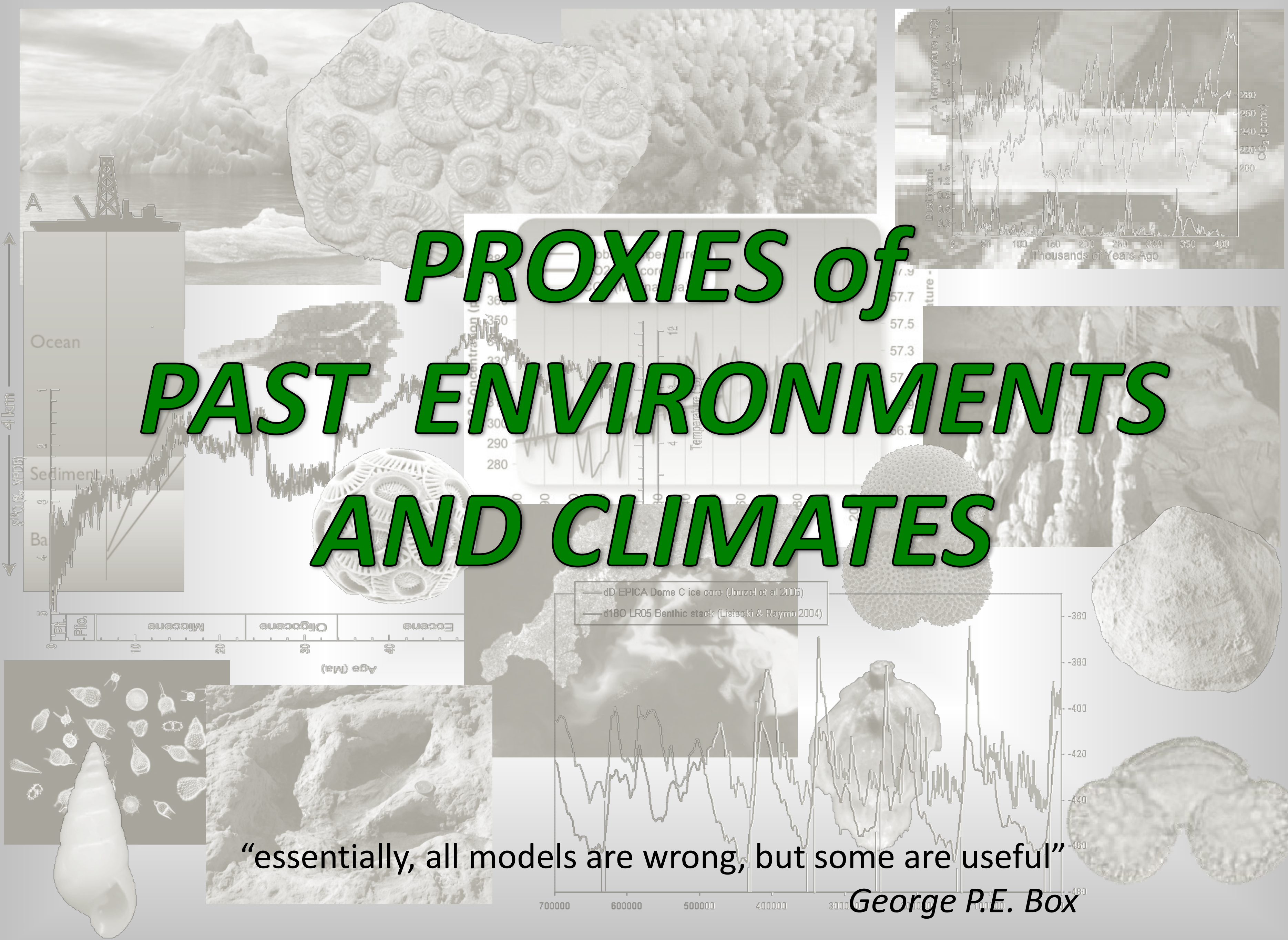
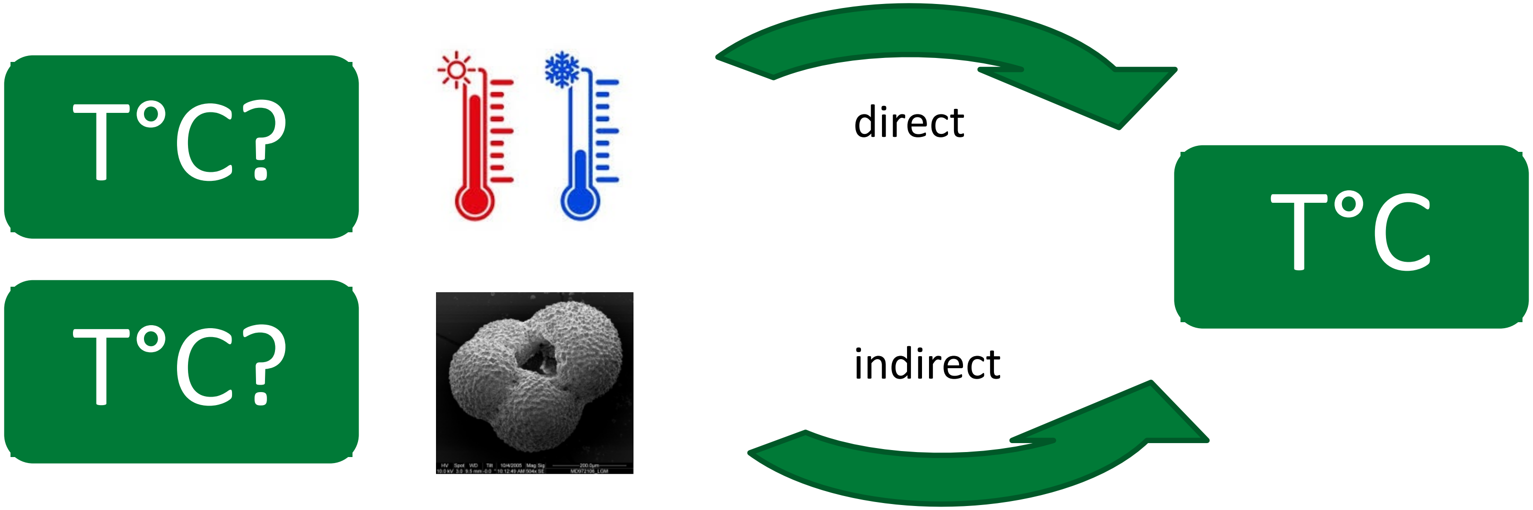


