ARCHIVES

of the past CLIMATE and ENVIRONMENTS

INTRODUCTION

To reconstruct the climate evolution on Earth we have a number of different tools.

The history of our planet is documented in four main archives: **sediments, ice, corals e trees (plus instrumental)**. We will examine these archives in detail.

In particular:

- How the climate record is **datable**,
- How the climate evolution is **recorded** in each archive,
- The **resolution** of each archive.

ARCHIVES

The history of past climates and environments is recorded and preserved in the archives (natural or not) that have a different signal resolution. In addition, each single archive has a **peculiar interval of time in which they can be used**.

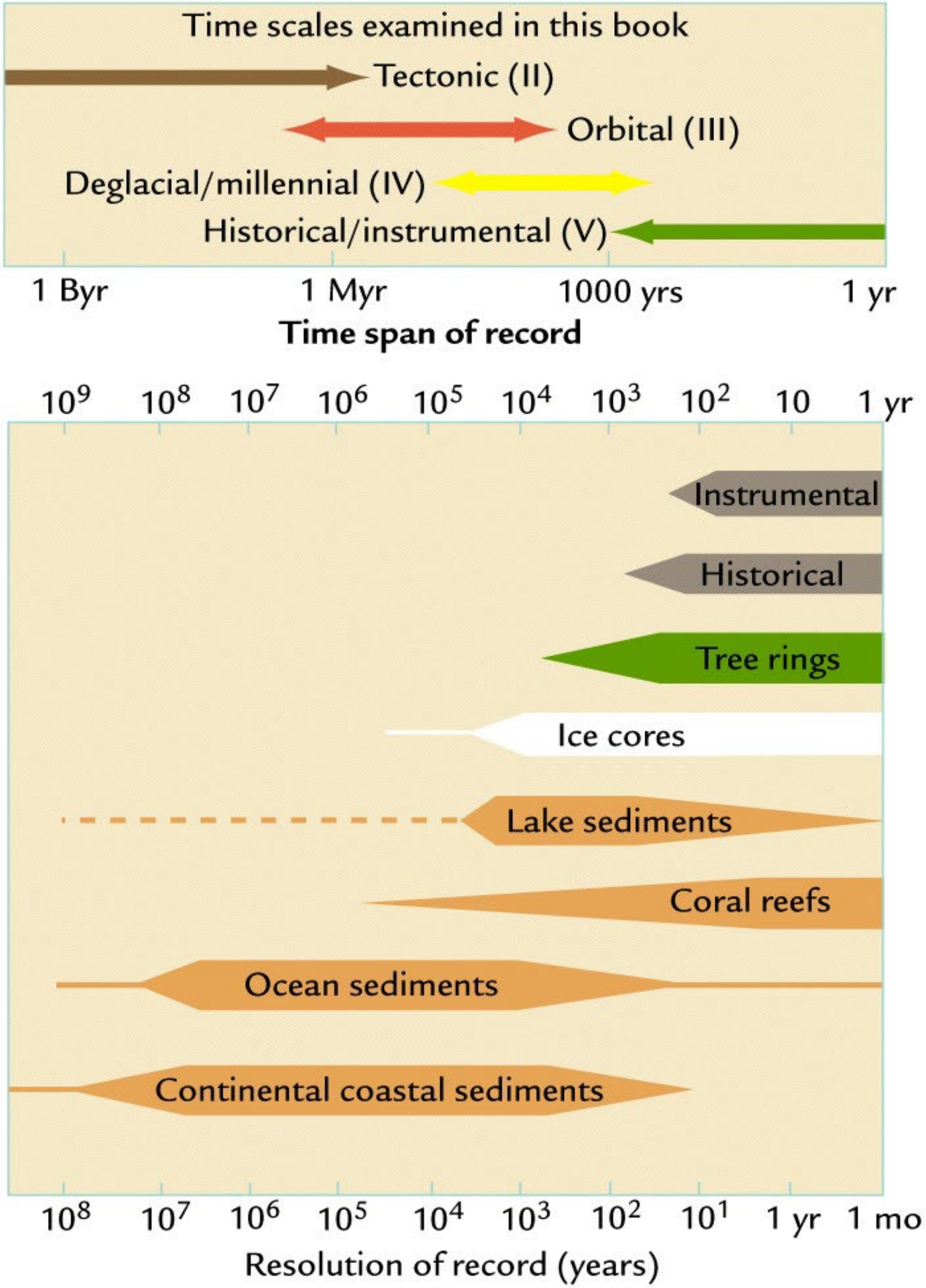
The main archives are:

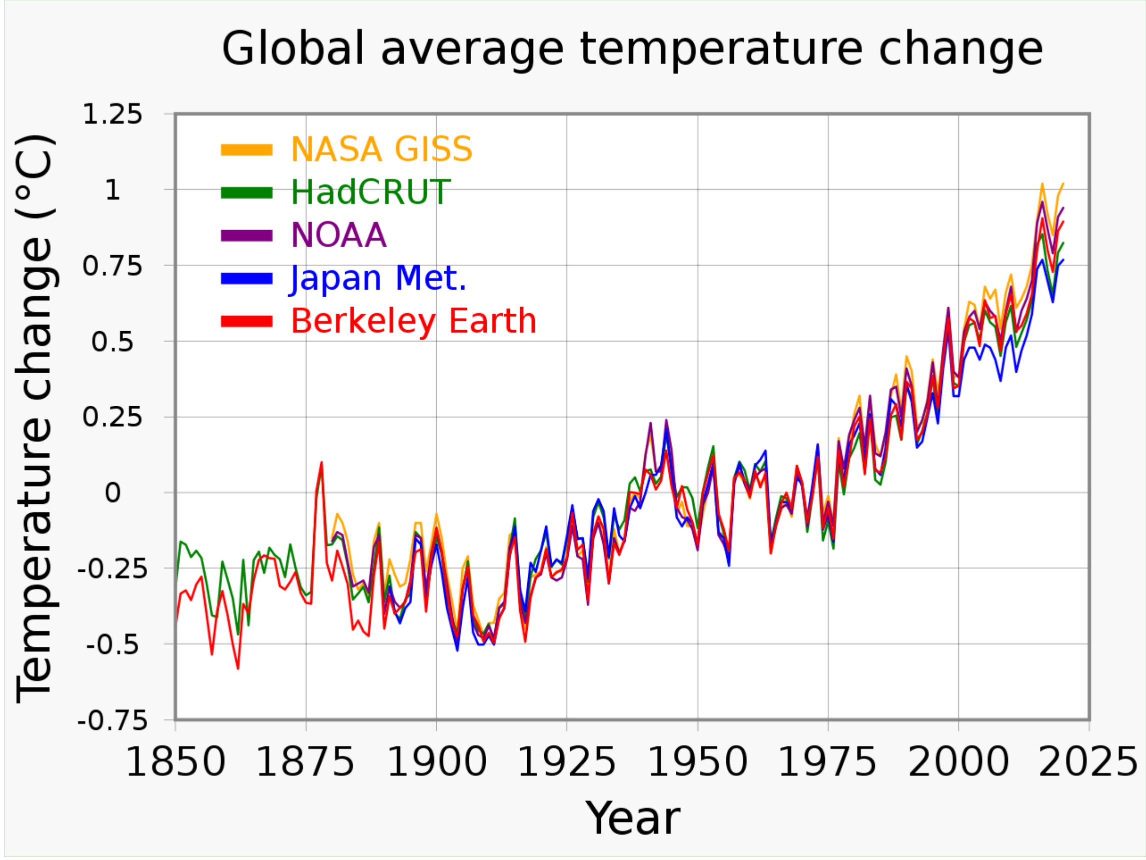
1) **TREES** (dendrochronology - ka)
2) **CORALS** (10^2 ka)
3) **ICE CORES** (ice caps and mountain glaciers (< 1 Ma)
4) **SEDIMENTARY ROCKS** (continental or marine- > 90% of the Earth History) and **SEDIMENTS** (lacustrine and marine - 10^2 ka up to 170 Ma)
5)**INSTRUMENTAL** (0-300 years)

Other information from:
-Speleothems;
-landscape (costal lines, glacial morphology, etc.);
-Historical archives (for instance the Plinius's chronicle of the Vesuvius eruption).

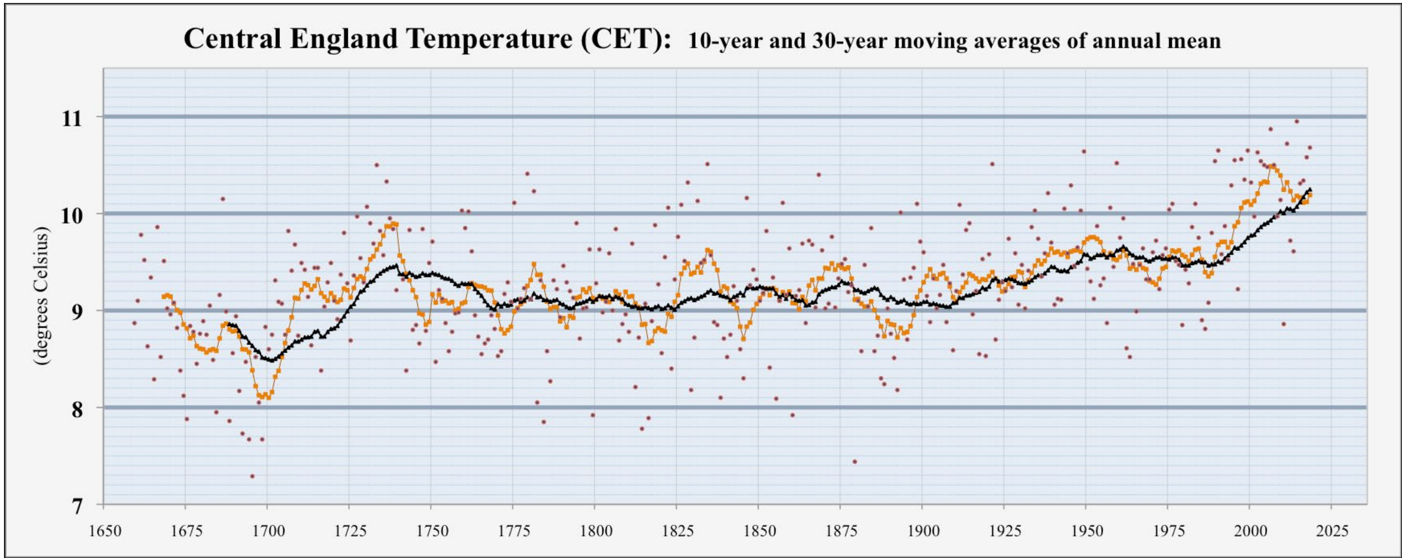

LENGTH of the RECORD

Length of the record in the different archives

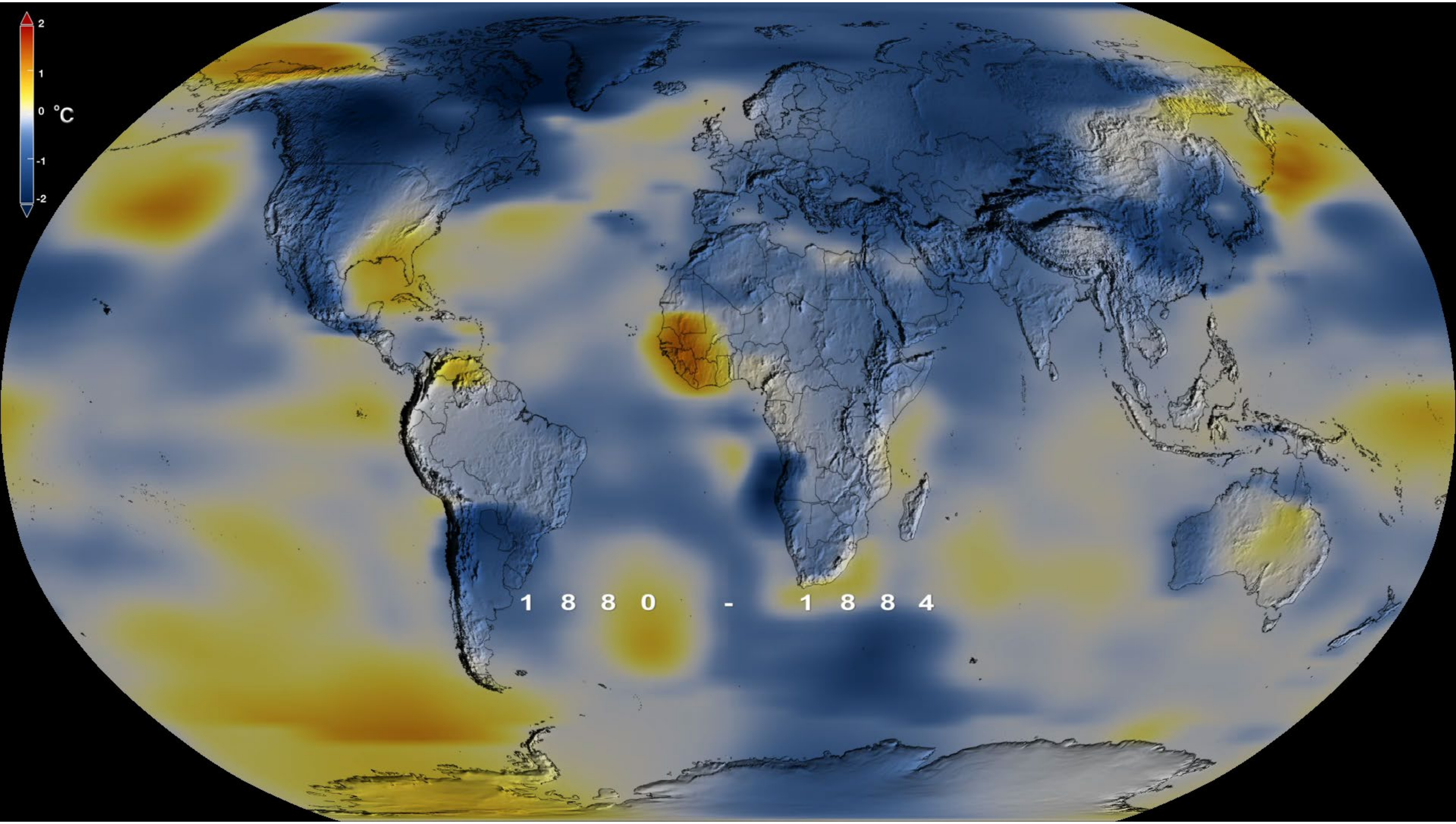




Temperature – Instrumental archives

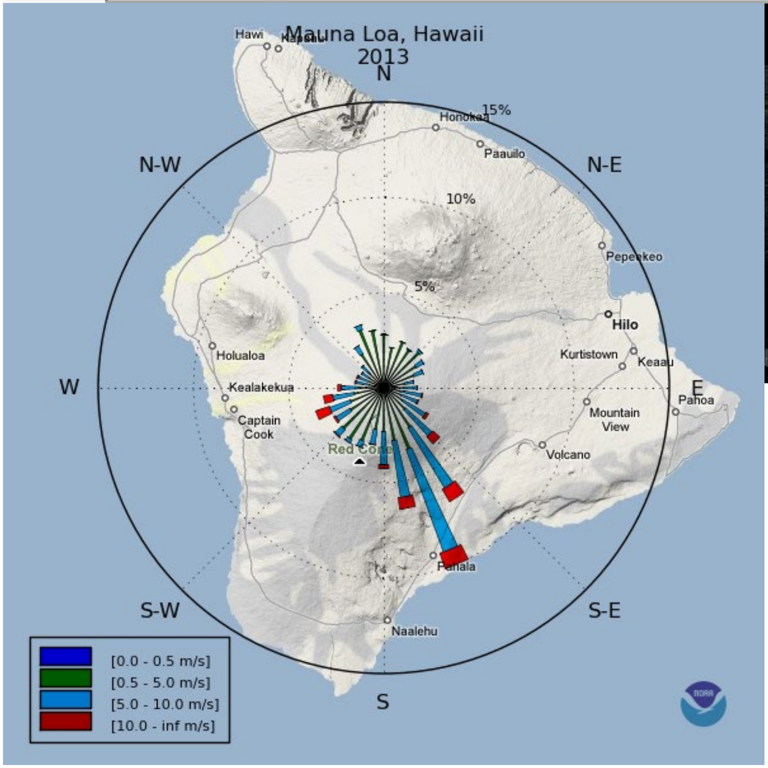


Global surface temperature heat map animation for 1880

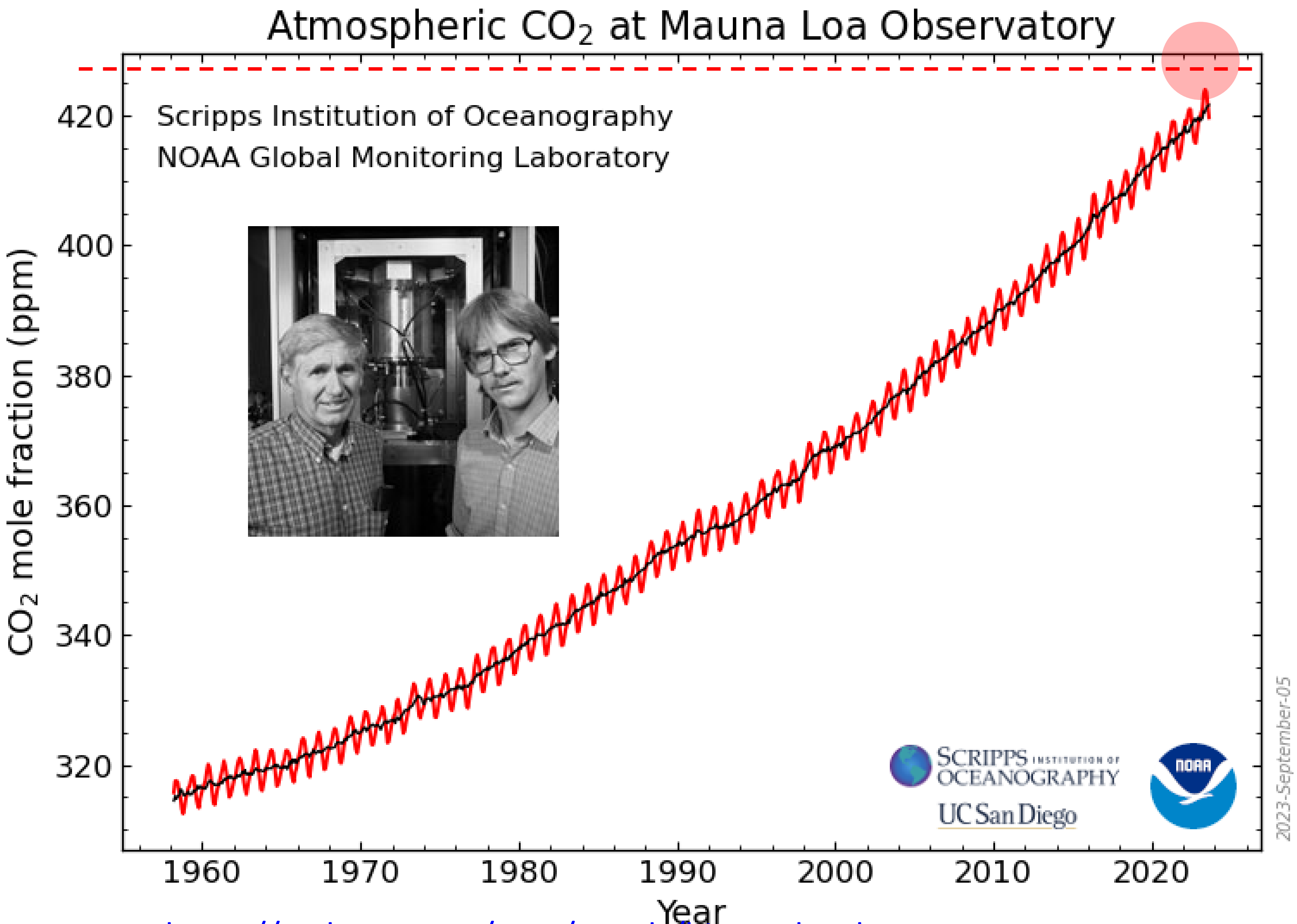


https://commons.wikimedia.org/w/index.php?title=File%3A1880-_Global_surface_temperature_-_heat_map_animation_-_NASA_SVS.webm

