striking coincidence in the sunspot cycle and the timing of the Little Ice Age. During the Little Ice Age, there is a minimum in sunspots, indicating an inactive and possibly cooler sun. This absence of sunspots is called the Maunder Minimum. This occurred during the coldest period of the Little Ice Age between 1645 and 1715 AD. But models and temperature reconstructions suggest this would have reduced average global temperatures by 0.4ºC at most, which does not explain the regional cooling of the climate in Europe and North America.

North Atlantic Oscillation

What does explain a drop of up to 2 degrees C in winter temperatures? The North Atlantic is one of the most climatically unstable regions in the world. This is caused by a complex interaction between the atmosphere and the ocean. The main feature of this is the North Atlantic Oscillation (NAO), a seesaw of atmospheric pressure between a persistent high over the Azores and an equally persistent low over Iceland. Sometimes the pressure cells weaken and that has severe consequences for the weather in Europe.

It is now thought that during the Little Ice Age NAO Index was more persistent in so called negative mode. For this reason the regional variability during the Little Ice Age can be understood in terms of changes in atmospheric circulation patterns in the North Atlantic region.

The **Medieval Warm Period** (MWP) was a time of warm climate from about AD 900–1300, when temperatures in some regions of northern hemisphere were about 1°C warmer than at present.

The effects of the warm period were particularly evident in Europe, where grain crops flourished, alpine tree lines rose, many new cities arose, and the population more than doubled.

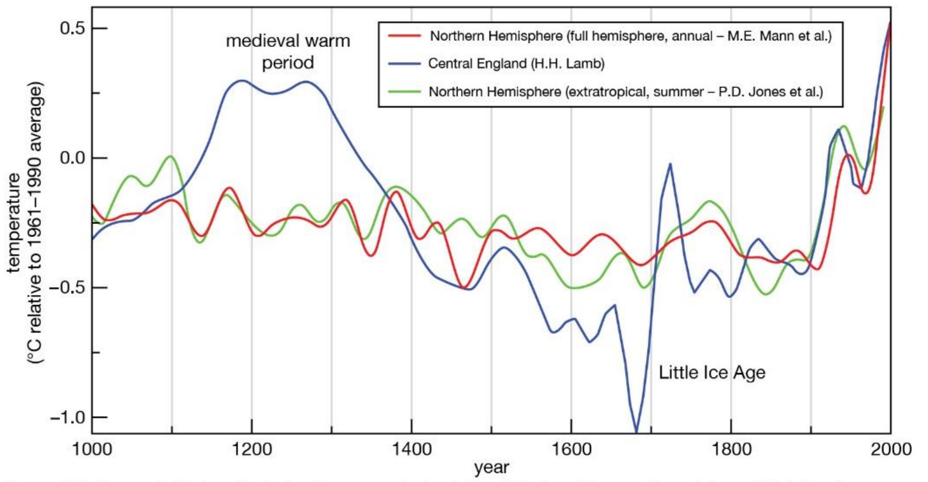
The Vikings took advantage of the climatic amelioration to colonize southern Greenland in 985 AD, when milder climates allowed favorable open-ocean conditions for navigation and fishing. The first Greenlanders brought grain seed, probably barley, oats, and rye, horses, cattle, pigs, sheep, and goats. The southern coastal area was forested at the time. Greenland settlements lasted about 500 years before cooling during the Little Ice Age ended the settlements.

About 620 farms have been excavated in Greenland.

During the Medieval Warm Period, wine grapes were grown as far north as England, where growing grapes is now not feasible. Wheat and oats were grown around Trondheim, Norway,

Winters, and Europe became largely dependent on grain crops.

Possible causes of the Medieval Warm Period include increased solar activity, decreased volcanic activity, and changes to ocean circulation.



Sources: M.E. Mann et al., "Northern Hemisphere Temperatures During the Past Millennium: Inferences, Uncertainties, and Limitations," *Geophysical Research Letters*, 26:759–762 (1999); P.D. Jones et al., "High-resolution Palaeoclimatic Records for the Last Millennium: Interpretation, Integration, and Comparison with General Circulation Model Control Run Temperatures," *Holocene*, 8:477–483 (1998); H.H. Lamb, "The Early Medieval Warm Epoch and Its Sequel," *Palaeogeography, Palaeoclimatology, Palaeoecology*, 1:13–37 (1965).