PROXIES of
PAST ENVIRONMENTS
AND CLIMATES

“essentially, all models are wrong, but some are useful”
George P.E. Box

PROXY: a DEFINITION

Geological archives hold **features, properties, information** known as proxies (e.g., lithology, fossil content, geochemistry), that provide insights into past environments and climates at various scales. The term "proxy" refers to a substitute in forensic terms.



T°C?

T°C?

direct

indirect

T°C

Unlike present temperatures measured directly, **past environmental and climatic conditions are inferred through proxies**—features that serve as substitutes for direct measurements, like a thermometer.

PROXY CALIBRATION

Rock formations and fossils are closely tied to their environments, providing clues about past climates/environments.

However, the scientific, quantitative approach we use to reconstruct these conditions makes the proxy calibration more complex and challenging.

PROXY CALIBRATION PROCEDURE

The goal is to understand the mechanisms—chemical, physical, and biological—by which a specific climatic parameter is recorded in geological archives. Once identified, this feature must be analyzed and calibrated.

For example, using fossils to estimate paleotemperature requires understanding how temperature influences the distribution of these organisms across time and space.

ARCHIVE

PROXY

CALIBRATION

ESTIMATION

EXAMPLES OF PROXIES-1

PROXIES can potentially give us information on temperature, rainfall, productivity, and various other environmental/climatic parameters:

Examples of proxies are:

- **Presence or absence of fossils (marine and terrestrial)**,
- **Abundance of certain taxa (marine and terrestrial)**,
- **Width of annual tree,**
- **Width of coral bands,**
- **Geochemical and isotopic composition.**

CLASSIFICATION OF PROXIES -1

Proxies can be classified based on:

a) **THE FEATURE/PROPERTY/INFORMATION IN THE ARCHIVE**

BIOTIC PROXIES

Biotic proxies rely on changes in the fossil (faunal and floral) compositions.