KEELING's CURVE – Instrumental archives



KEELING's CURVE – Instrumental archives

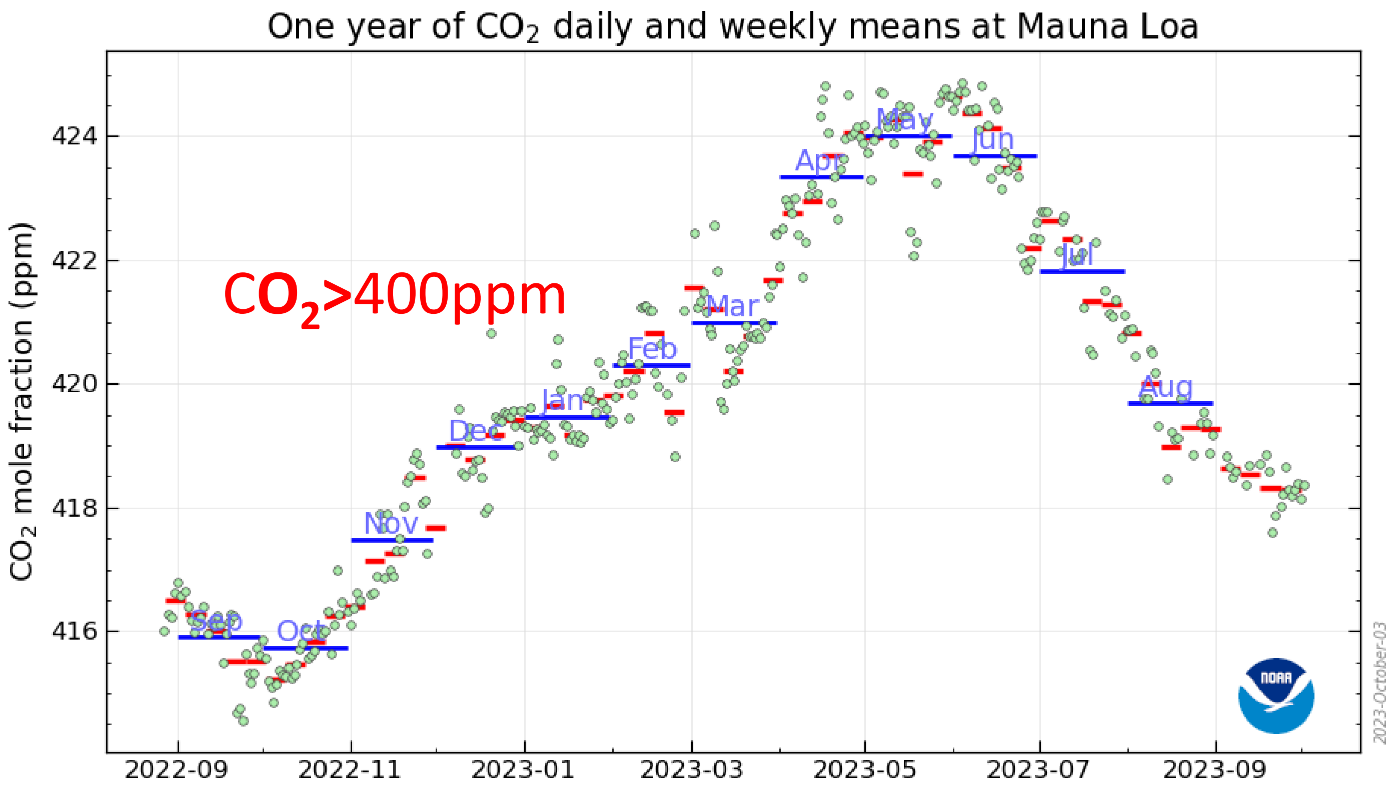


https://gml.noaa.gov/ccgg/trends/history.html

https://www.youtube.com/watch?v=9UJsB4HseJs https://www.youtube.com/watch?v=dXBzFNEwoj8

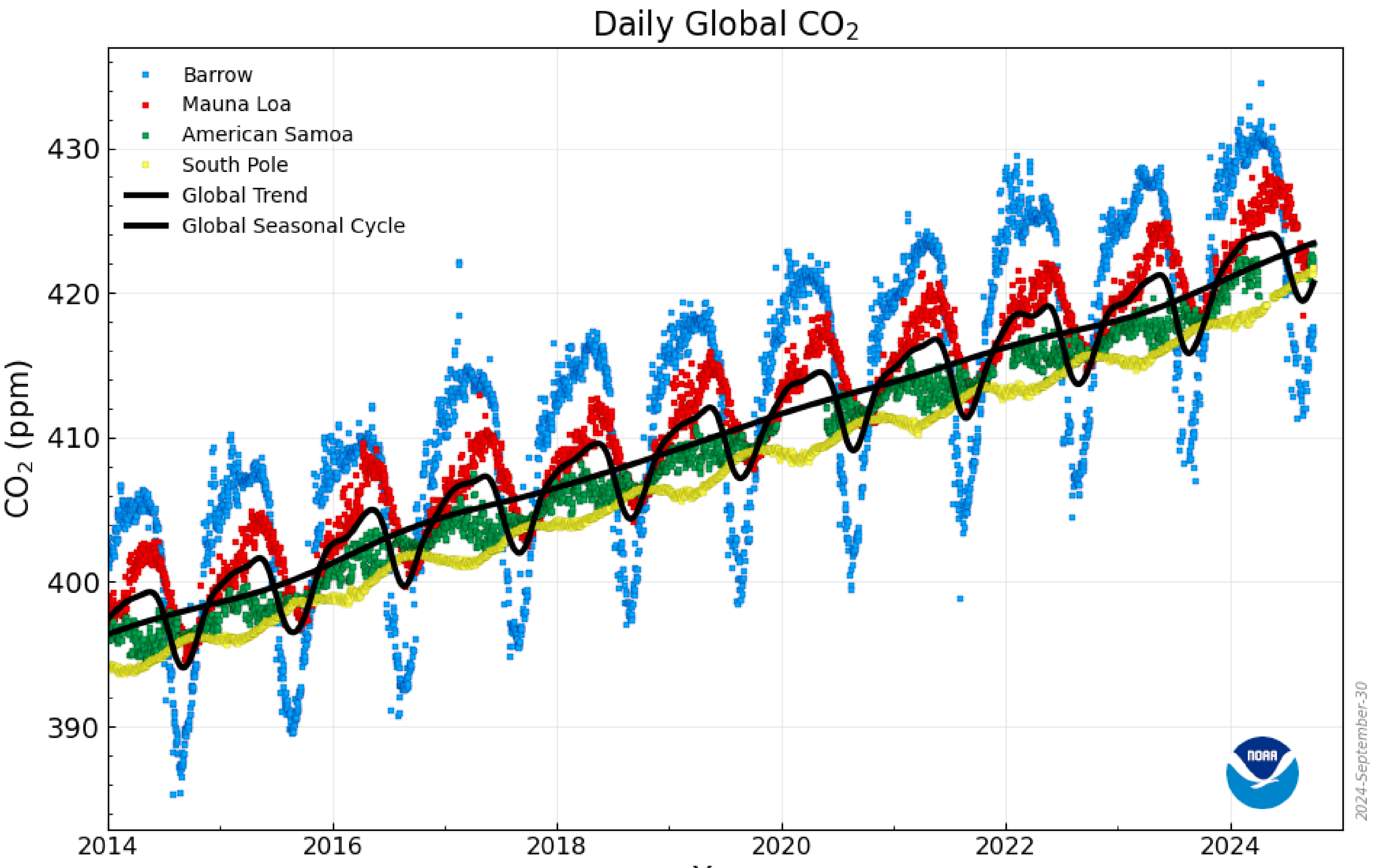
KEELING's CURVE – instrumental archives

September 29: 423.42 ppm
September 28: 423.42 ppm

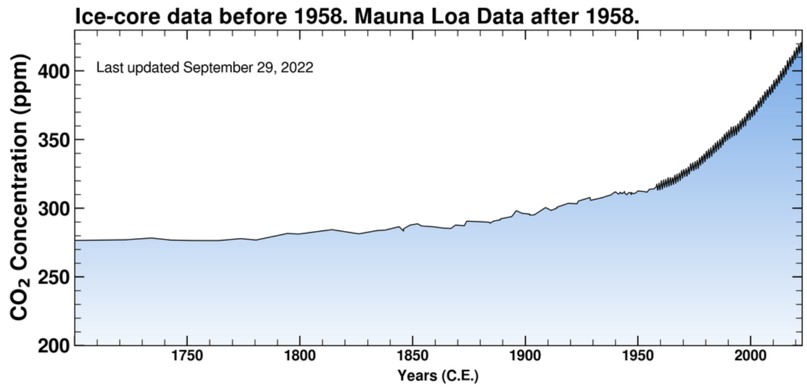


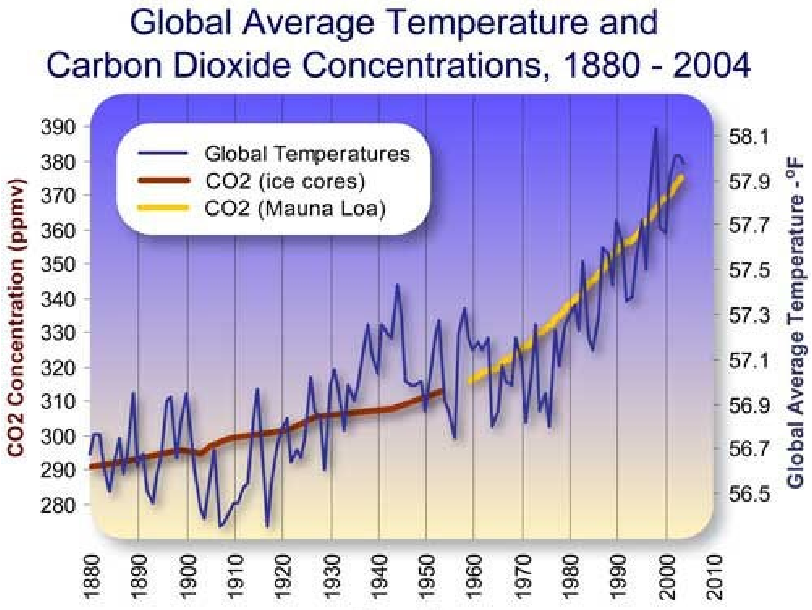
[Respiration/Phosynthesis ratio– ARPA Valled'Aosta]

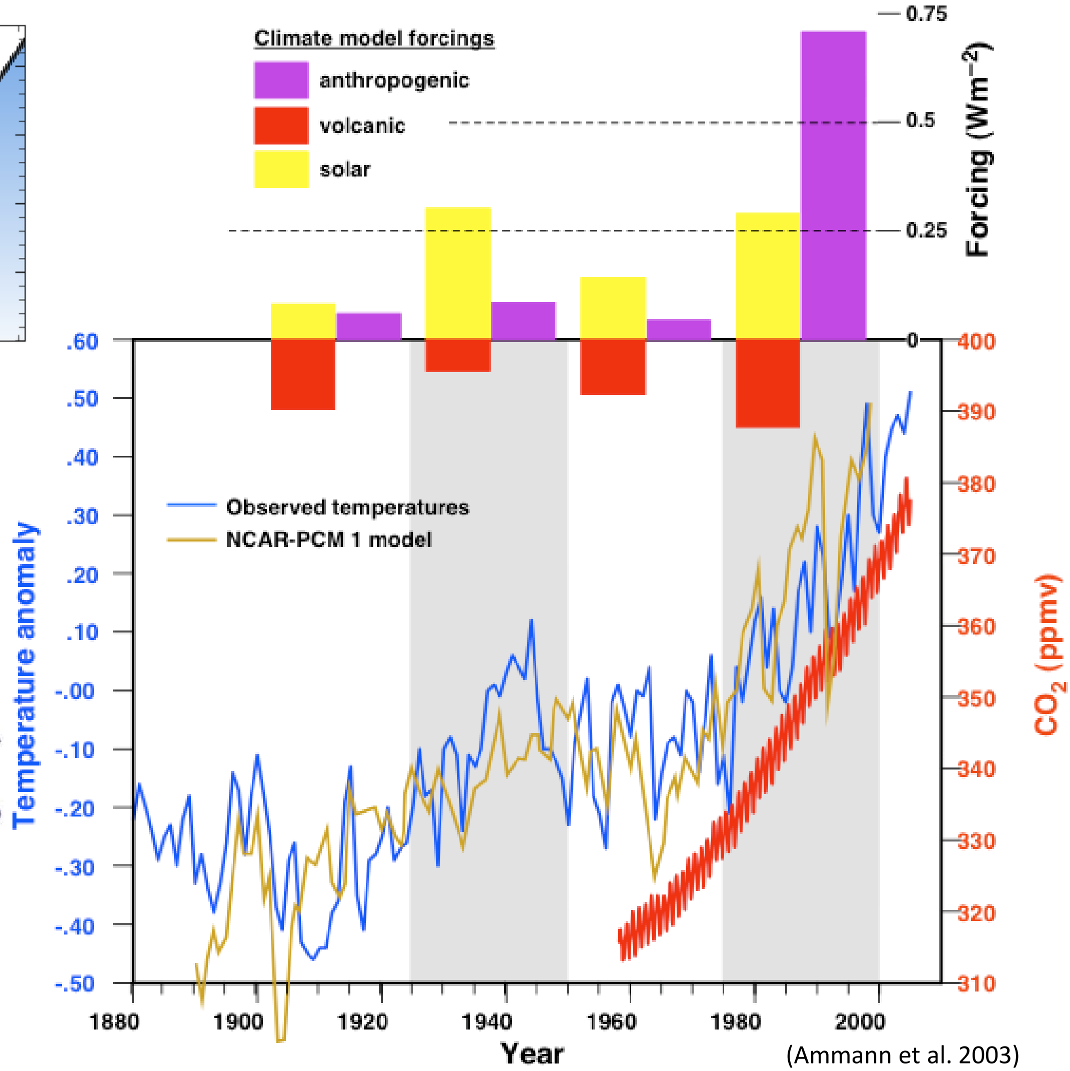
Recent Global CO2 Trend– instrumental archives



CO_2 and Temperature







(Ammann et al. 2003)

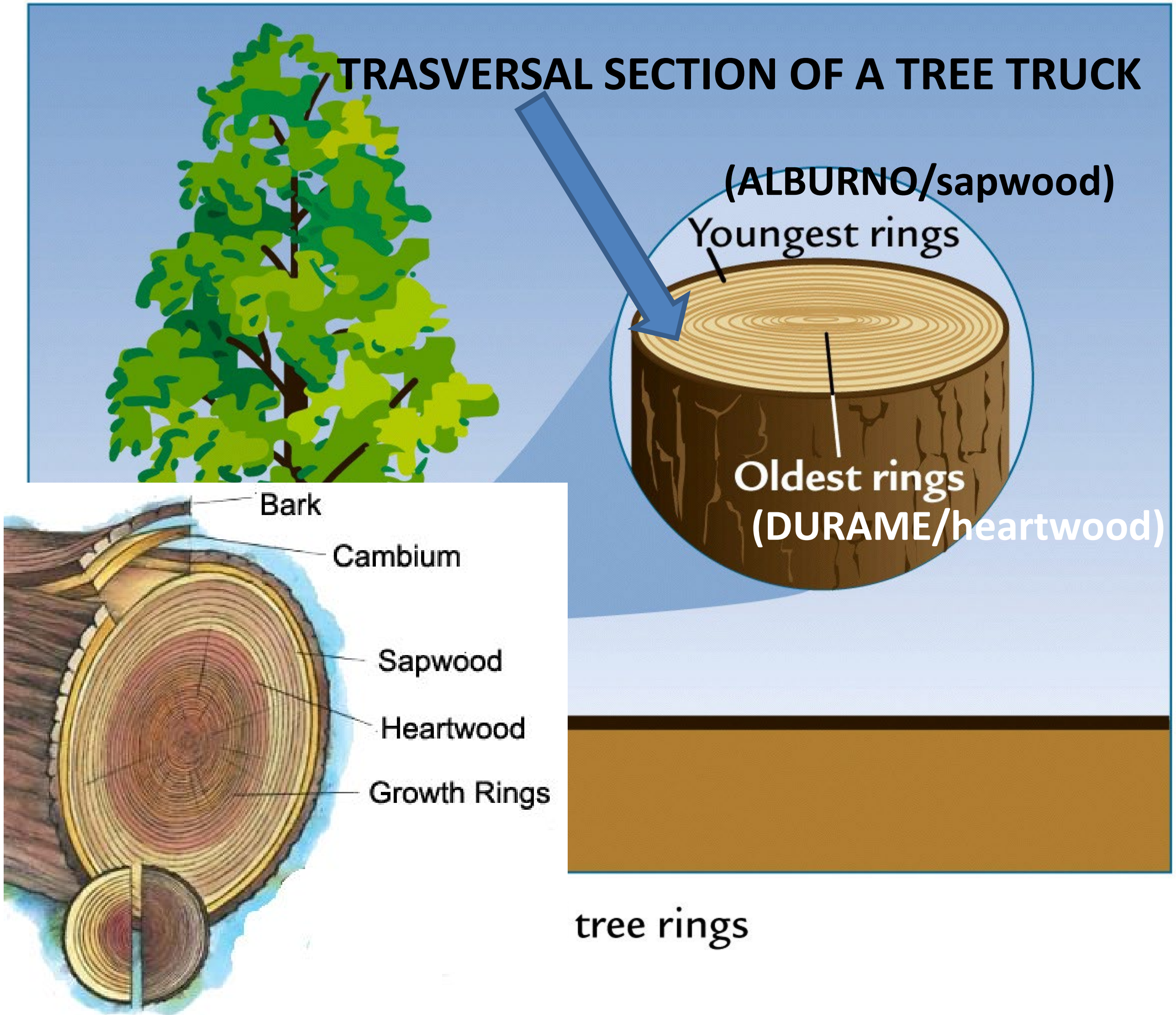
CO_2 and Temperature take-home message

In summary, **CO_2 and temperature are interconnected in the Earth-climate system** and represent two sides of the same coin when it comes to climate.

Human activities that increase CO_2 levels have a direct impact on global temperature and the planet's climate, with significant consequences for the biosphere and life on Earth.


TREES

DENDROCHRONOLOGY - 1



tree rings

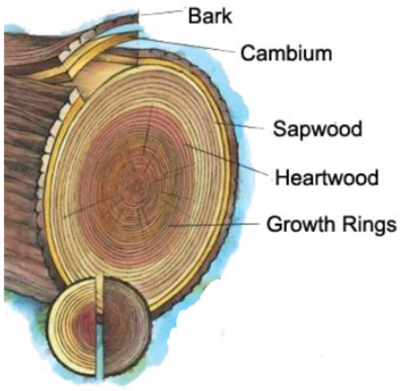
The tree radially grows (∅) during its life cycle, producing a new layer (sapwood- **ALBURNO**) located between the old wood (heartwood- **DURAME**) and the bark (**corteccia**). In normal conditions a ring is formed seasonally so that you can see a series of number of concentric rings in the transversal section.

These rings are the focus of dendrochronology.

Anatomy of a tree

https://www.fs.usda.gov/learn/trees/anatomy-of-tree

This information is courtesy the Arbor Day Foundation



A: The **outer bark** is the tree's protection from the outside world. Continually renewed from within, it helps keep out moisture in the rain, and prevents the tree from losing moisture when the air is dry. It insulates against cold and heat and wards off insect enemies.

B: The **inner bark**, or "phloem", is pipeline through which food is passed to the rest of the tree. It lives for only a short time, then dies and turns to cork to become part of the protective outer bark.

C: The **cambium cell layer** is the growing part of the trunk. It annually produces new bark and new wood in response to hormones that pass down through the phloem with food from the leaves. These hormones, called "auxins", stimulate growth in cells. Auxins are produced by leaf buds at the ends of branches as soon as they start growing in spring.

D: Sapwood is the tree's pipeline for water moving up to the leaves. Sapwood is new wood. As newer rings of sapwood are laid down, inner cells lose their vitality and turn to heartwood.

E: Heartwood is the central, supporting pillar of the tree. Although dead, it will not decay or lose strength while the outer layers are intact. A composite of hollow, needlelike cellulose fibers bound together by a chemical glue called lignin, it is in many ways as strong as steel. A piece 12" long and 1" by 2" in cross section set vertically can support a weight of twenty tons!