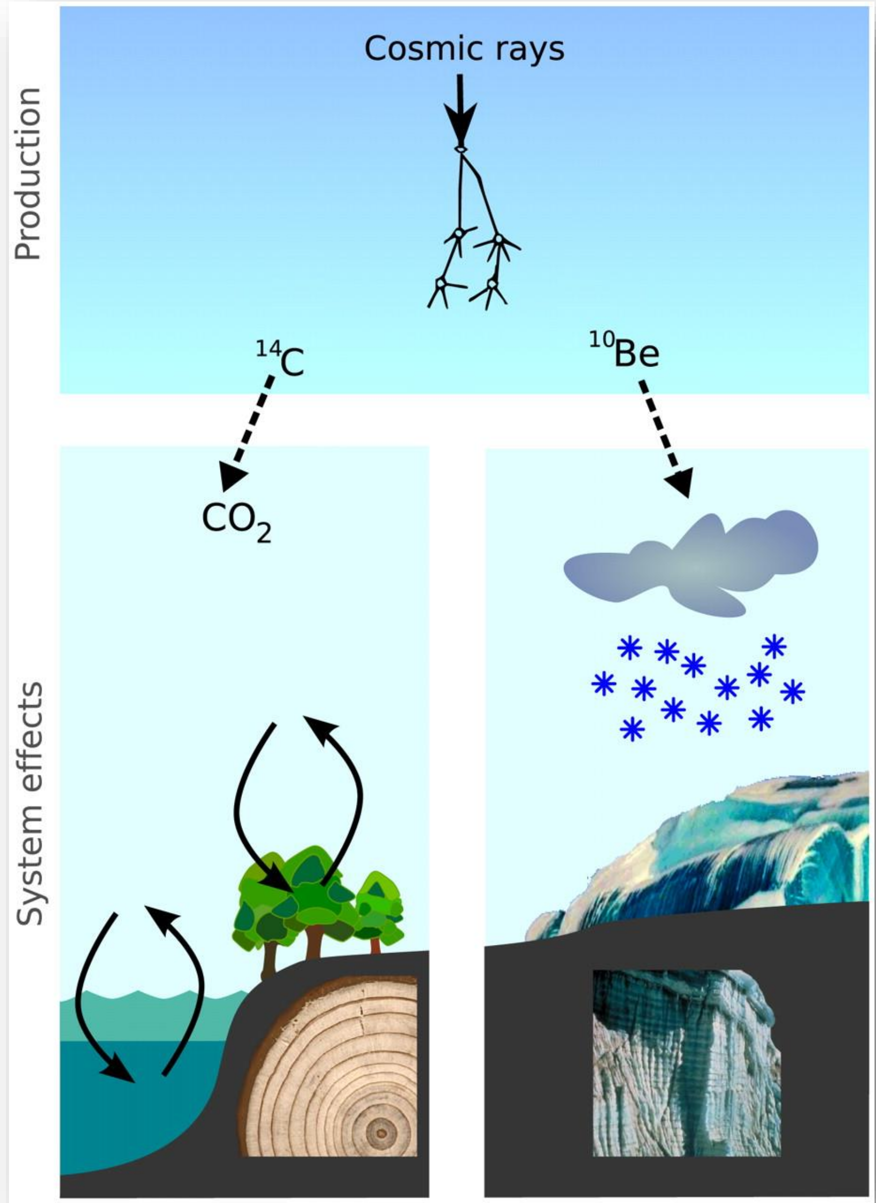
Source: britannica.com

One of the most important factors shaping the Earth's climate is solar activity, and more specifically - the amount of energy reaching the surface of the planet from the sun. Currently, we can measure solar activity using special instruments, also mounted on satellites. In the past, scientists counted spots on the Sun (the more active the star, the more spots). But how do we know what solar activity was prior to observation? Isotope research - this time radioactive - comes in handy. In the upper atmosphere several radioactive isotopes are produced when cosmic rays collide with atmospheric molecules at high speed. These isotopes are known as cosmogenic isotopes. The production rate of the cosmogenic isotopes depends on the strength of the cosmic radiation, which again varies with the strength of the Earth magnetic field and with the solar activity. Therefore, records of cosmogenic isotope production rates are invaluable for understanding the relation between past climate change, the Earth magnetic field, and variations in the solar activity. Currently, the exact influence of past and future variations in the solar activity on climate is much debated. The cosmogenic ice core profiles provide one of the key records to resolve this controversy.