GEOLOGICAL-GEOCHEMICAL PROXIES

Geological-geochemical proxies quantitatively reflect interactions between various reservoirs. Each proxy, whether physical or chemical, is analyzed, and its variations are examined in relation to climatic and environmental conditions.

CLASSIFICATION OF PROXIES -1

Proxies can be classified based on:

a) **THE PARAMETER TO BE EVALUATED**

- **TEMPERATURE PROXY**
- **SEA LEVEL CHANGE PROXY**
- **RAINFALL PROXY**
- **PRODUCTIVITY PROXY**
- **ETC.**

PROXY OUTPUT CLASSIFICATION

Qualitative

Descriptive information that provides non-numerical insights, often based on observations or categorizations. It focuses on the qualities of phenomena without assigning numbers, such as visual descriptions or historical records.

Semiquantitative

Data that is not fully numerical but provides a rough estimate or rank. It uses scales or categories to approximate numerical values, offering partial quantitative detail (e.g., low, medium, high).

Quantitative

Precise, numerical data that can be measured, calculated, and analyzed statistically, providing specific values for comparison and interpretation.

PROXY OUTPUT CLASSIFICATION

Qualitative

Description of Fossil Assemblages: This output includes narrative descriptions of variations in fossil species found in a sample. For example, a narrative of fossil plant species found in a sediment deposit.

Qualitative Images or Graphics: Visual representations, such as photographs or illustrations, showing variations in proxies. For example, a pictorial representation of past vegetation.

PROXY OUTPUT CLASSIFICATION

Semiquantitative

Relative Abundance Diagrams: These diagrams show the percentages of different fossil taxa in a sample. For example, a pie chart representing the proportion of plant species in a specific period.

Diversity Indices: Diversity indices provide a semi-quantitative measure of the variety of species present in a sample. For example, the Shannon-Wiener Index calculated for a set of marine fossils.

PROXY OUTPUT CLASSIFICATION

Quantitative

Numeric Abundance Values: These outputs provide quantitative data on the abundance of each taxon in samples. (e.g., n/g).

Quantitative Temporal Trends: These graphs show the variations of proxies over time with precise numerical data. For example, a graph representing the variations in average annual temperature over the last 10,000 years based on isotopic measurements in ice core samples. Statistical Calibrations: Using regression techniques or other statistical analyses, it is possible to calibrate proxy data to obtain quantitative estimates of past temperatures or other climatic conditions.