Leaves make food for the tree, and this tells us much about their shapes. For example, the narrow needles of a Douglas fir can expose as much as three acres of chlorophyll surface to the sun. The lobes, leaflets and jagged edges of many broad leaves have their uses, too. They help evaporate the water used in food-building, reduce wind resistance — even provide "drip tips" to shed rain that, left standing, could decay the leaf.

DENDROCRONOLOGY - 2

In temperate climates where there is an alternation of cool and warm seasons, trees grow forming concentric rings which are observable in the transversal section of the tree trunk (**tree rings or growth rings**). The wood produced during spring is lighter (legno primaverile/ spring wood or primaticcio/ first ripe) while the one produced during summer or autumn (legno estivo/summer wood o legno tardivo/late wood) is darker.

Transversal section of a tree trunk: annual concentric rings

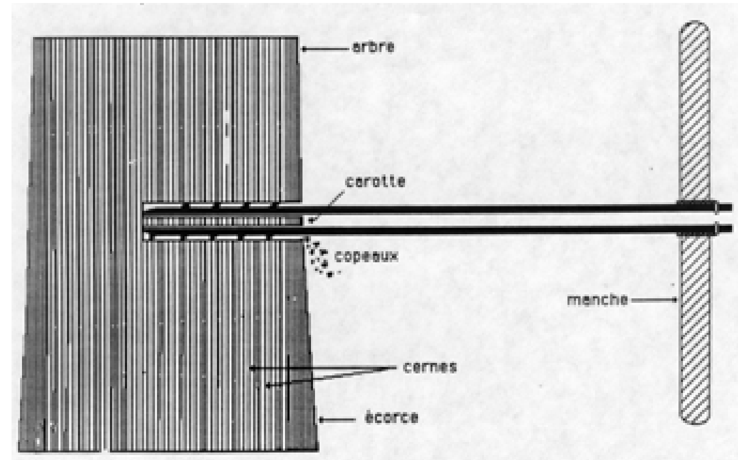
The width of each single ring depends on different factors:
BIOLOGICAL (species, age, social hierarchy, extraordinary conditions),
STATIONARY (altitude, soil, exposure, slope gradient, ….)
CLIMATIC (temperature, humidity, rainfall, …).

A tree quickly adapts to changes in these factors, **altering its growth** and, consequently, the amount of wood it produces, leading to **variations in the width of its annual rings.**

DENDROCRONOLOGY - 3

How to study tree rings

Drill along the transversal section of a tree trunk using a Pressler incremental borer

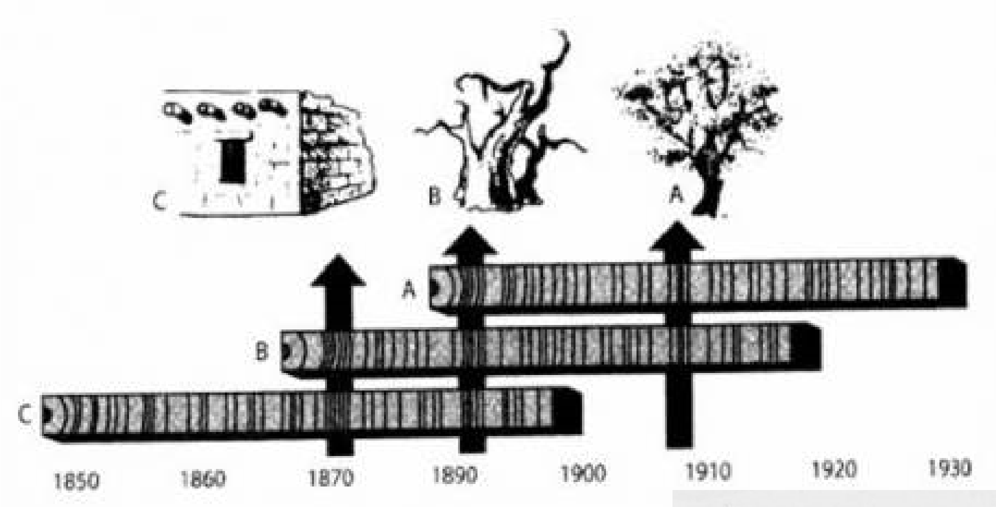


Coring using a Pressler incremental borer

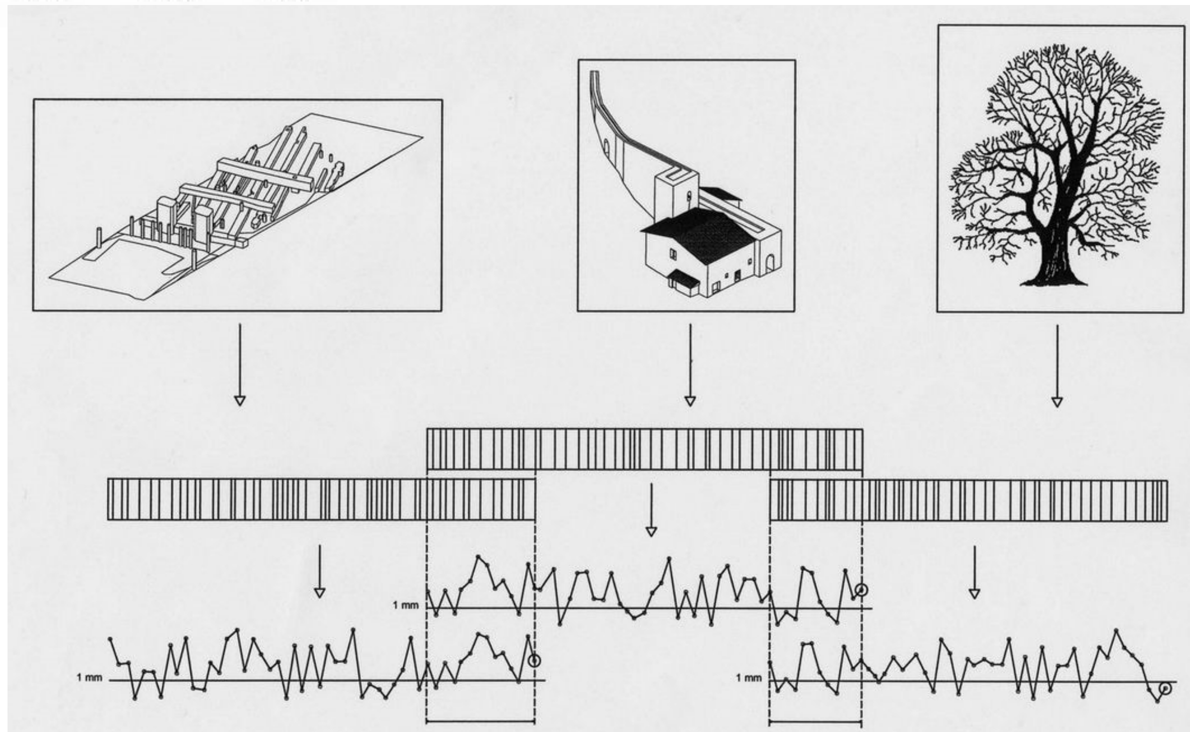
If you are curious to know how a Pressler incremental borer works
https://www.youtube.com/watch?v=sKfK2nqb5XM

Counting tree rings

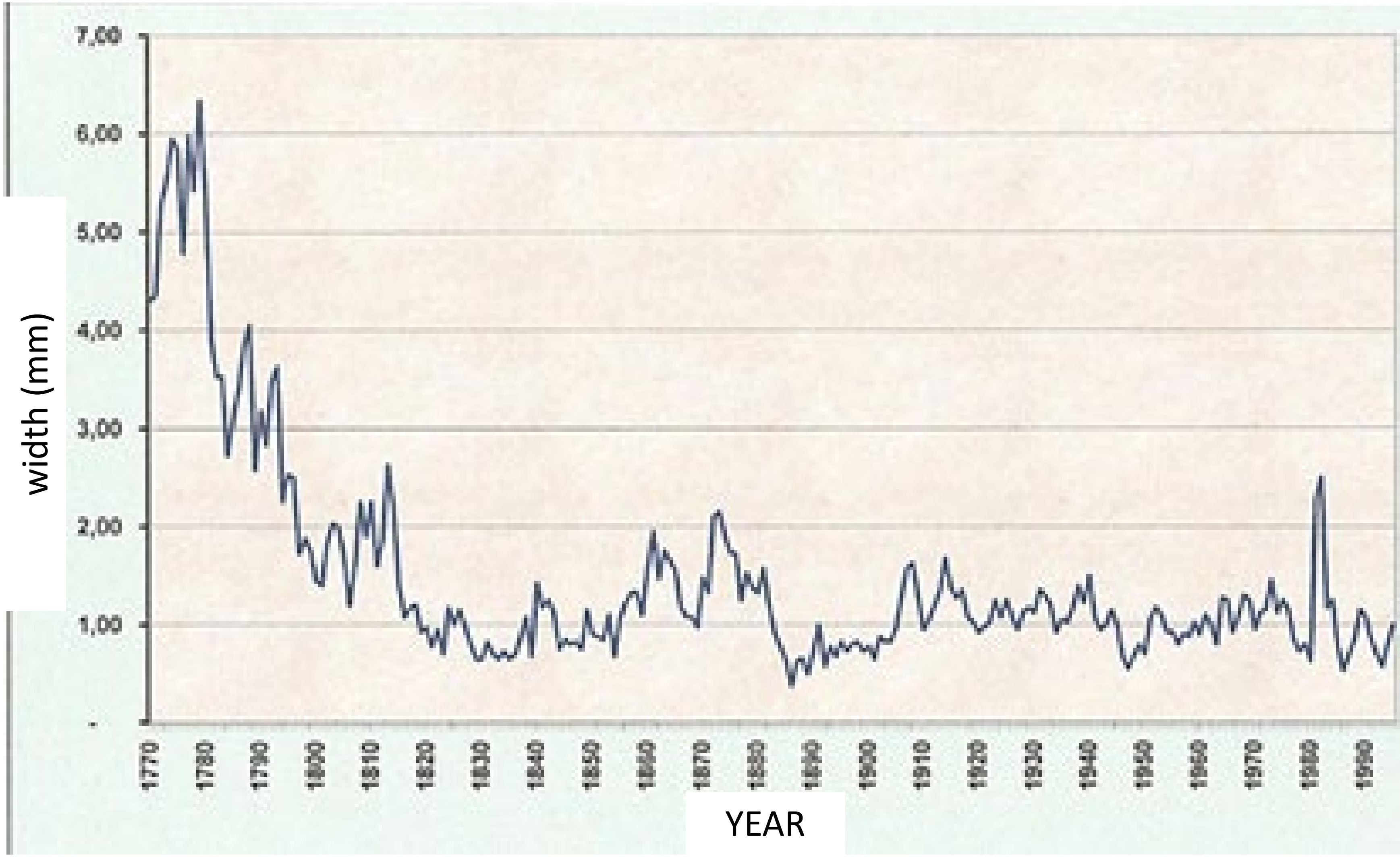
DENDROCRONOLOGY - 4



MATCHING: you correlate the tree cores with the reference/master curves.
Time interval: last 20 kyr.



DENDROCRONOLOGY - 5

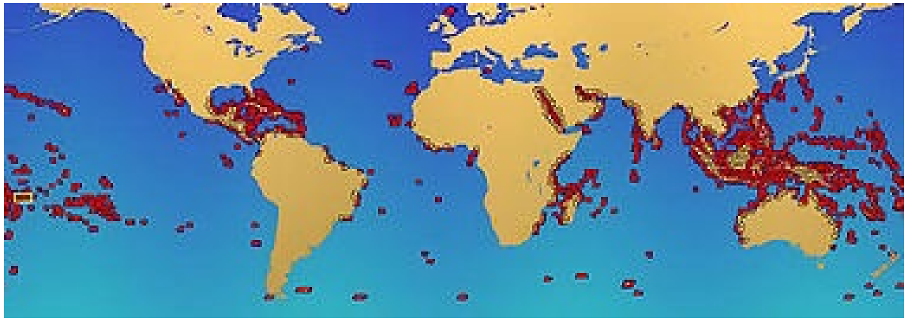


Dendrochronological curve of a linden tree (223 years old) - Parco Ducale of Parma

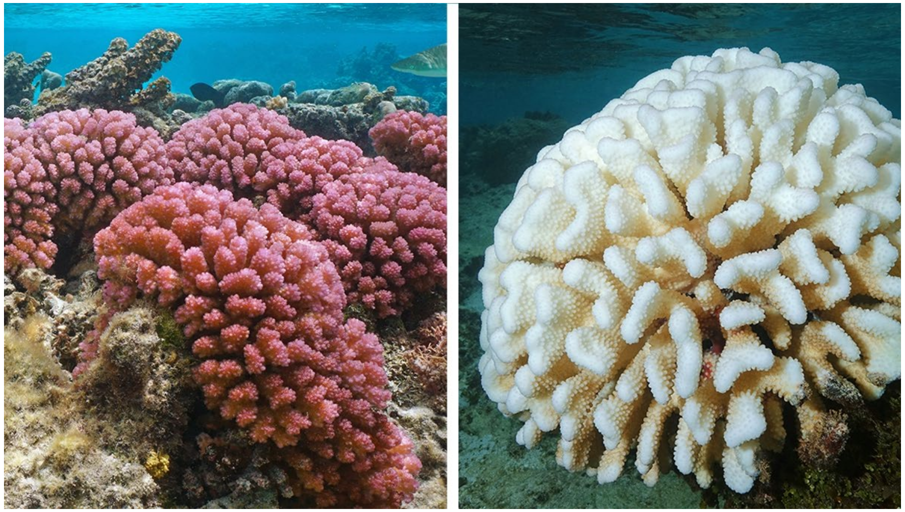

CORALS

CORALS - 1

Hermatypic corals are reef-building corals that have symbiotic algae (zooxanthellae) in their tissues. These algae provide energy through photosynthesis, enabling the corals to build $CaCO_3$ (aragonite) skeletons, which form coral reefs. These corals thrive in shallow warm, sunlit waters where photosynthesis is possible. Hermatipic corals thrive at tropical-subtropical latitudes. They grow forming annual bands.
They are important archive where to find important paleoenvironmental and paleoclimatic info.



Coral barriers (•) develop in tropical waters (30°N - 30°S).



Side-by-side image of healthy and bleached coral.

CORALS - 2

Exit

Go to **wooclap.com** and use the code **PCCM24**

Looking at the coral specimen in the image, one can observe denser and less dense bands, which represent seasonal patterns. When do the denser bands form?

1 | 0% | 0

2 | 0% | 0

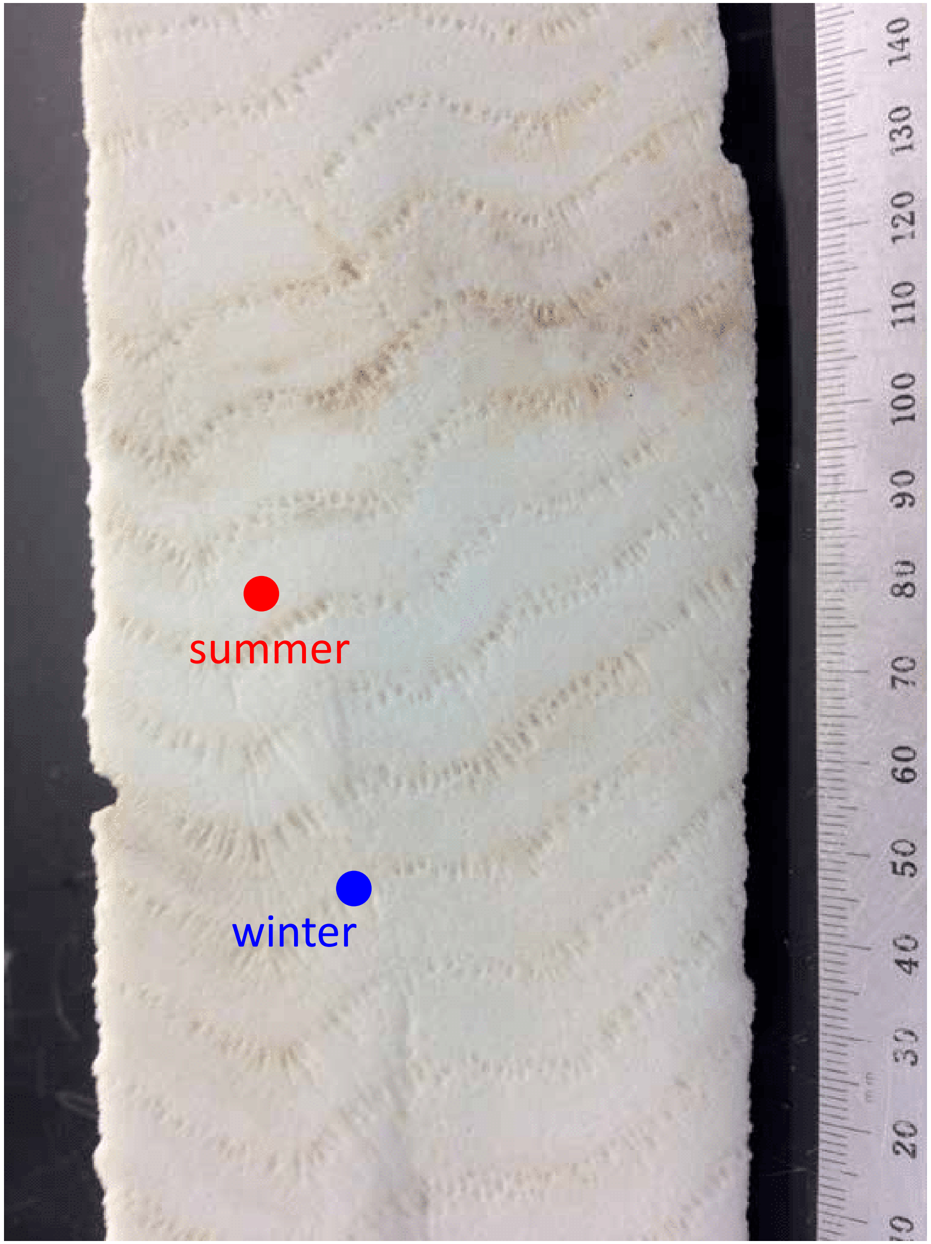
wooclap

Messages

100 %

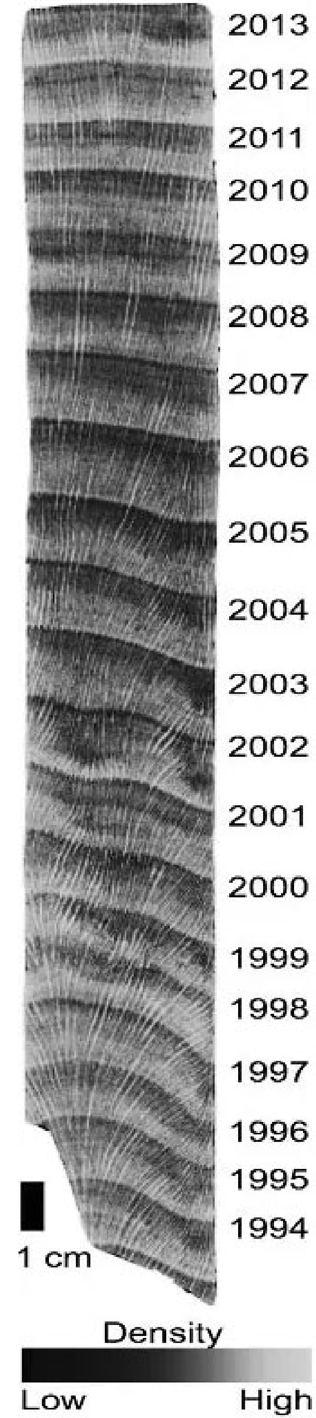
0 / 25

CORALS - 3



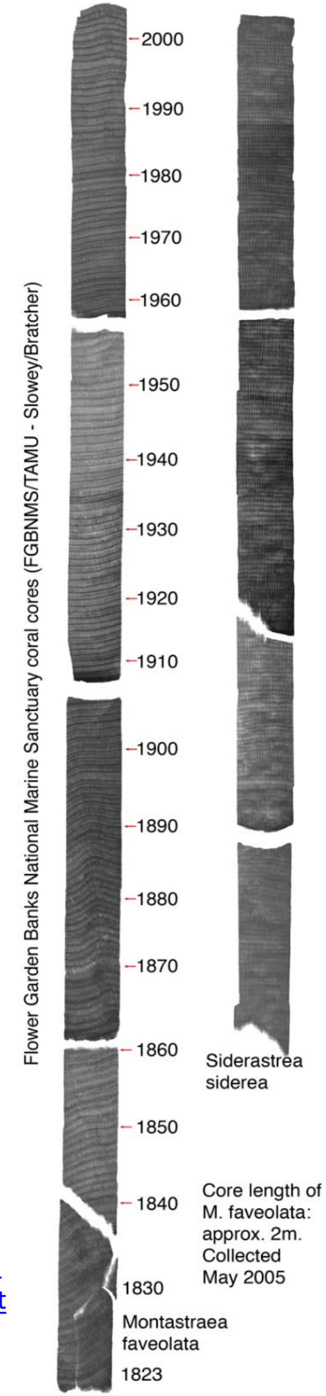
X-rays of coral cores allow scientists to examine the annual growth bands in reef-building corals.