COSMOGENIC ISOTOPES

10Be (Beryllium)

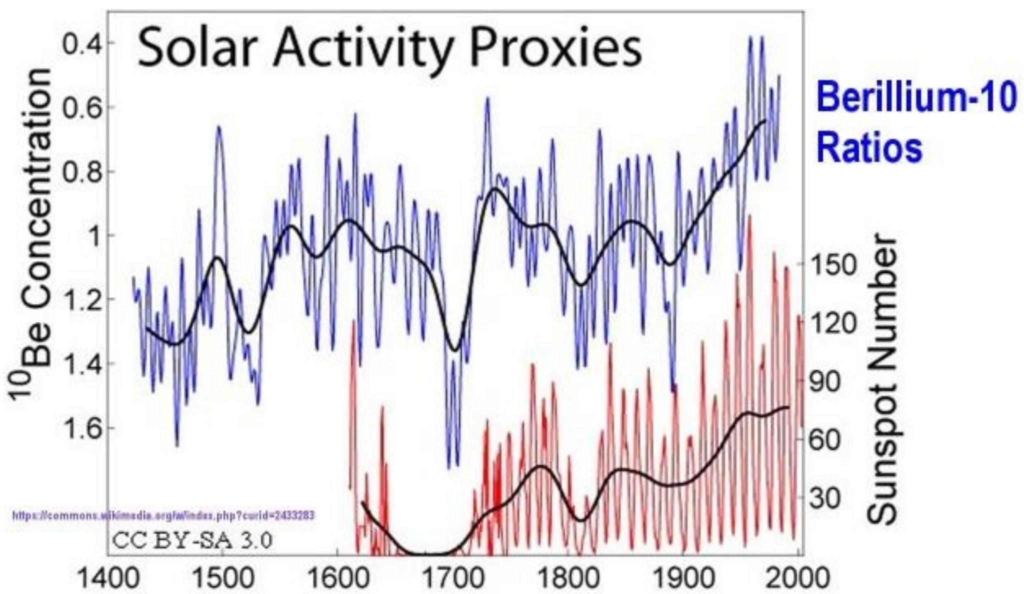
14C (Carbon)



Changes in solar activity mean not only fluctuations in the amount of energy reaching Earth. There are also changes in intensity of the magnetic field spread by our star. This field more or less protects the solar system from galactic cosmic radiation (accelerated charged particles - atomic nuclei - once emitted in our galaxy and rushing through space). When a high-energy (accelerated) cosmic ray molecule collides with an atomic nucleus located in a rock, soil or atmosphere, it can undergo nuclear transformation and cause the formation of a radioactive isotope that does not exist naturally on Earth (since the decay of such an atomic nucleus compared to the planet's existence is short, those that were on Earth during its creation have long ago collapsed). For example, the **beryllium 10Be** isotope is produced in the atmosphere by **extrasolar** cosmic rays (collisions with atoms of oxygen and nitrogen).. **The stronger the solar activity is, the less of this radiation reaches the Earth and the less 10Be is formed**. Based on the analysis of **10Be** content in ice cores, periods of increased solar activity can be determined. They are in very good compliance with solar activity determined by the number of spots.

The situation is similar with the **14C isotope**. The most well-known of the cosmogenic isotopes is probably Carbon-14 (^{14}C) which is widely applied for radiometric dating. However, the abundance of ^{14}C in ice sheets is very low, and ^{14}C-measurements can generally not be used for dating of ice cores. It is formed in the upper layers of the Earth's atmosphere as a result of the interaction of cosmic rays with 14N nitrogen. During periods of minimum solar activity - when its magnetic field weakens (and thus the cosmic ray stream strengthens) - more 14C isotope is formed, which, diffusing into the lower atmosphere, is deposited, among others in annual tree growths.

In the 1960s, as a result of nuclear weapon tests, 14C concentration in the atmosphere almost doubled, and later as the atoms moved to other carbon reservoirs (oceans and terrestrial ecosystems), it has fallen and is now 10% higher than in in the 1950s. On the occasion of the Cold War, we received a very handy tool for dating (for example, layers of glaciers) and tracking the flow of carbon in nature (for example, its propagation deep into the oceans). Estimations of solar activity obtained through the isotopes of various elements give not entirely unequivocal results related to, among others with differences in the processes to which samples from different regions were subjected, and changes in the Earth's magnetic field that affect the diversity of the inflow of charged cosmic ray particles to different regions of our planet. It would be handy to have a solar activity indicator that was formed a long time ago and was not exposed to these factors.
Where to get it Meteorites in which cosmic radionuclides are present, for example 44Ti, can be explored.