Match each type of proxy output with its description

Go to **wooclap.com** and use the code **PCCC2023**

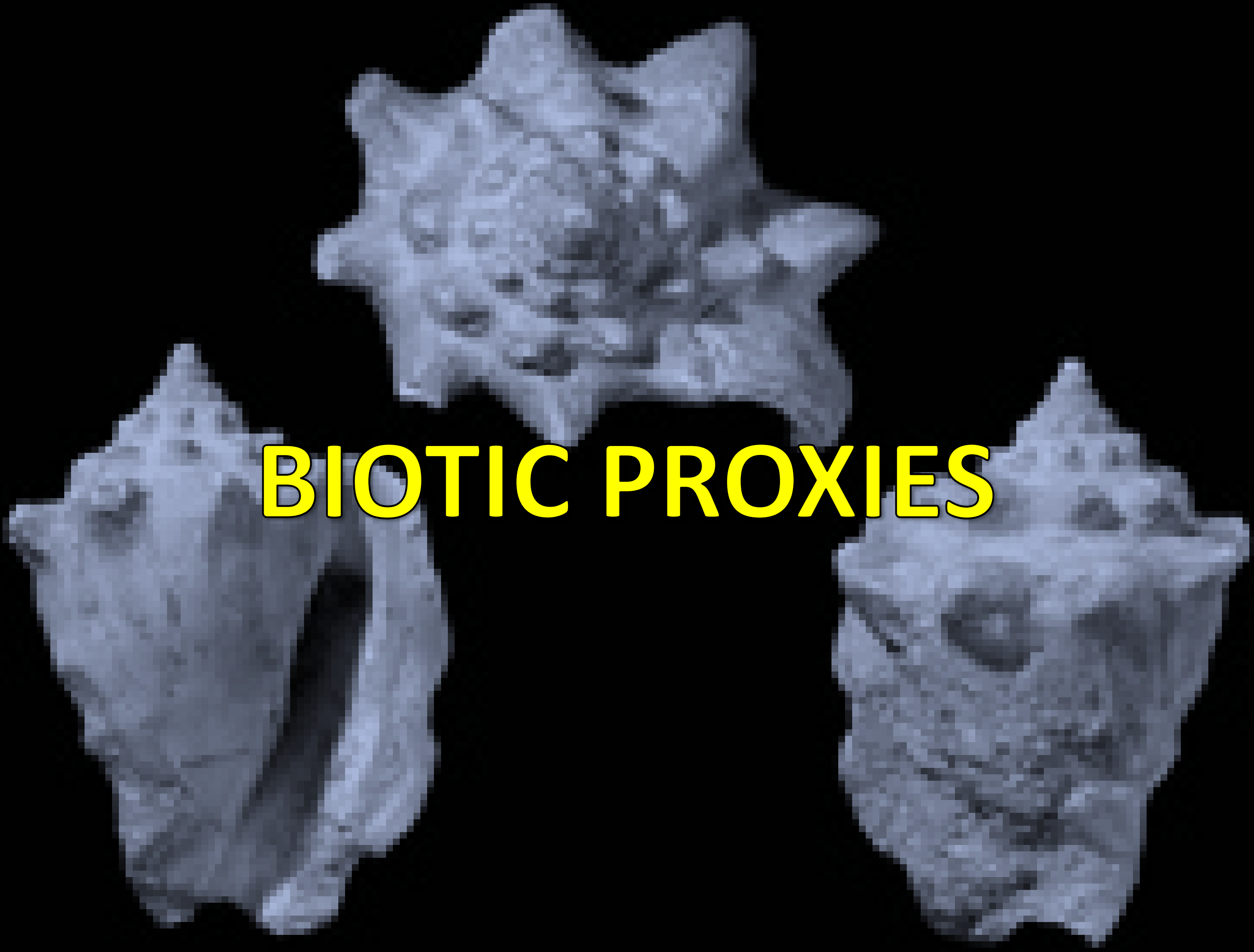
Match each type of proxy output with its description

The most frequent answers are

semiquantitative	
qualitative	
quantitative	es
qualitative	
semiquantitative	a
quantitative	ta