Slow, high-density growth that takes place during the summer. Lighter bands show the faster, low-density growth that takes place during the winter.



CORALS -4

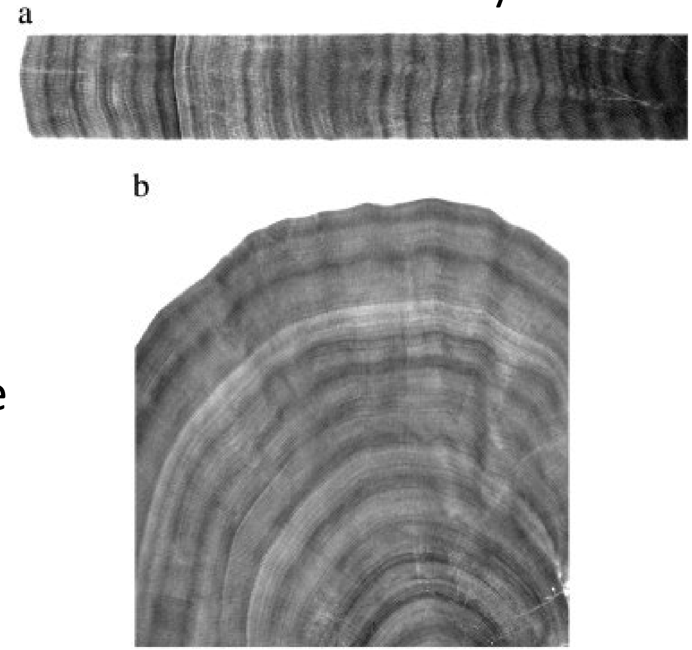
Scientists can take a look back in time to determine when temperatures were warmer or cooler, by simply examining the depth of each growth band. Larger low-density bands indicate warmer winter temperatures.



https://flowergarden.noaa.gov/science/coralcores.html#:~:text=Dark%20bands%20show%20the%20slow,takes%20place%20during%20the%20winter.&text=Within%20each%20band%20scientists%20can,learn%20more%20about%20atmospheric%20conditions

CORALS -5

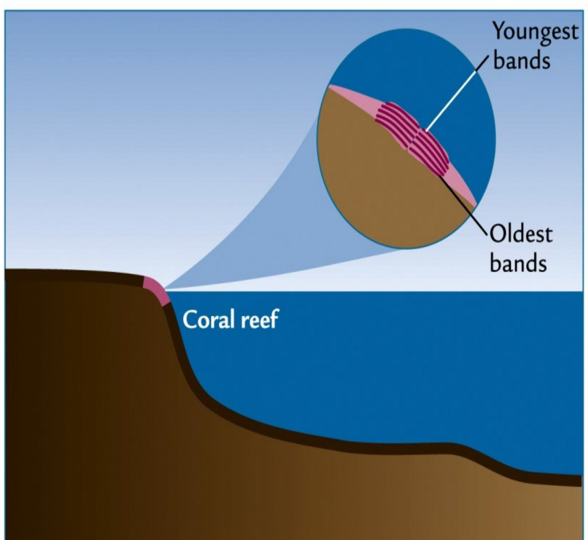
Coral at x-ray



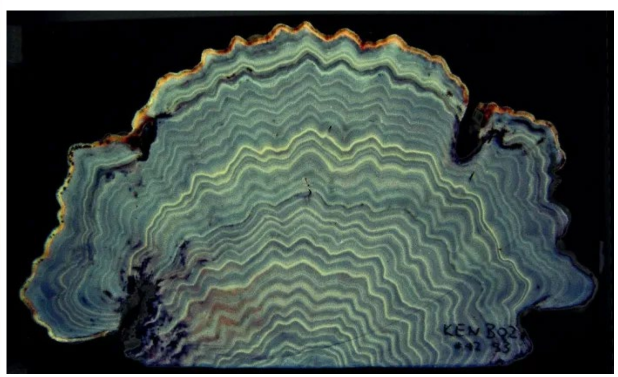
Coral record the seasonal changes in the texture of their skeleton ($CaCO_3$).

X-RAY IMAGES

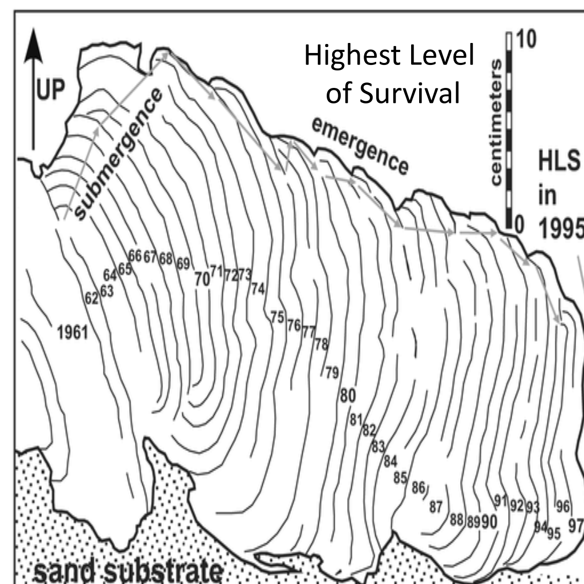
The lighter part grows in summers, when it grows rapidly, while darker part form in winters, when the growing decreases (coral bands). Corals usually live some hundred years. Putting together fossil and living corals you can obtain a longer interval.



D Annual coral bands



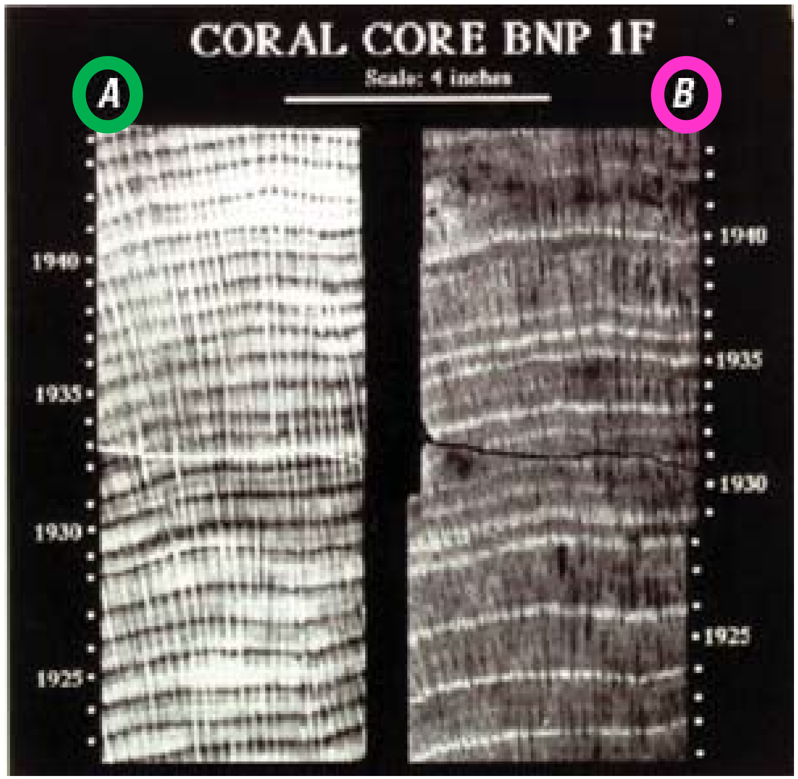
A slice of Great Barrier Reef coral under ultraviolet light



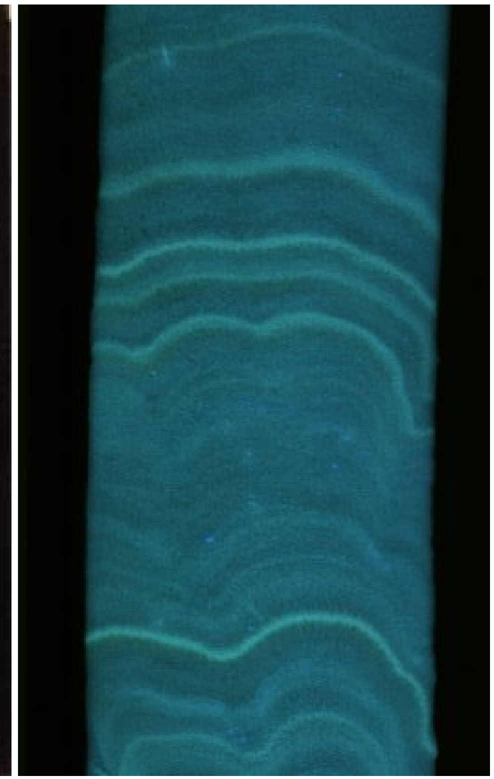
CORALS -6

X-RAY OF A CORAL CORE

Growth rings are visible (similar to the tree rings). The variation in the thickness of coral bands indicates a modification in climatic conditions.



Montastraea faveolata - Florida, USA



UV light shone through a slab from a Porites coral colony shows light luminescent lines which correspond to flood events.

FLUORESCENCE

Light layers correspond to intense rainfall and hurricanes. For an instance the light band at 1928 (summer) corresponds to the Okeechobee hurricane that caused more than 2000 victims (North-central Florida).

CORALS - 7

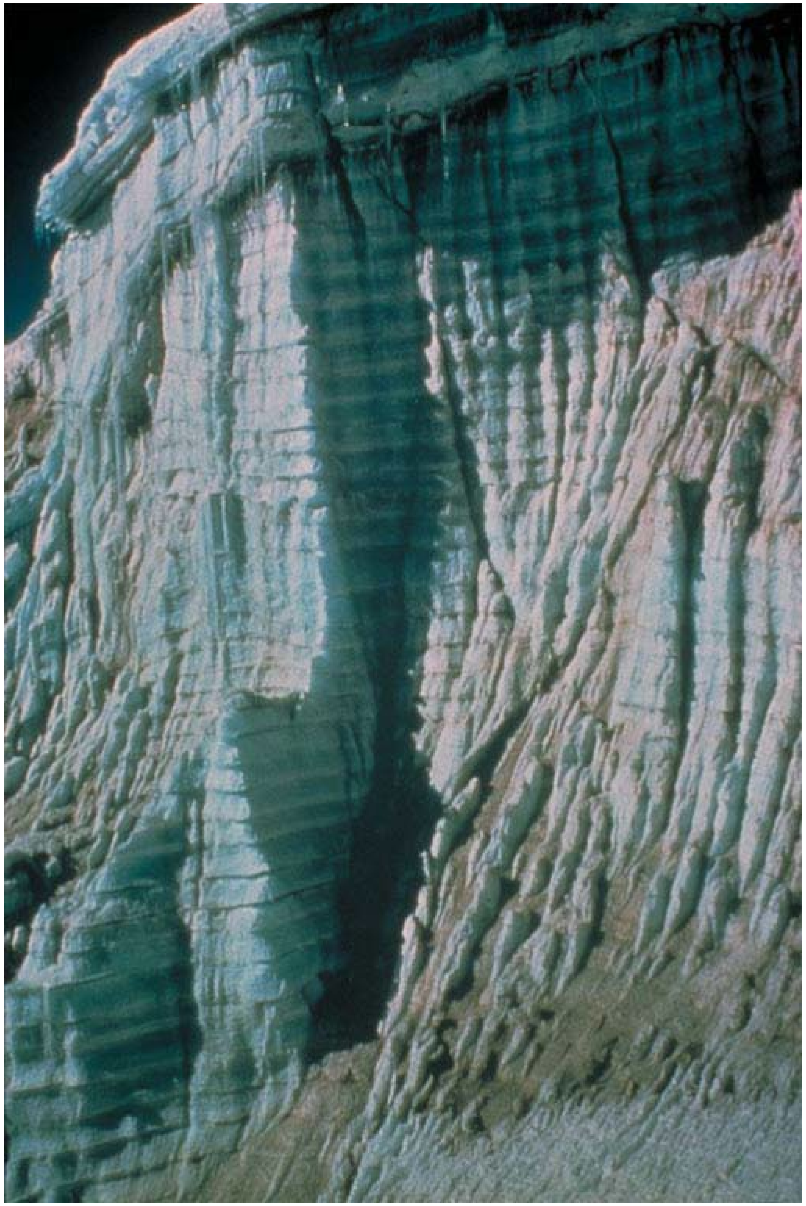
Summary

Apart from coral bands, the changes in the elemental composition in Scleractinian corals skeletons, provide important proxies for reconstructing ancient seawater (SW) chemistry.

It is recognized, that the uptake and partition of elements that coprecipitate with $CaCO_3$ of coral skeleton (e.g. Mg, Sr, etc.), changes in response to biotic and abiotic factors e.g., temperature, calcification rates and particularly Sea Water chemistry.


ICE

ICE 1



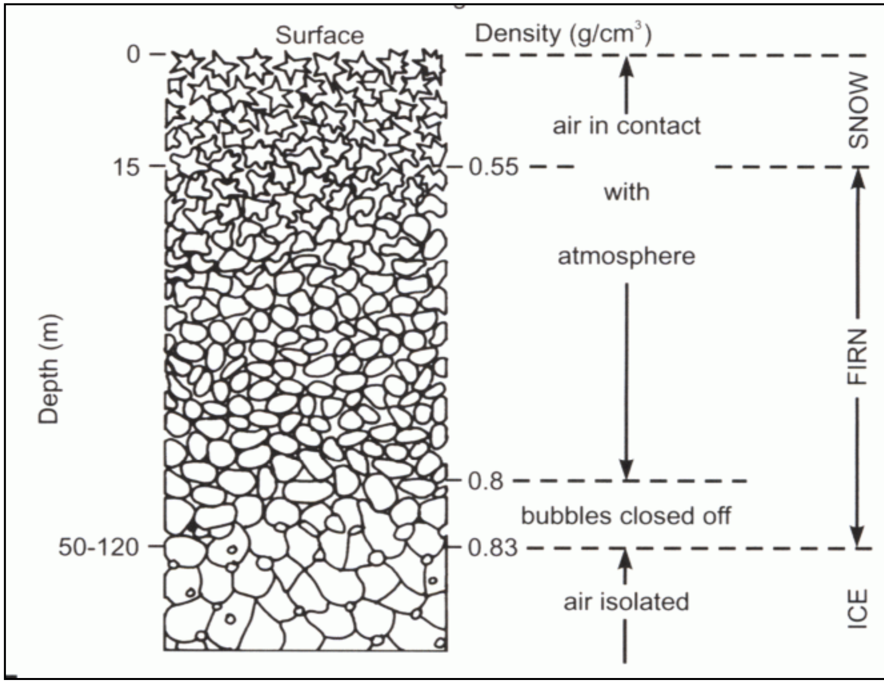
Important paleoenvironmental and paleoclimatic information is archived in the ice caps and mountain glaciers.

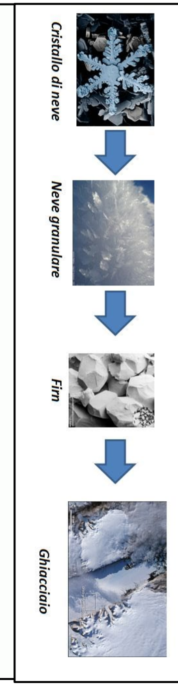
TIME INTERVAL:
ICE CAPS→ 10^5 kyr
MOUNTAIN GLACIERS→ kyr

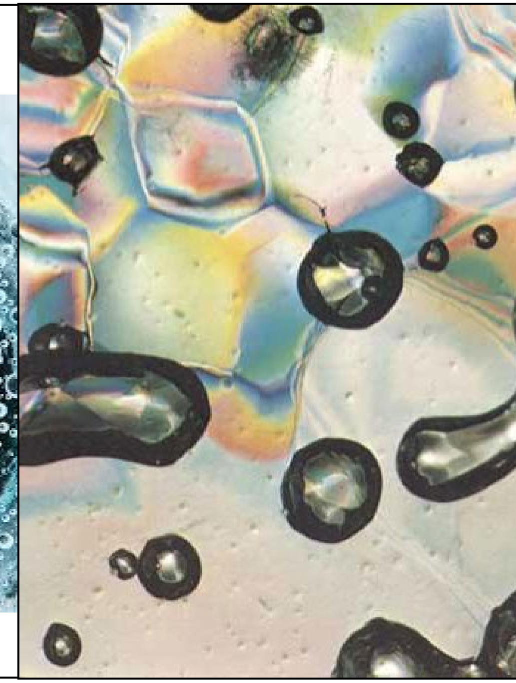
The peculiar feature of ice-caps sedimentation is shown in the picture: alternation of darker layers (enriched in dust) and lighter layers (with less dust)

ICE - 2

AIR BUBBLES IN ICE CORES







Scheme of the entrapment of air during the recrystallization of snow crystals.

Air bubble inside the ice

Scheme of the entrapment of air during the recrystallization of snow crystals.
Firn forms as snow crystals are compressed by the weight of overlying snow layers. When the individual crystals approach their melting point, they become semi-liquid, allowing them to flow and move. This reduces the space between them, increasing the ice porosity. As the crystals bind together, they trap air bubbles. These air bubbles, which would typically rise to the surface, become enclosed within the forming ice.

ICE - 3

AIR BUBBLES IN ICE CORES

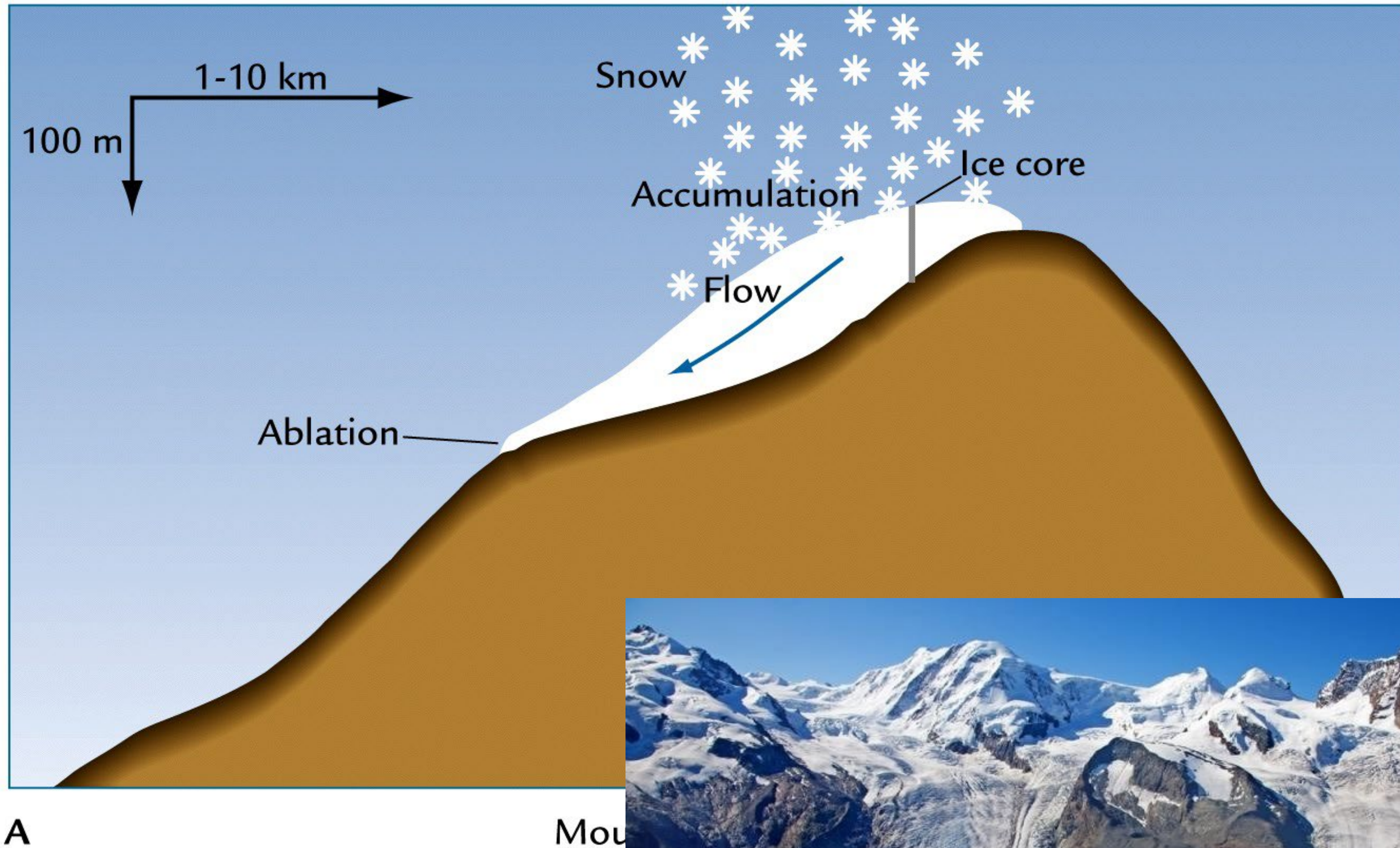
https://icecores.org/about-ice-cores#:~:text=Ice%20cores%20are%20cylinders%20of,the%20bottom%20of%20the%20core

https://www.youtube.com/watch?v=y_Pk0HrF5uk

The most important property of ice cores is that **they are a direct archive of past atmospheric gasses**. Air is trapped at the base of the firn layer, and when the compacted snow turns to ice, the air is trapped in bubbles. This transition normally occurs 50-100 m below the surface.