Source: 9,400 years of cosmic radiation and solar activity from ice cores and tree rings; Friedhelm Steinhilber et al. PNAS April 17, 2012 109 (16) 5967-5971

Death of a Bishop written in an ice core

The largest lead pollution of the atmosphere in the pre-industrial era occurred in northern Europe in the years 1150–1200. Such evidence was obtained by testing lead isotopes in Swedish lake sediments. The increase in lead pollution almost certainly reflects the increase in urban population and the development of the economy. These studies show that most pollutants were emitted in England, Germany, Wales and Poland. The British-American research team from the University of Notthingham, University of Maine, Long Island University and Harvard University used the latest techniques and evidence from written and archaeological sources to check it thoroughly, using a core taken from the Colle Gnifetti glacier in Switzerland. For example, in the core, we see pollution decreases in the years of the deaths of the three rulers mentioned. Interregnum and uncertainty caused by the death of the current ruler were associated with a decrease in orders for lead and silver, which is also visible in the records regarding collected taxes. In turn, from the tax records of 1190 and 1200, and therefore in the first year of the reign of Richard the Lionheart and John Without Earth, we see an increase in the amounts collected. Production increased because the political situation stabilized and the administration of the new ruler placed new orders. This is also clearly seen in ice core impurities.
A decrease in pollution is also observed in times of political crises or the ruler's absence. We see such a decline, for example, in 1170. This is the year of the culmination of the dispute between King Henry II and the Archbishop of Canterbury Thomas Becket, culminating in the murder of the bishop, which was known all over Europe.

H.M.S. Challenger –the expedition that changed everything

The Challenger expedition from 1872 to 1876 was the first global scientific cruise and delivered important data on the oceanography, biology, and sediment composition of all major ocean basins. The research included the documentation of microfossils in sediment samples. The scientific results of this expedition were published in more than 50 volumes. One volume was dedicated to the description and illustration of radiolarians by Ernst Haeckel (1887), another volume to the documentation of foraminifera. Data obtained are to this day matter of reexamination!

How old are tree records?

The oldest dendrochronological records for the southern hemisphere are provided by annual growth of Kauri from New Zealand (4,500 years) and Patagonian cypress from Chile and Argentina (3600 years).
In conducted research at the turn of the 20th and 21st century data from the analysis
In Europe, the longest
reconstructions of thermal conditions were made for Alpine area (AD 755 – AD 2004) and around the lake Torneträsk in northern Sweden (AD 500 – AD 2004).
.

Pack rats time capsules

Another proxy method that scientists use to reconstruct past periods of climate change is through analysis of plant remains from fossil **pack rat middens**. A pack rat midden is a debris pile constructed by a woodrat. Fossil pack rat (also known as wood rat) middens often contain abundant fossilized remains of leaves, twigs, fruits, seeds, bones, shells, and other dateable materials. These findings help reconstruct the past environment, illustrating what the climate conditions were at the time. Information about past atmospheric conditions is also contained in the middens. Scientists derive this data through analysis of the ratios of stable isotopes of oxygen, carbon, and deuterium. Radiocarbon dating has identified some middens that are more than 50,000 years old.
Zoologists examine the remains of animals in middens to get a sense of the fauna in the neighbourhood of the midden, while paleobotanists can reconstruct the vegetation that grew nearby. Middens are considered reliable "time capsules" of natural life, centuries and millennia after they occurred. Woodrat middens are composed of many things, including plants fossils and fecal pellets.

Peatland Cinderella

The International Union for the Conservation of Nature (IUCN) describes peatlands as a "Cinderella" habitat which has been "overlooked and undervalued.
Peatland conservation is seriously hampered by the sheer invisibility of the peatland habitat, yet peatlands represent a major habitat and landscape type providing a wide range of ecosystem services - not unlike the fairytale Cinderella.
This is not the only connection between peatlands and literature. Peatlands have earned their own significant place in world literature. Sir Arthur Conan Doyle was inspired by mysterious, gloomy bogs of Dartmoor and made them not only a scene,
but also a significant character in one of his famous Sherlock Holmes stories –
The Hound of the Baskervilles.
Sir Arthur Conan Doyle's description of Dartmoor bogs has captured imaginations for more than 100 years.