https://app.wooclap.com/events/PCCC2023/0

BIOTIC PROXIES



PAST VEGETATION

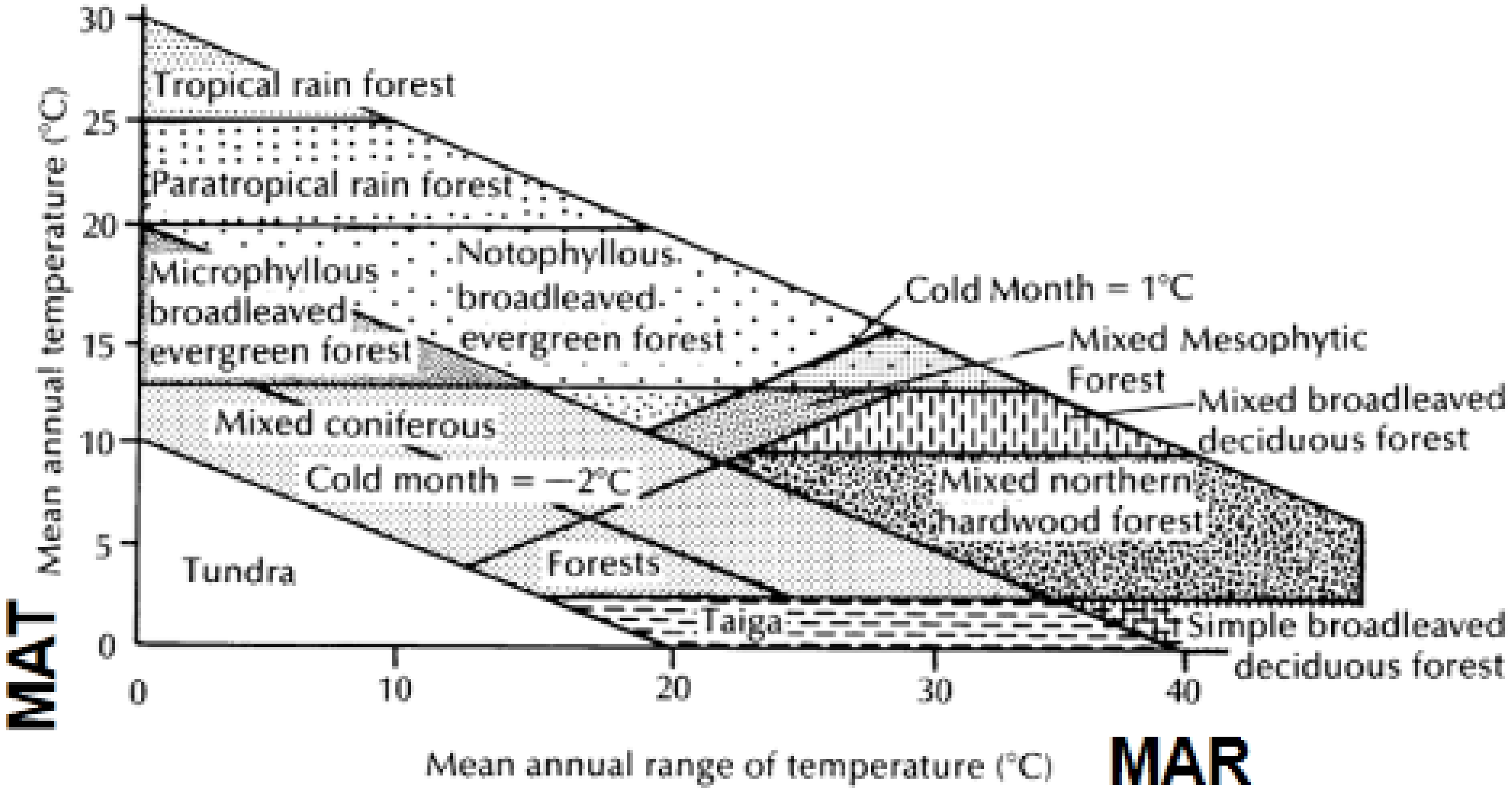
Terrestrial plant assemblages are closely tied to precipitation and temperature.

By reconstructing the vegetational history of a region, we can infer past climatic parameters like rainfall and temperature.

EXAMPLE
Fossil plant remains similar to modern species can provide climate insights based on taxonomic uniformitarianism).
For example, palms cannot survive multiple frost nights, so finding fossil palms at high latitudes suggests past climates were much warmer than today.

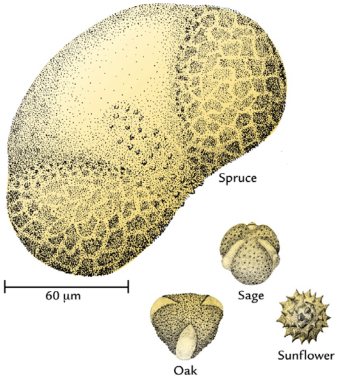
PAST VEGETATION

When water is not a limiting factor, vegetation types are primarily linked to temperature, even tracing back to the Cretaceous period.