ICE - 4

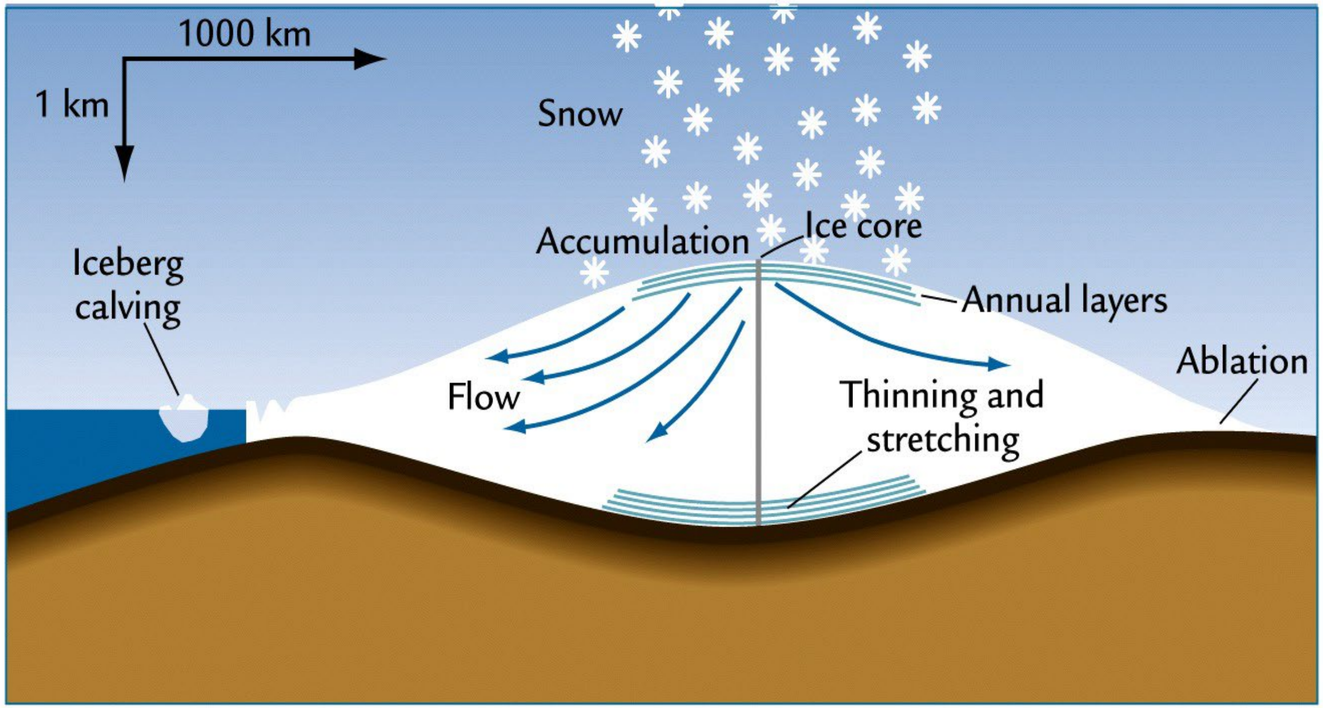
MOUNTAIN GLACIER



Winter snowfall deposits every year on mountain glaciers. The total thickness could vary from few to hundred of meters (summer ablation).

ICE – 5

ICE CAPS



B Continental ice sheets

Ice core layering

In **GREENLAND**, where <u>snowfall</u> is rapid and <u>relatively high</u> (ca. 600mm), annual layers remain visible for 10^2 kyr.
In Greenland, the annual layers are visible in the upper part (younger), while they are deformed going deeper until they first thin and eventually disappear. In those conditions, you need a flow model to estimate the age of the icecap.
In **ANTARCTICA**, where the <u>snow accumulation is lower</u> (ca. 130mm), the annual layering is less visible but goes deeper.

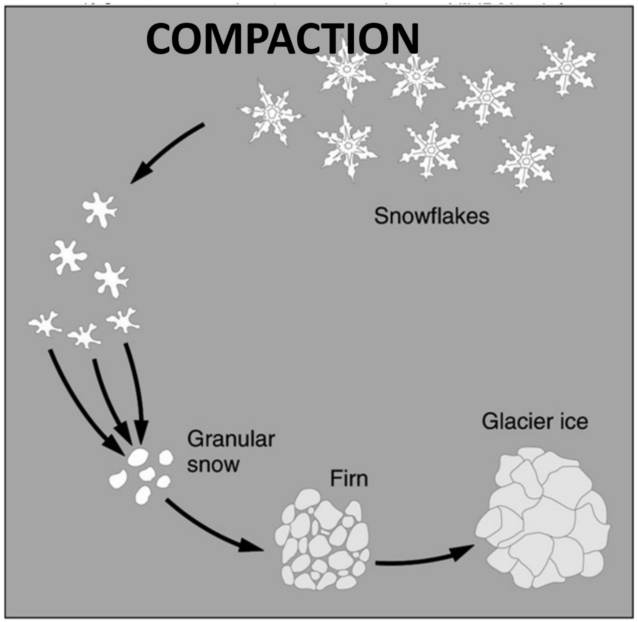
Which is the best ice cap archive, Antarctica or Greenland?

https://app.wooclap.com/events/PCCC24/0

ICE - 6

The **RESOLUTION** (= the smallest interval you can distinguish) depends on the snow accumulation rate. When the snow becomes gradually more compact due to the weight of the upper layers, resolution decreases with deep. While in the upper layers (that are annual) you can distinguish the single season/year, going deeper the annual layers start to be indistinguishable one from each other.

The **LENGTH OF THE RECORD** depends on the specific core and could vary from few years to 800 kyr (EPICA project).



DEPTH INCREASE

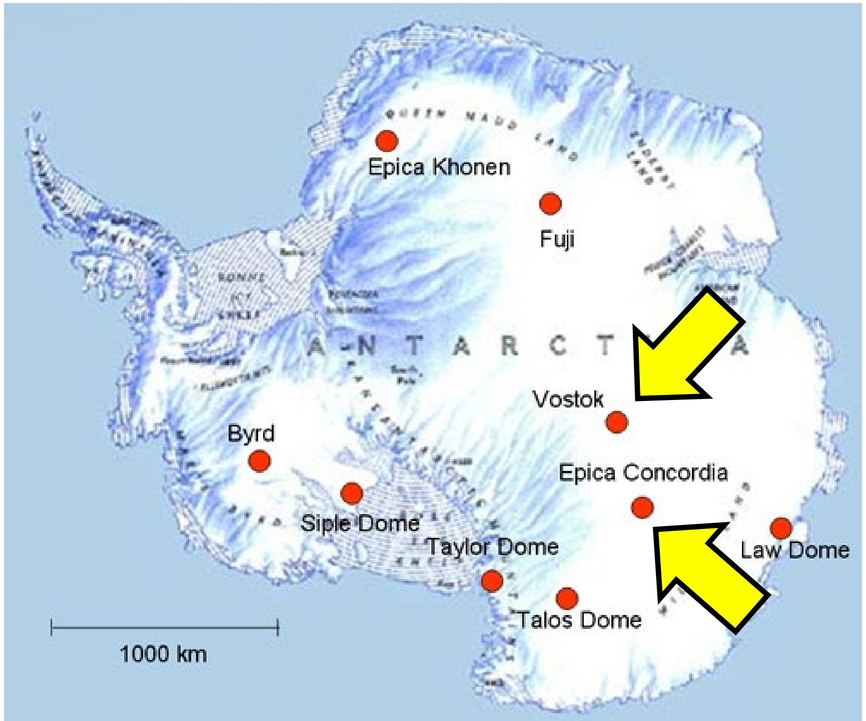
LOSS OF RESOLUTION

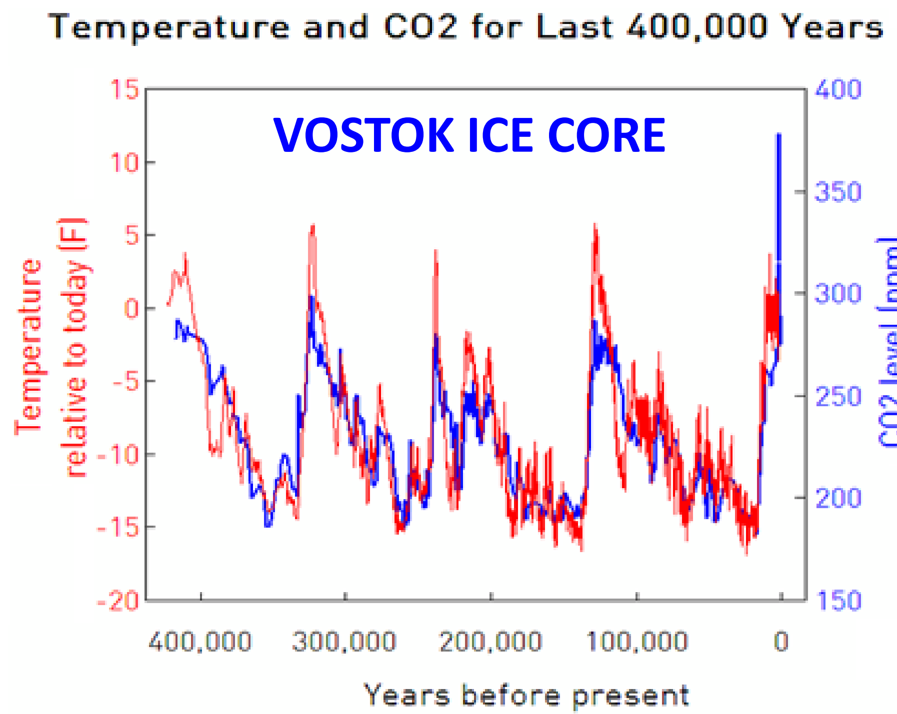
ICE - 7

GREENLAND DRILLING

The N-GRIP (North Greenland Ice-Core Project) drilling site is near the center of Greenland, 2917 m, ice thickness 3085). Drilling began in 1999 and was completed at bedrock in 2003. The N-GRIP site was chosen to extract a long and undisturbed record stretching into the last glacial.

ICE - 8
ANTARCTIC DRILLING

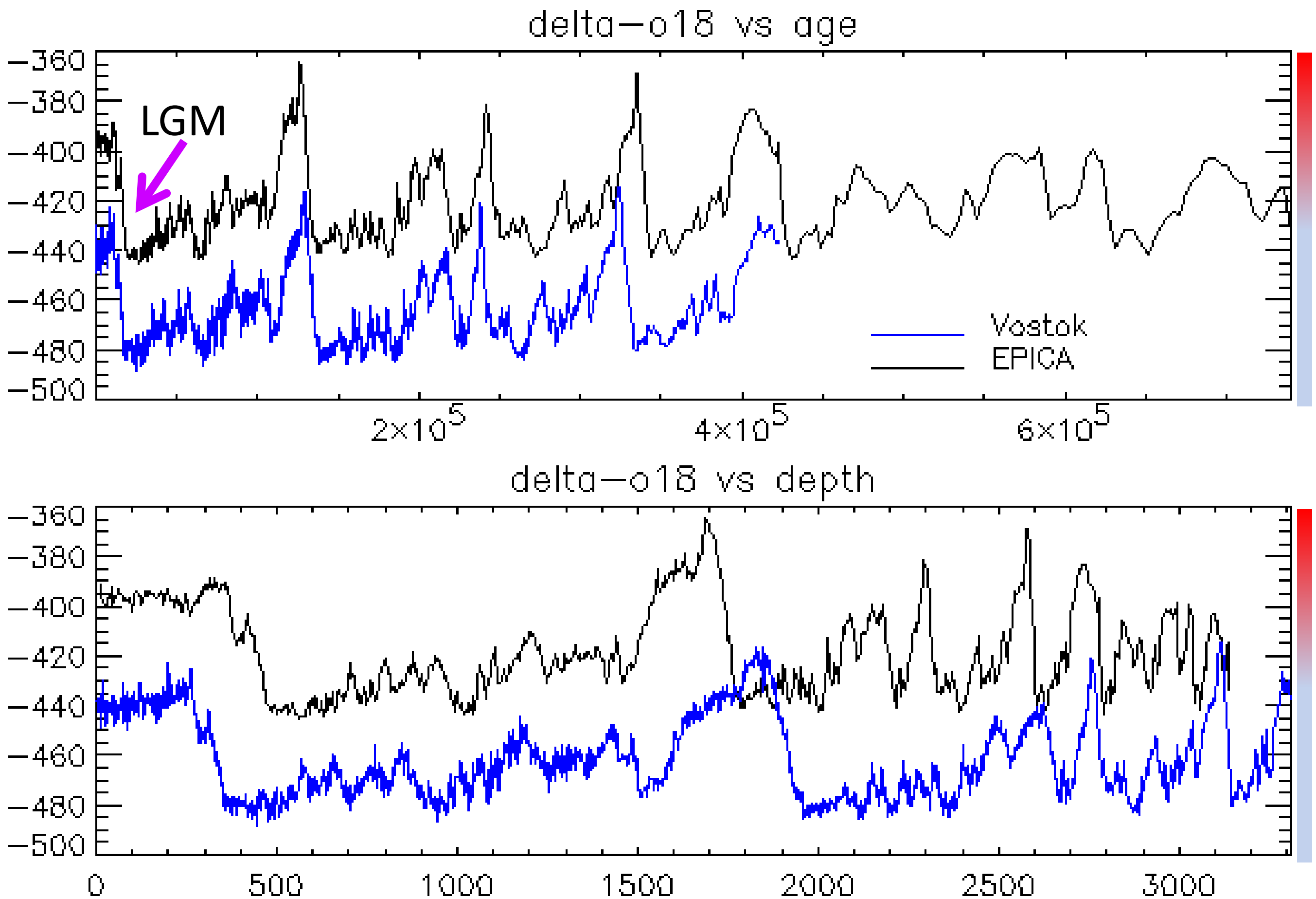


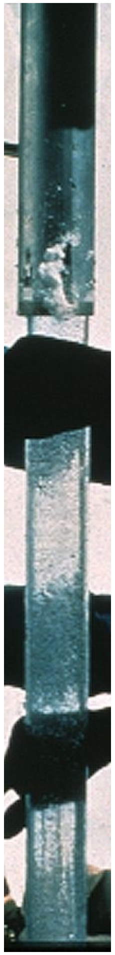


The **VOSTOK** drilling project (Antarctica), together with other drillings in Greenland, stimulated other ice drilling project in Antarctica (end 1998; 3700m recovered). From the'90, the European scientific community has planned a very ambitious drilling project: **EPICA** (European Project for Ice Coring in Antarctica) (end 2004, 3270m) This was both technically a scientifically (paleoclimate reconstruction) disrupting.

ICE - 9

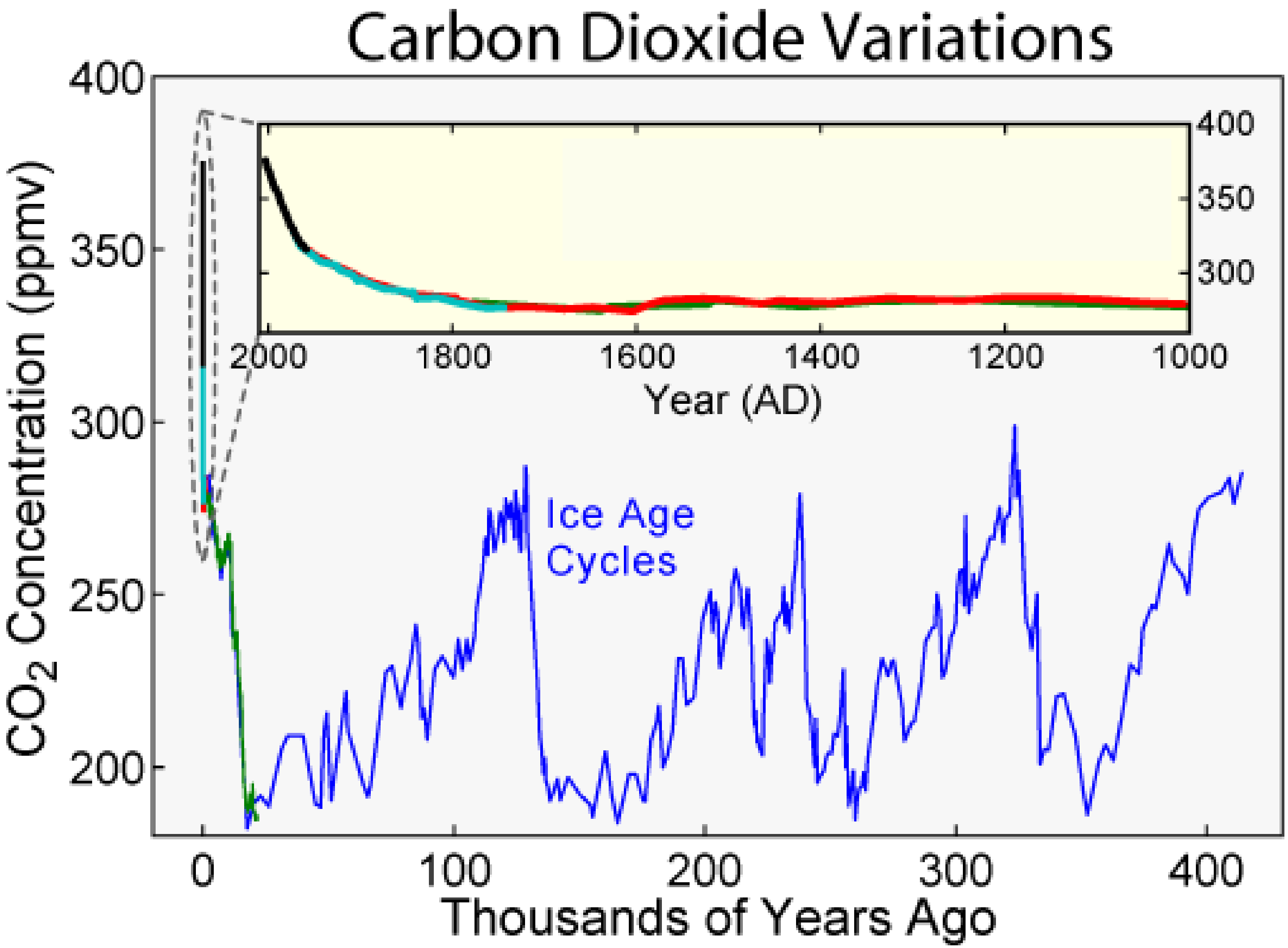
EPICA vs VOSTOK





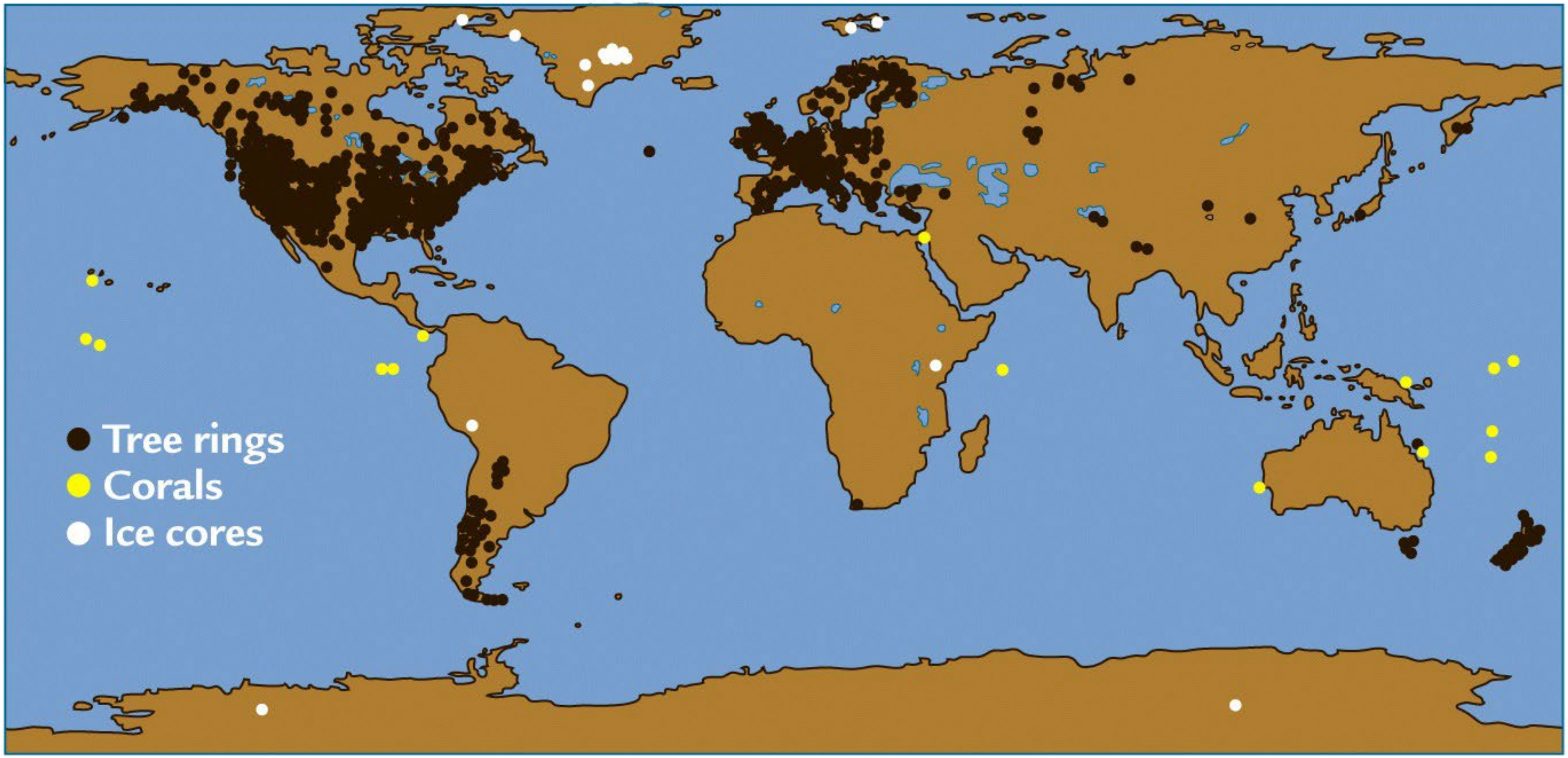
The ice cores retrieved by **EPICA** continuously document the last **820.000 years**, where the last 9 climatic cycles (glacial – interglacial) have occurred. These climatic changes are caused by variation in insolation due to change in astronomical parameters (precession, tilt, eccentricity).

ICE - 10



ICE CORES ALLOW FOR A DIRECT MEASUREMENT OF ATMOSPHERIC CO_2 IN THE PAST

ARCHIVES – DATA BASE



ICE CORES, CORALS e gli **TREES** document the history of climate in the more recent part of the Earth history.

SPELEOTHEMS

SPELEOTHEM -1

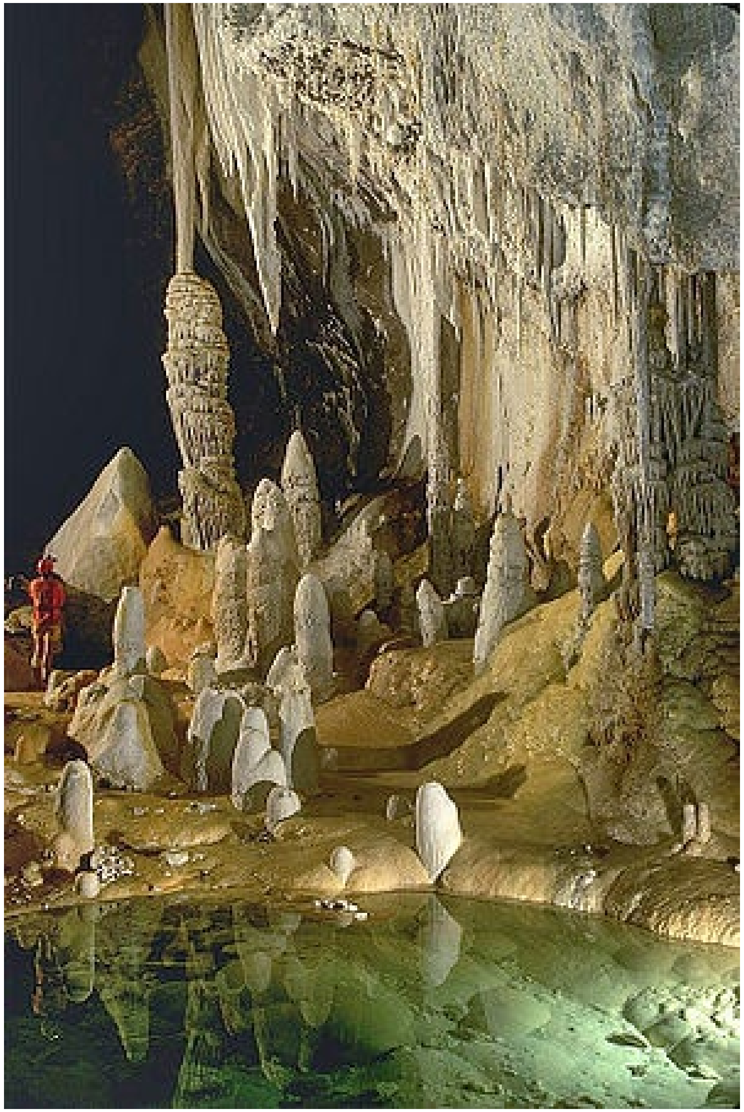
SPELEOTHEM: is secondary cave deposit. It usually forms in carbonatic rocks (not only).

The infiltration of water in rocks could dissolve some minerals, typically calcite/aragonite ($CaCO_3$) or gypsum ($CaSO_4 \cdot 2H_2O$).

The efficiency of this process depends on the amount of CO_2 in the solution, the temperature and other factors. When the solution (water + dissolved ions) enters in the cave, CO_2 tends to escape and cause the precipitation of calcite.

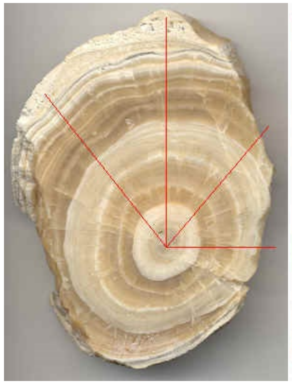
$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{2+} + 2HCO_3^-$

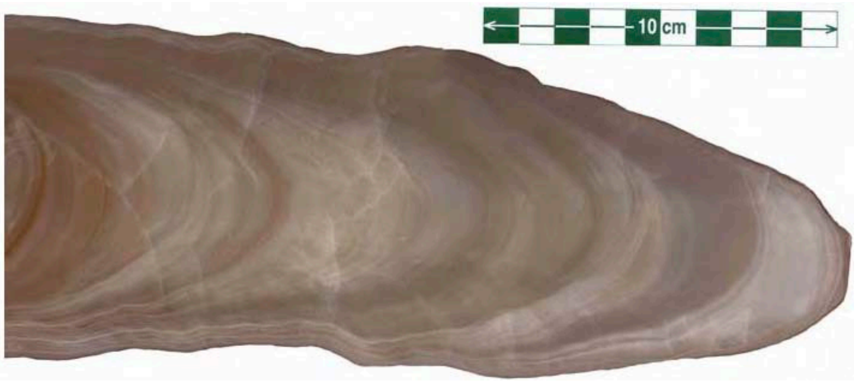
Over time (tens of kyr), the precipitation of calcite originates the speleothem.

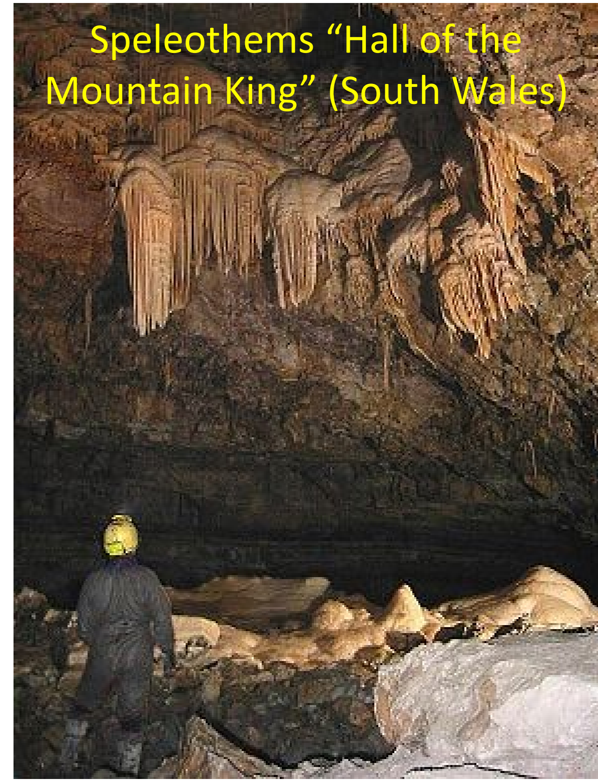


Lechuguilla Cave, New Mexico

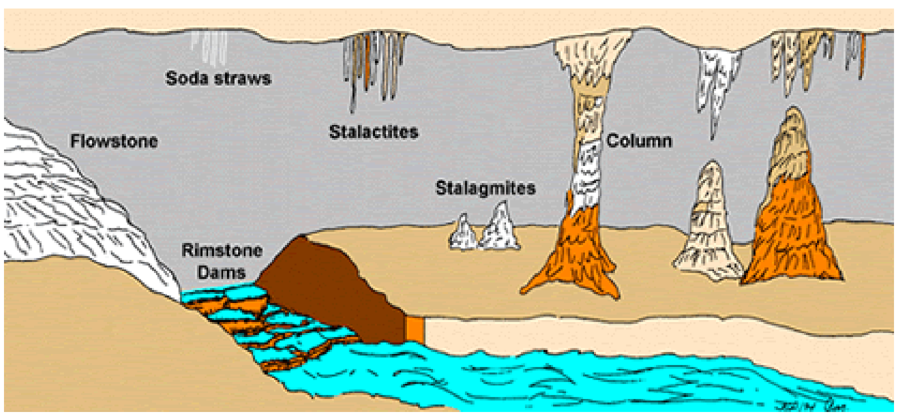
SPELEOTEMs -2



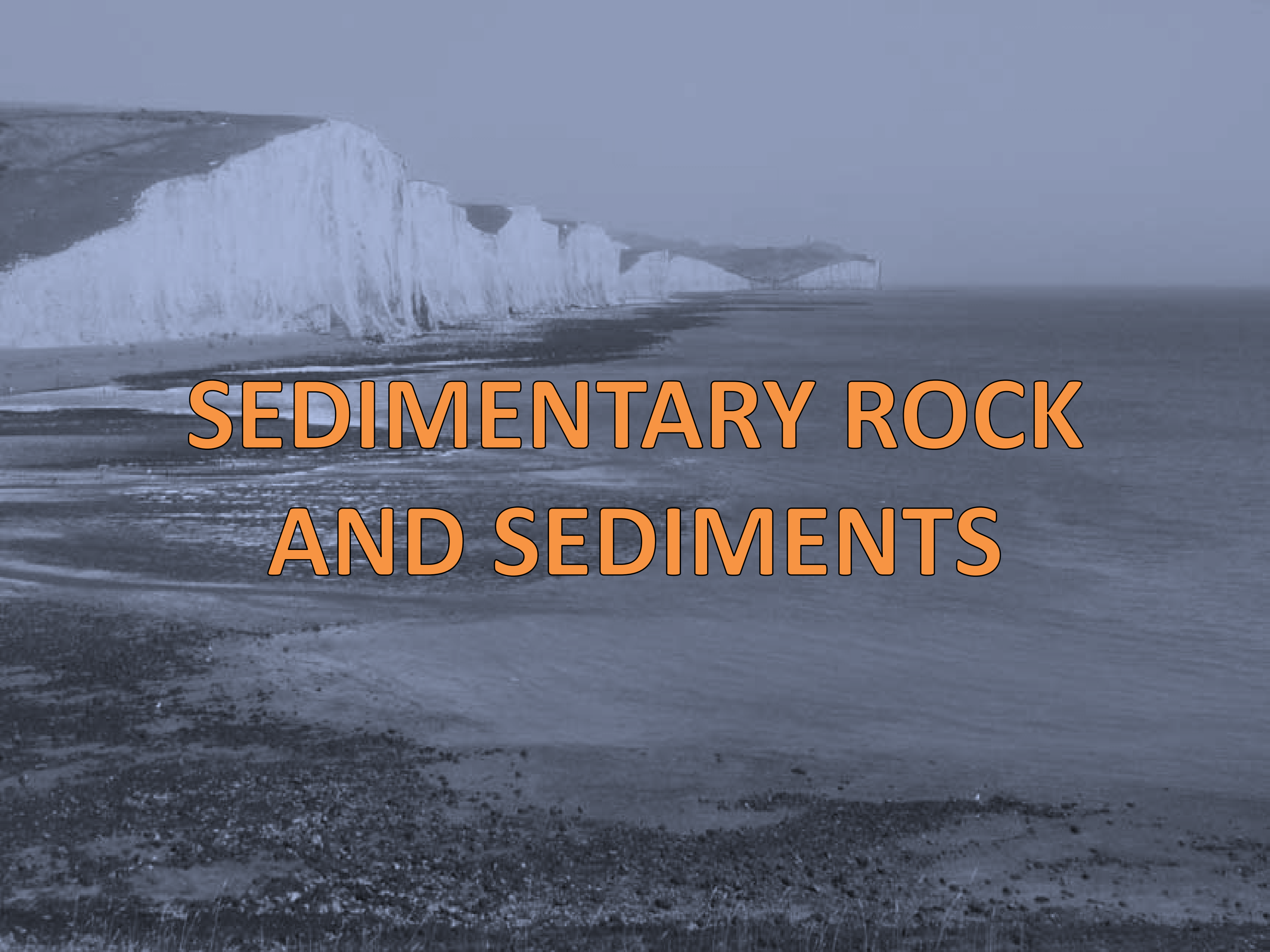




Speleothems are archives to study past climate changes. Speleothems are datable radiometrically (radioactive decay U/Th - late Quaternary).



Stalagmites are useful for paleoclimatic applications because they have simple geometries and contain climate proxies such as O and C isotopes and trace elements. These data can be used to reconstruct changes in rainfall, temperature, vegetation, .. over the last 500kyr.

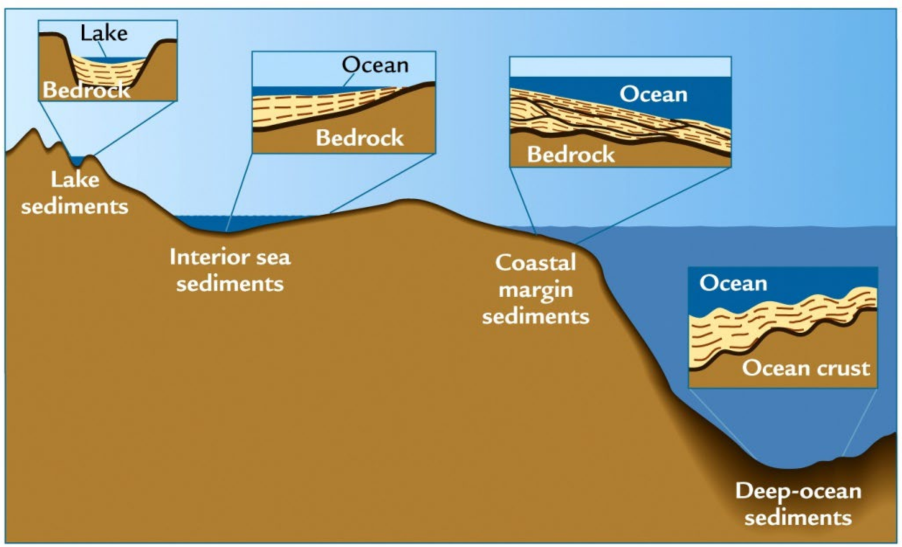

SEDIMENTARY ROCK
AND SEDIMENTS

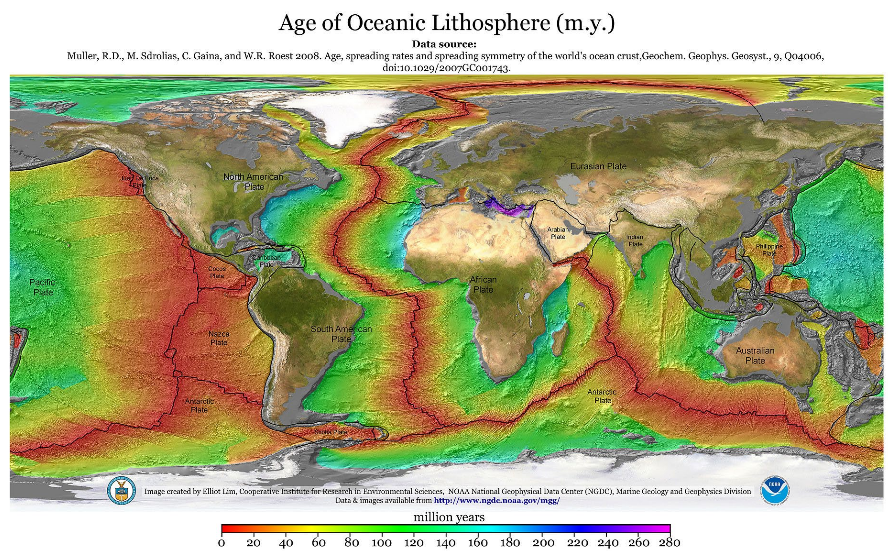
ARCHIVES

As the human history is narrated in the chronicles, the climate history is documented in the archives.

Types of archives

Sediments represent the 99% of the climatic archives. The best archives are the continuous sequences deposited in marine environment. Other type of sediments are affected by runoff, erosion, …..) as it is the case of continental sediments (see figure).