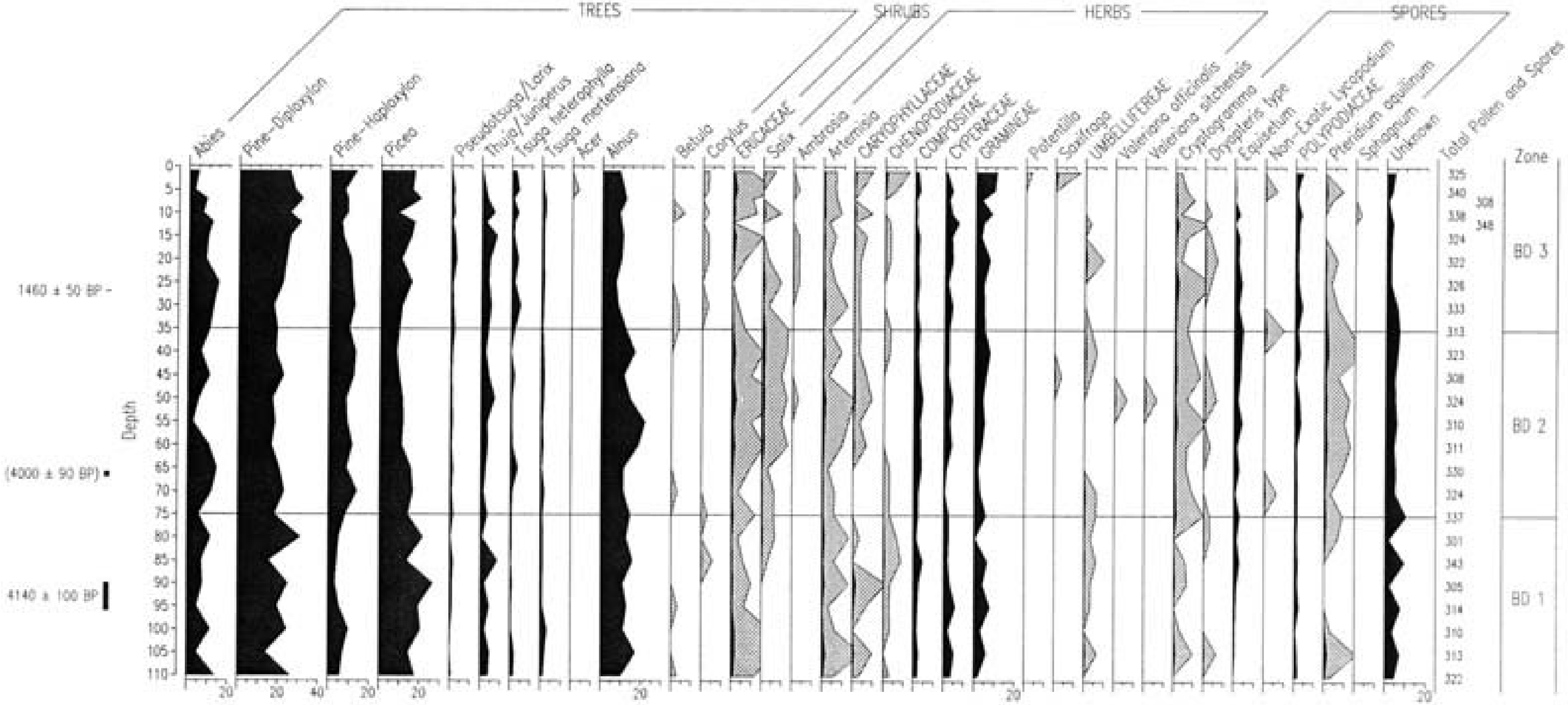
Correlation between vegetational types and temperature regimes

POLLENS



Pollens serve as a reliable indicator of continental climate conditions.

These conditions can be reconstructed by analyzing the variations in the abundance of different pollen types, referred to as '**pollen spectra**'.



Pollen spectrum

WIDTH OF TREE RINGS

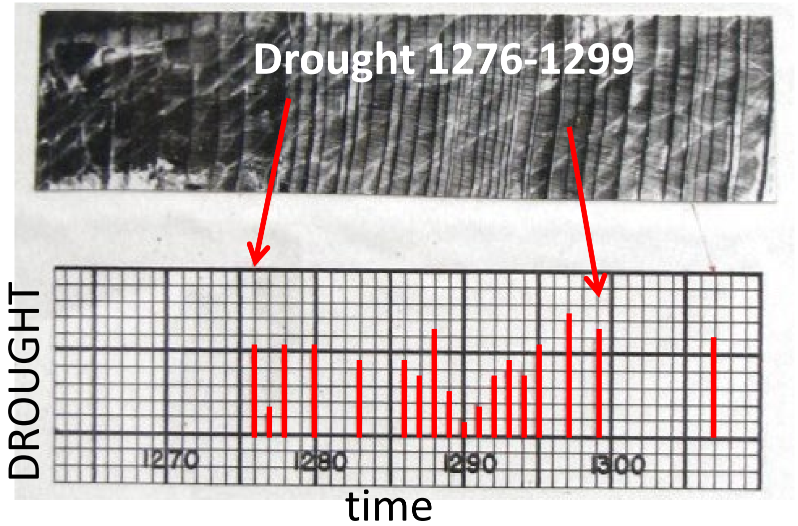
Tree ring width serves as an environmental proxy.