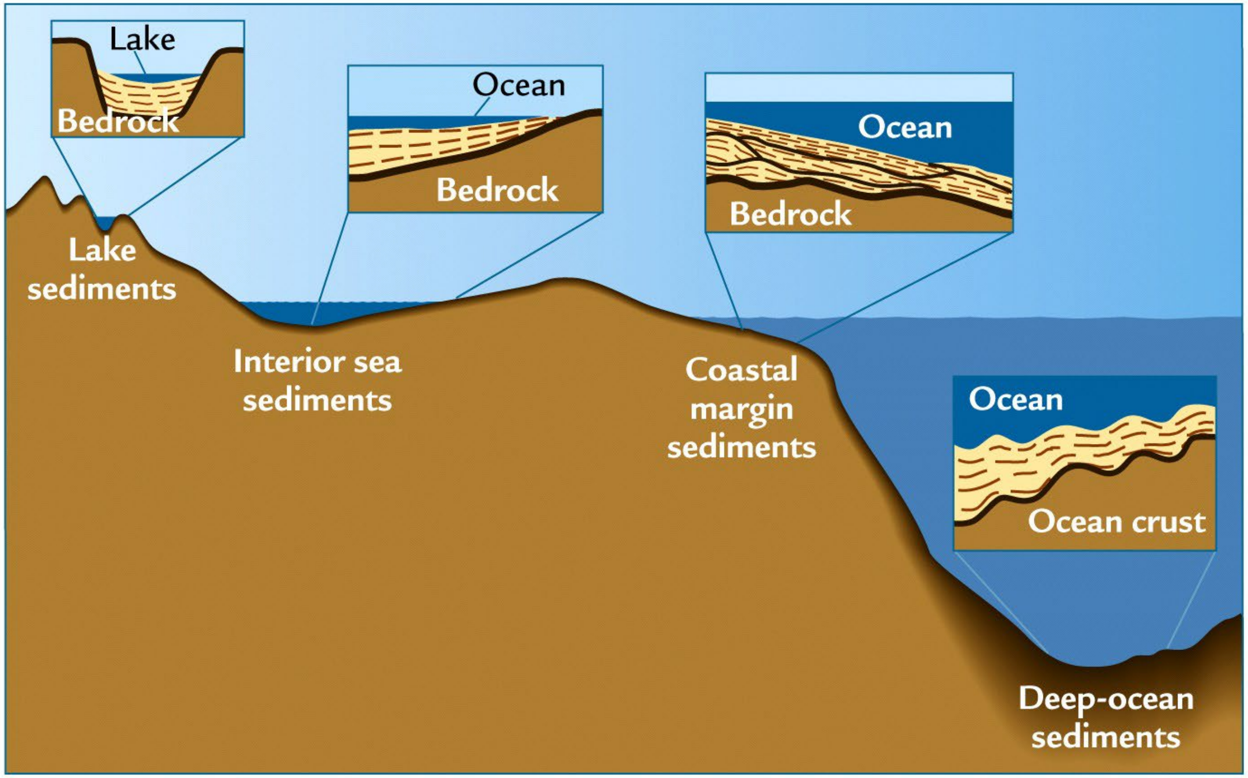


NOAA - http://www.ngdc.noaa.gov/mgg/ocean_age/data/2008/ngdc-generated_images/whole_world/2008_age_of_oceans_plates.jpg

Erosion and tectonic activity caused the finding of older sediments to be less probable. For intervals older than 170-200 Ma, the records essentially comes from continents.

SEDIMENTARY ROCK AND SEDIMENTS- 1

SEDIMENTATION AND DISGREGATION IN CONTINENTS



RAINFALL e **SUPERFICIAL FLOW** erode the outcropping rocks and transport the resulting sediments in the rivers as clasts (**PHYSICAL WEATHERING**) o dissolved in water (**CHEMICAL WEATHERING**).

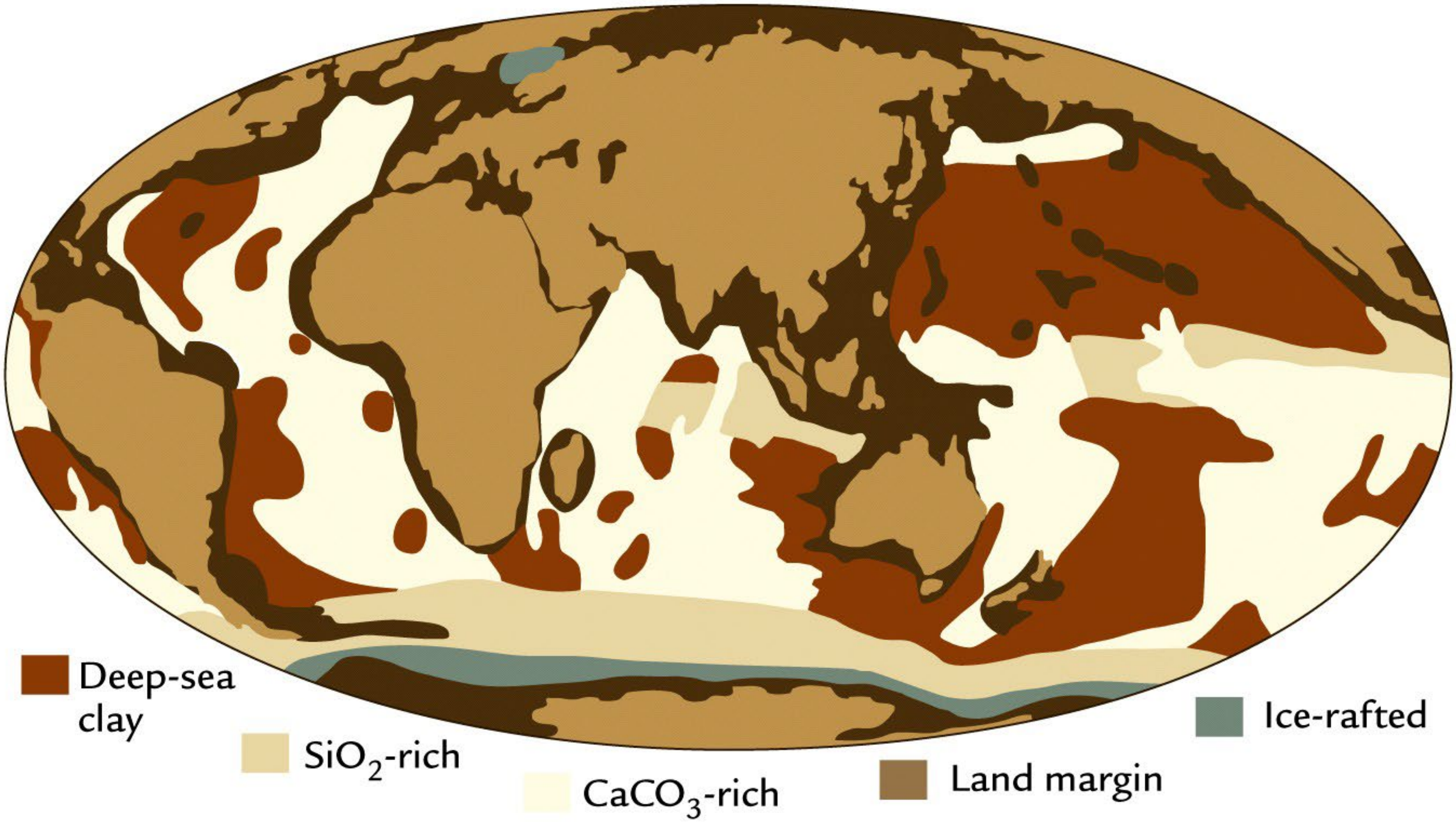
Sediments are deposited in low-energy environments. Most of them reach the ocean through the river runoff. This could happen directly or with some other “stops”.

Which kind of sediments do you expect to find on the ocean floor?

https://app.wooclap.com/events/PCCC24/0

SEDIMENTARY ROCK AND SEDIMENTS- - 2

OCEAN SEDIMENTS



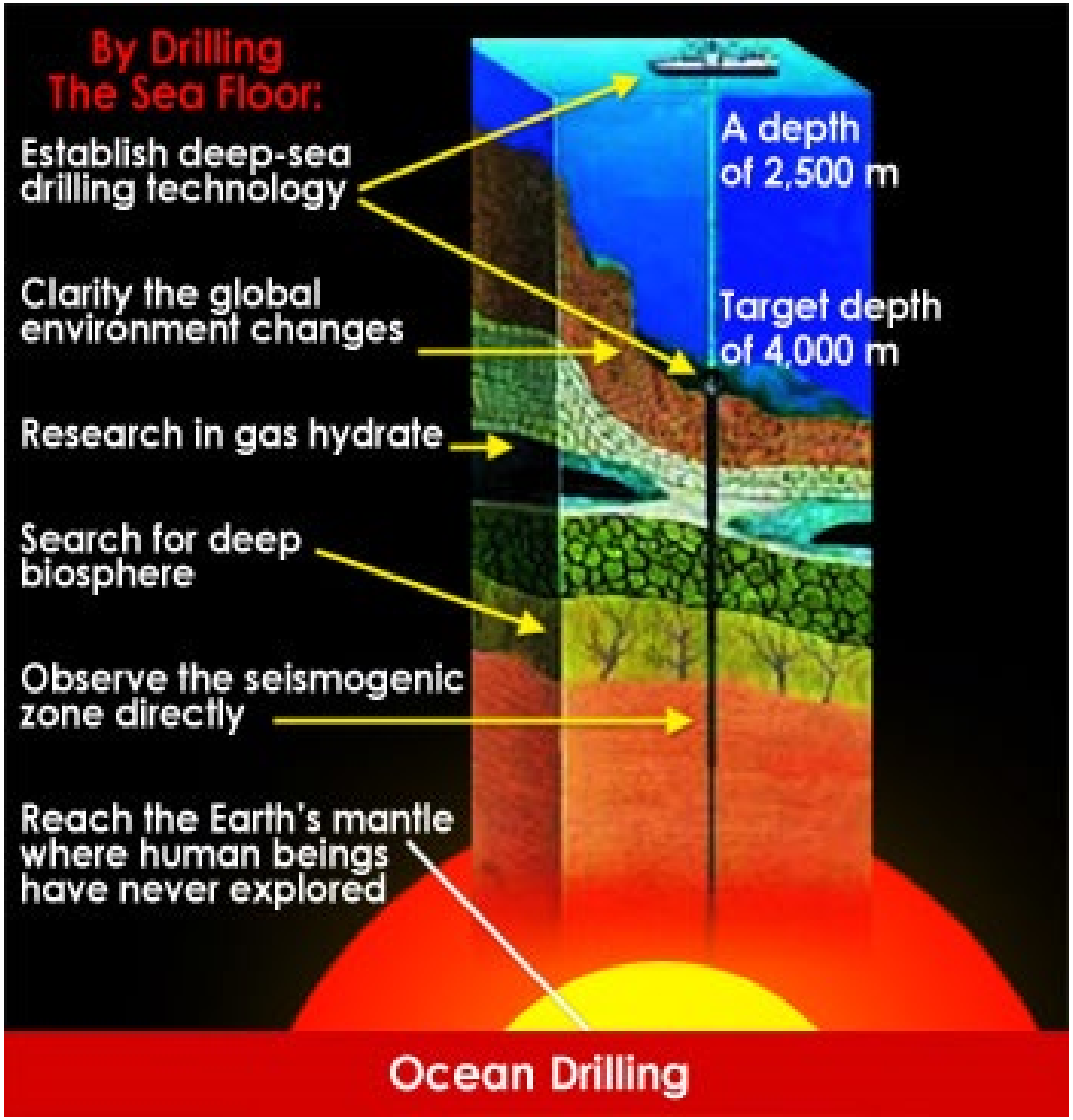
Map of the sediments on the ocean floor

SEDIMENTARY ROCK AND SEDIMENTS - 3

OCEAN DRILLING

INTERNATIONAL OCEAN DISCOVERY PROJECT (IODP- 2013-2023)

Is an international research project focused on the study of the HISTORY AND STRUCTURE OF THE EARTH USING ROCKS AND SEDIMENTS PRESENT IN THE OCEAN FLOOR, also monitoring the environments close to the sea bed. IODP is the continuation of Deep Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP), that, thanks to ocean exploration, has revolutionized our view of the history of life and related global processes. IODP uses different drilling technologies (riser, riserless, and mission-specific).

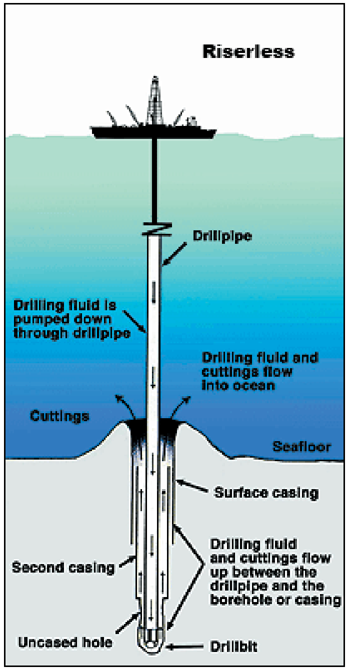


http://www-odp.tamu.edu/ http://www.aarji.com/IODP/

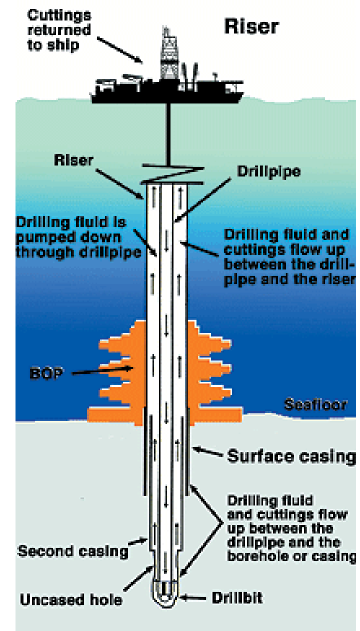
SEDIMENTARY ROCK AND SEDIMENTS - 4

IODP is a multi-platform marine research program involving a riserless drilling vessel, a riser drilling vessel, and mission-specific platforms. Three Implementing Organizations (IOs), in Japan, the USA, and Europe, serve as science operators of the various ships and platforms.

Riserless Vessel: **JOIDES** Resolution



Riser Vessel: **CHIKYU**



Mission-Specific Platforms

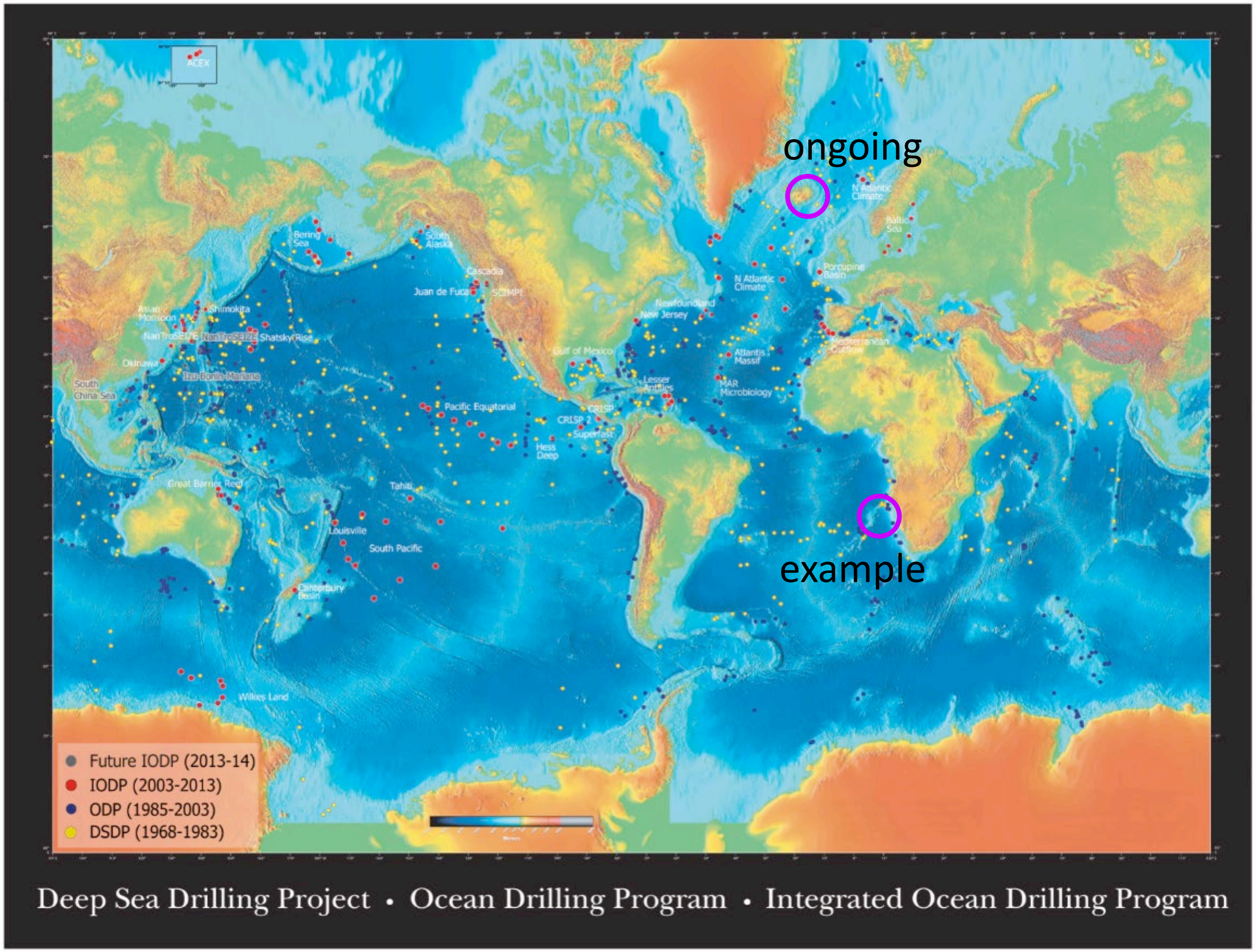
Riserless drilling technology uses seawater as the primary drilling fluid, which is pumped down through the drillpipe. The seawater cleans and cools the drill bit and lifts cuttings out of the hole, piling them in a cone around the hole.

The riser system includes an outer casing that surrounds the drill pipe to provide return-circulation of drilling fluid to maintain pressure balance within the borehole. A blowout preventer (BOP) protects the vessel from gas and oil. This technology is necessary for drilling several thousand meters into the Earth.

Arctic Ocean (2004)

SEDIMENTARY ROCK AND SEDIMENTS - 5

STUDY AREAS OF THE PROJECT



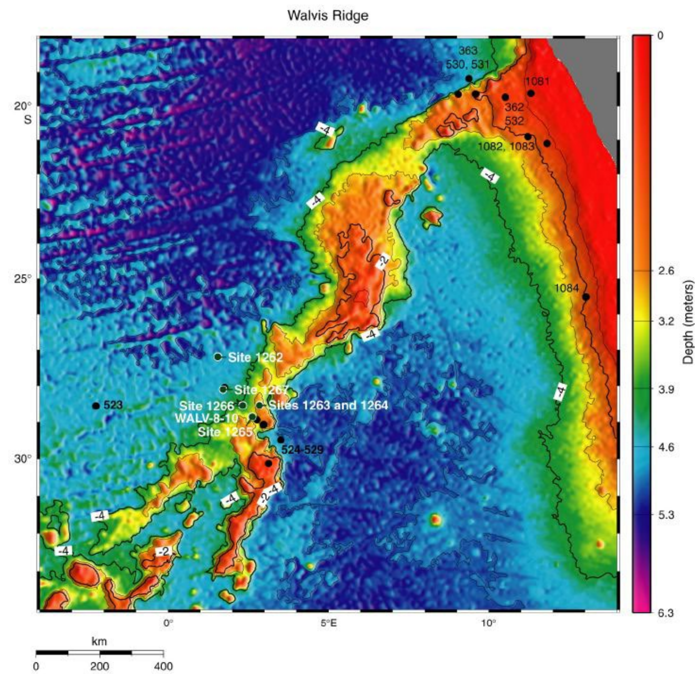
Km of sediments retrieved all around the world.

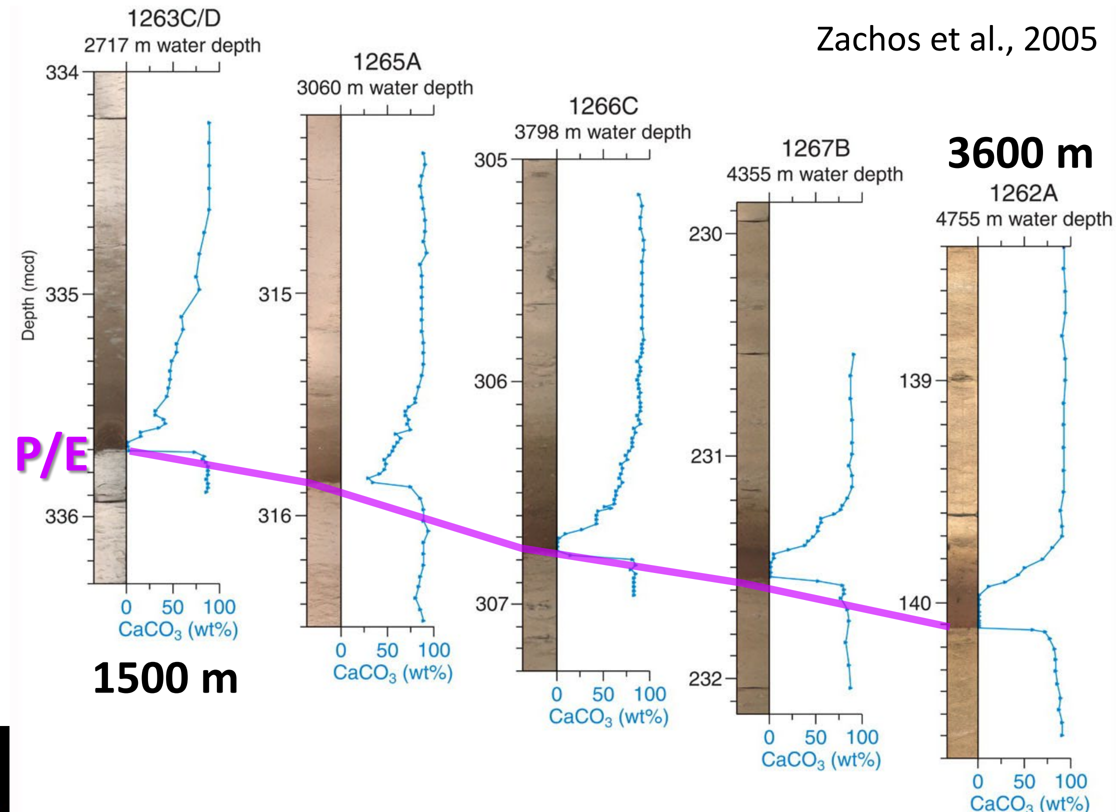
The ocean cruises are named **Expedition/Leg** and have a 2 months duration.

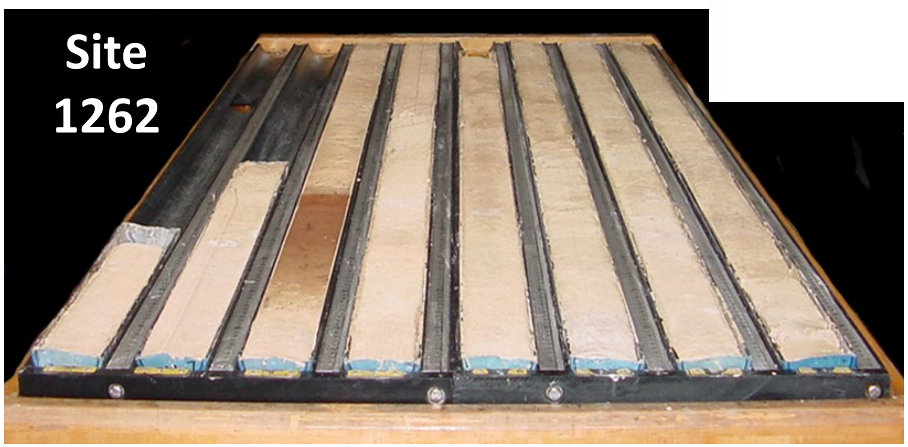
The ongoing expedition is Exp. 400 (NW Greenland Glaciated Margin).

SEDIMENTARY ROCK AND SEDIMENTS - 6

AN EXAMPLE: WALVIS RIDGE (Leg 208)







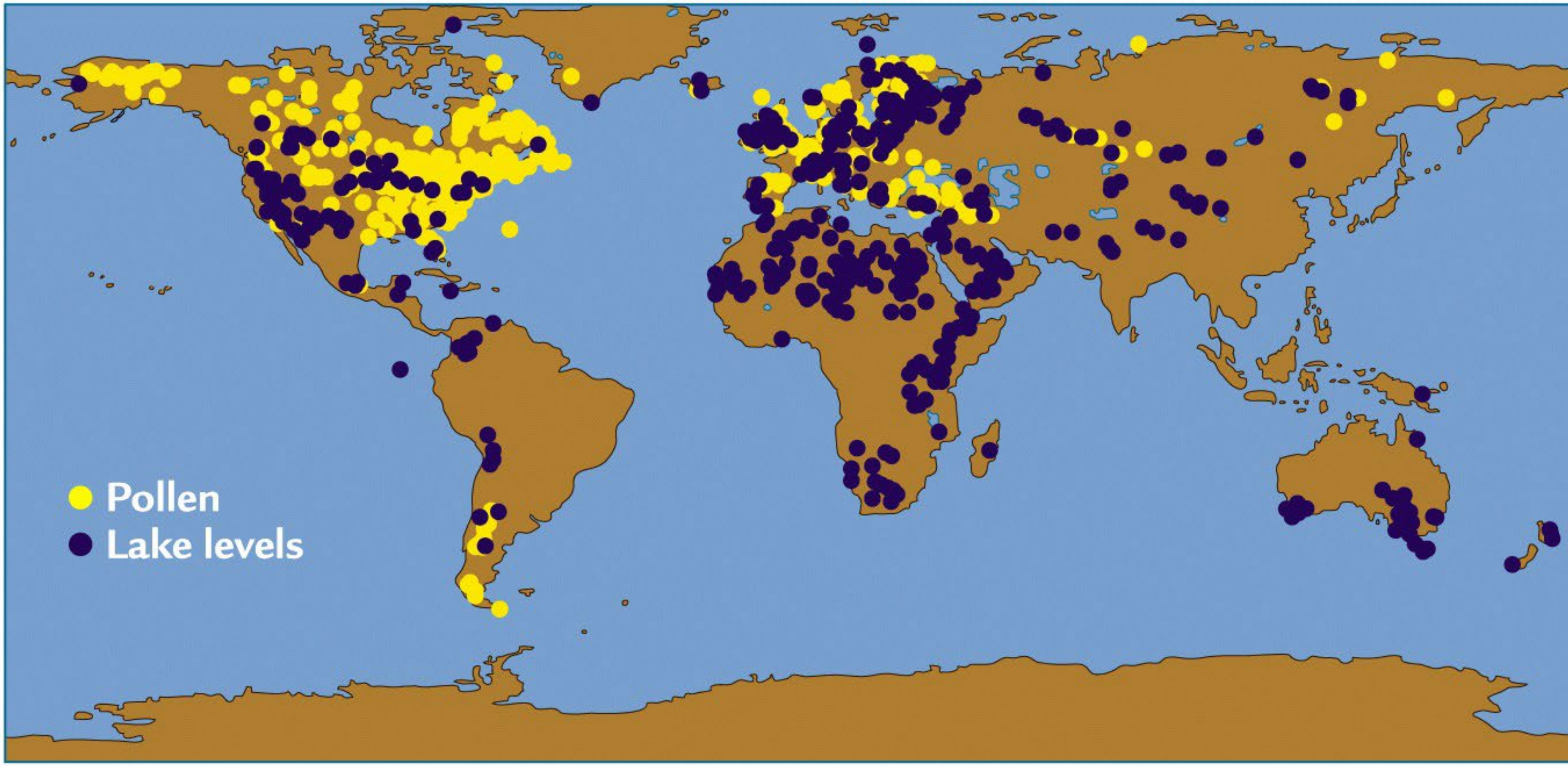
The drilling locations are named **Sites**. One site can be drilled multiple times (**Hole** A, B ecc.). From each Hole you retrive a different number of **cores** (ca. 9 m) depending on the scientific aim. Cores are subdivided in sections (ca. 1.5 m). Above a depth transect.

IODP DRILLING PROJECT

https://www.youtube.com/watch?v=jWO6LnsGj1s

LACUSTRINE SEDIMENTS

LACUSTRINE SEDIMENTS- 1



Hundrends of cores have been retrieved from the lake floors all around the world. These sediments are analyzed in terms of pollen content and **lake levels.**

LACUSTRINE SEDIMENTS- 2

VARVES

Varve (annually laminated) deposits

VARVE (from Swedish, *varv*) represents a laminated layer deposited in one year.

Formal definition: varve refers to each of the separate components comprising a single annual layer. Recently the term **annually laminated** is used as a synonymous of varve.

LACUSTRINE SEDIMENTS - 3

VARVE GENESIS

Varves form in a variety of sedimentary environments, MARINE and LACUSTRINE. They are the result of seasonal variations and are caused by sedimentary, biological and chemical processes.

LACUSTRINE

The archetype of the «classic» varve is the light/dark couplet deposited in a glacial lake. **The light layer** consists of a set of coarser sediments (silt to fine sand) deposited under high-energy conditions during the thaw, which results in a discharge (of sediments and water) into the lake. In winter, the water discharge decreases as well as the amount and size (clay) of sediments. These sediments slowly reach the lake floor in a relatively low-energy environment forming **dark layered sediments.**

In addition to season variations and related sedimentary processes, a necessary condition for the formation of a varve is the **absence of bioturbation**. As a consequence, varves commonly form under anoxic conditions.

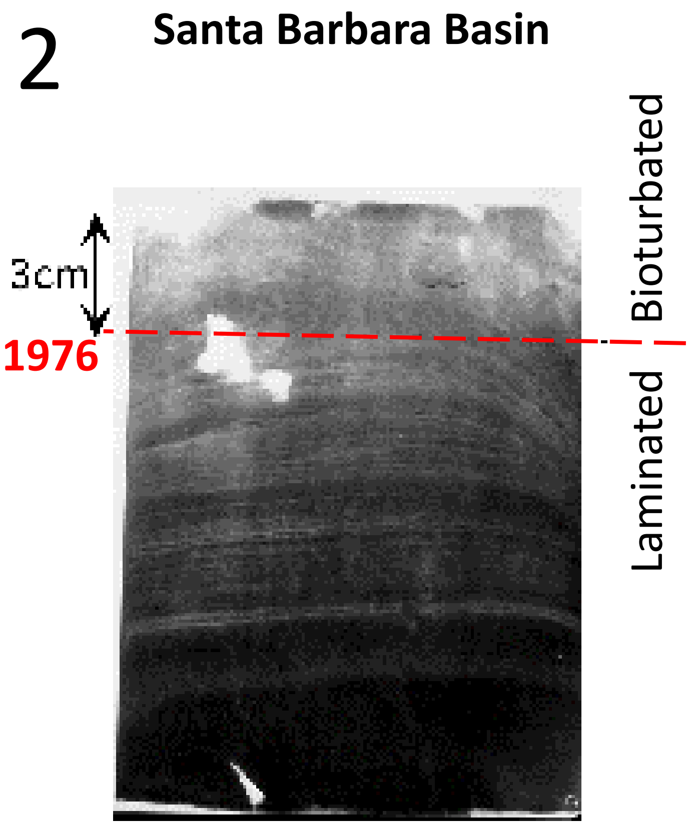
MARINE

The sediments depositing in the Santa Barbara Basin (California) are an example of annually laminated sediments in **marine environment.**

LACUSTRINE SEDIMENT - 4

Drilling in a Swedish glacial lake

ANOXIC SEDIMENTS (SANTA BARBARA BASIN)



MARINE VARVE SEDIMENTS (SANTA BARBARA BASIN)

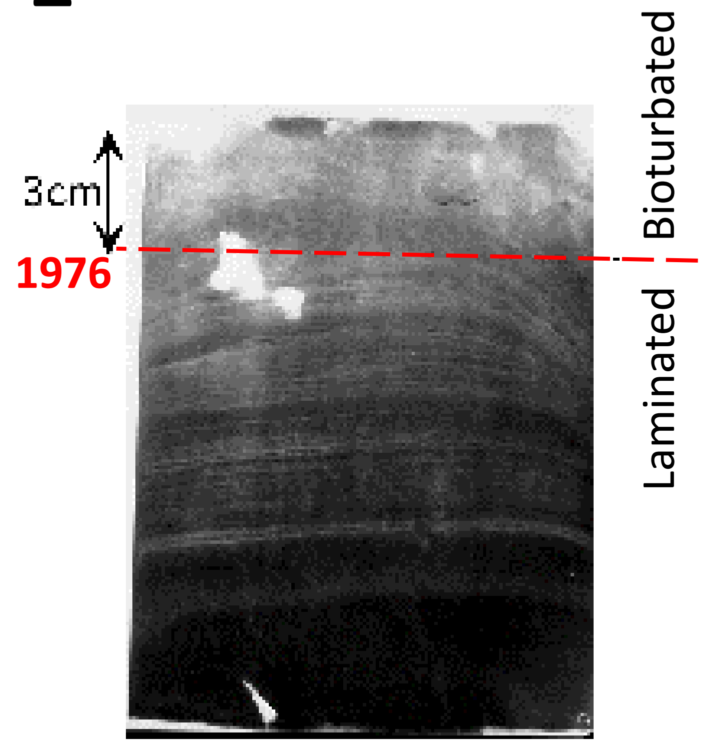
The deposition of laminated sediments suddenly stops in (Fig. 1) 1976 (radiometric dating ^{210}Pb). In Fig. 2, you can appreciate that the upper part of the core is strongly bioturbated. The increase in bioturbation coincides with a **warming** and a **decrease in productivity** in the sea waters of the Californian current system.

What is the likely reason why laminated sediments suddenly stopped in 1976 in the Santa Barbara Basin, as observed in the previous image?

https://app.wooclap.com/events/PCCC24/0

ANOXIC SEDIMENTS (SANTA BARBARA BASIN)

2 Santa Barbara Basin



The increase and decrease of surface biomass control the amount of available oxygen. The higher the biomass (surface productivity), the lower the oxygen content, resulting in less life at the seafloor, and consequently, the sediments are laminated. The opposite occurs when biomass is lower.

OTHER SEDIMENTS - 1

CONTINENTAL MARGIN SEDIMENTS
Continuous sequences punctuated by erosive episodes. In such environments, changes in sea levels play a pivotal role.

Certain METEORIC AGENTS atmospheric factors are primarily responsible for the formation of distinct sediment types.

-ICE

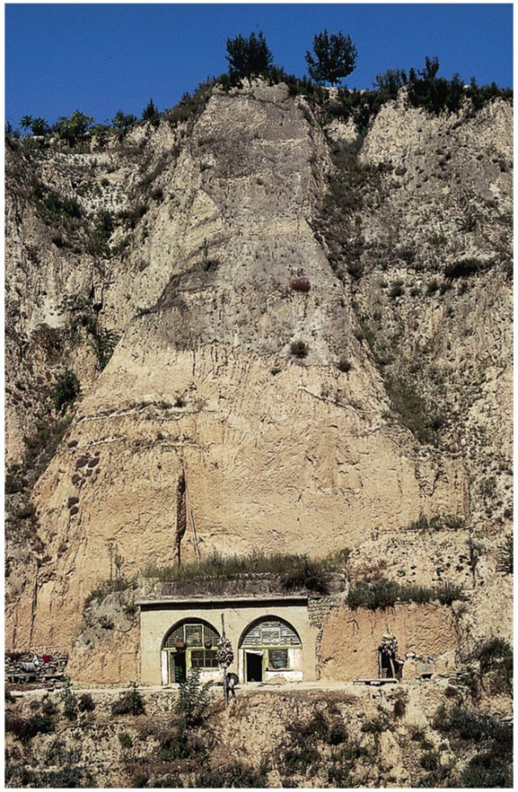
Moraine deposits are composed of detrital rocks carried by glaciers. The continuous advance and retreat of glaciers erase intermediate phases, creating a uniform record of their waxing and waning..
Investigating climate through the study of moraines is like trying to decipher the words on an erased chalkboard.
ICE-RAFTED DETRITUS: sediments of glacial origin transported by the ocean

OTHER SEDIMENTS - 2

-WIND

DUNES: Sands typically form in desert environments due to the action carried out by the wind.

LOESS: Sediments from arid regions are transported by the wind and settle in areas where the wind's intensity is reduced. In southeastern China, these deposits have reached significant thickness, measuring hundreds of meters, and were formed within the past 3 million years.



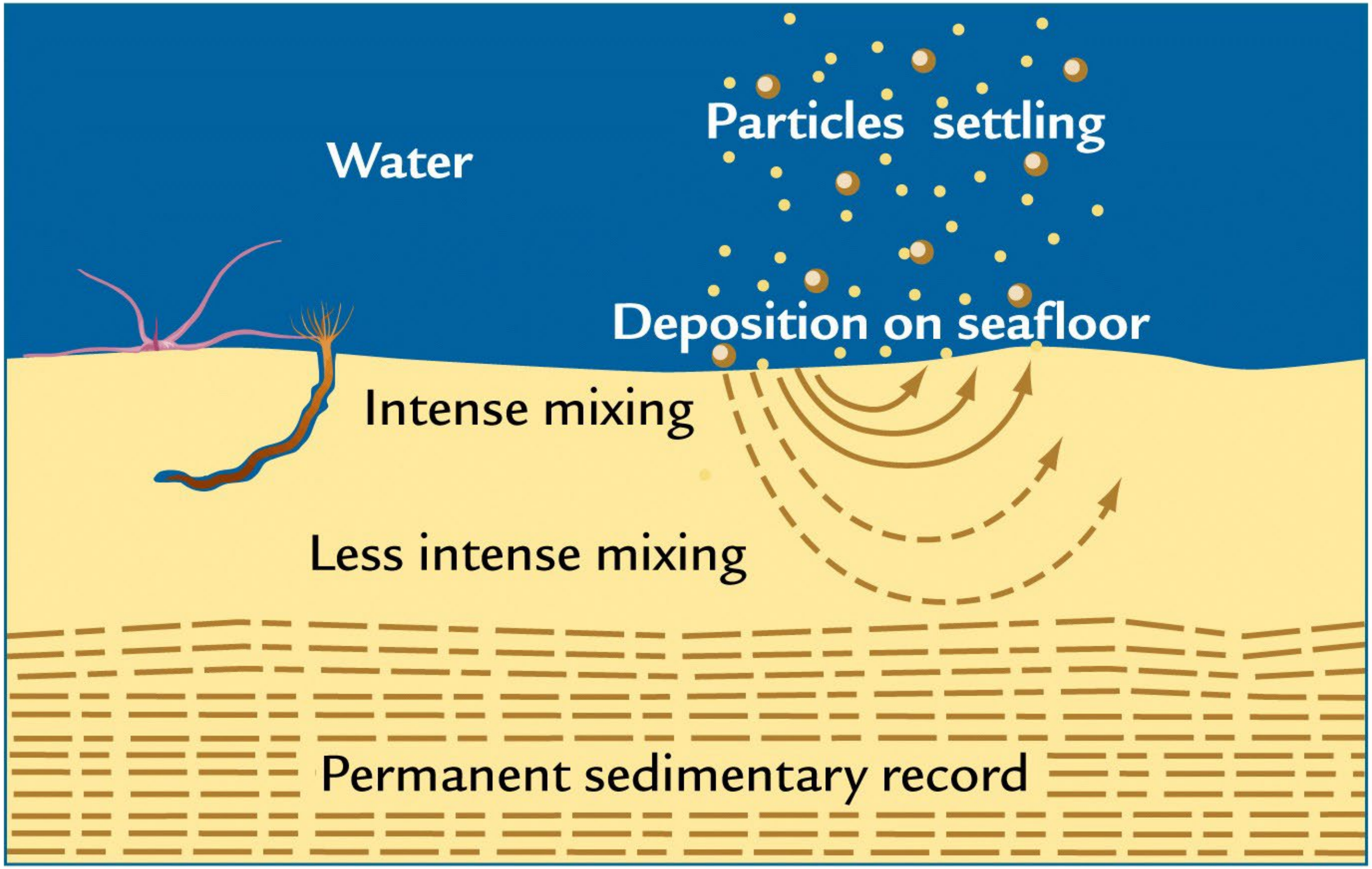
SIGNAL RESOLUTION AND ALTERATION

The temporal resolution of the signal recorded in the archive depends on two main factors:

(1) Processes that perturb /are able to alter the pristine sedimentation (bioturbation)

(2) The sediment accumulation rate

BIOTURBATION



The bioturbation, in a pelagic environment, is active in the first 10-20 cm. Depending on the accumulation rate, sediments/fossils that are mixed up could significantly vary. High sedimentation rate = ???

TEMPORAL RESOLUTION