When growth is temperature-limited, ring thickness reflects conditions during the growing season. An equation links ring width to temperature changes.

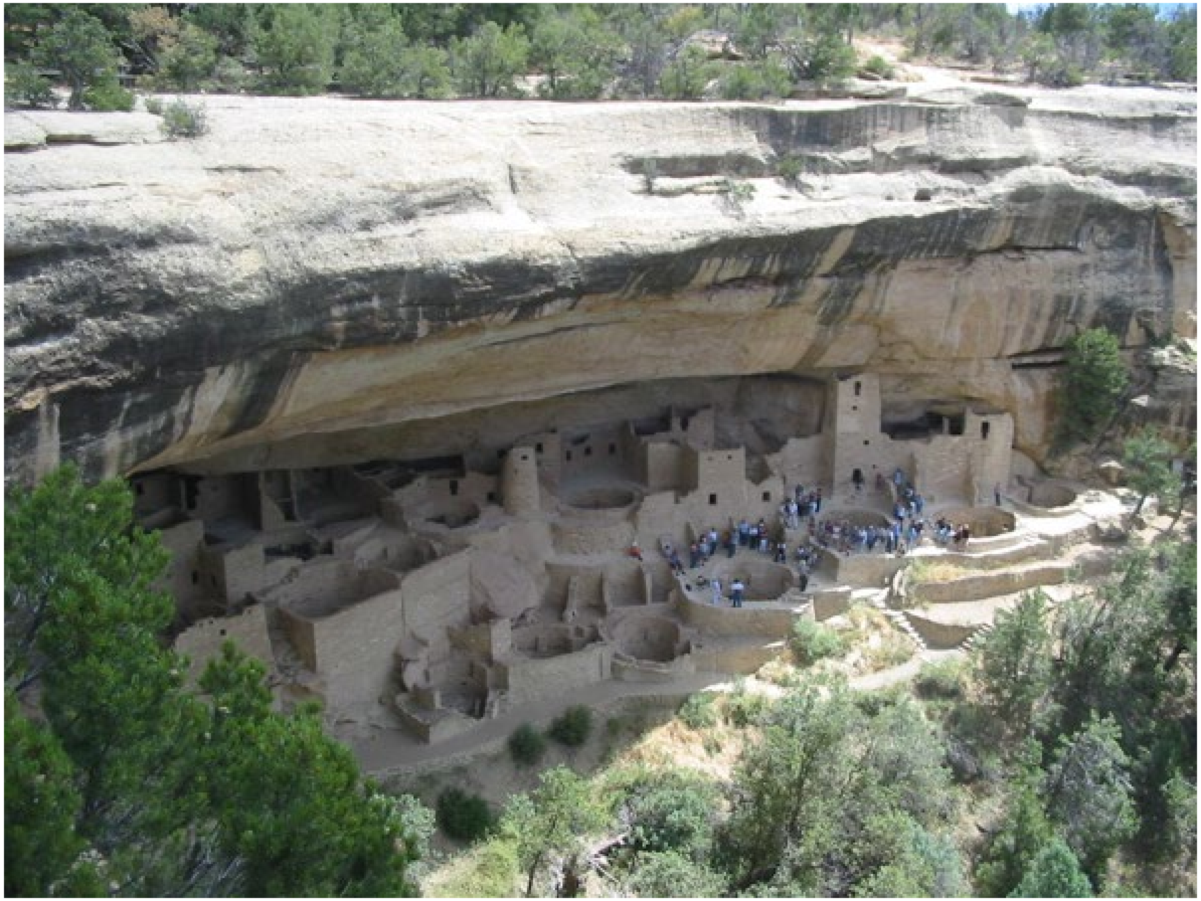
In semi-arid regions, where growth is water-limited, ring width can also estimate precipitation variations.

USA - drought 1276-1299

The prolonged drought from 1276 to 1299 may have contributed to the abandonment of Mesa Verde's cliff dwellings (CO). The figure shows a tree-ring graph from Oraibi (AR), highlighting this dry period.

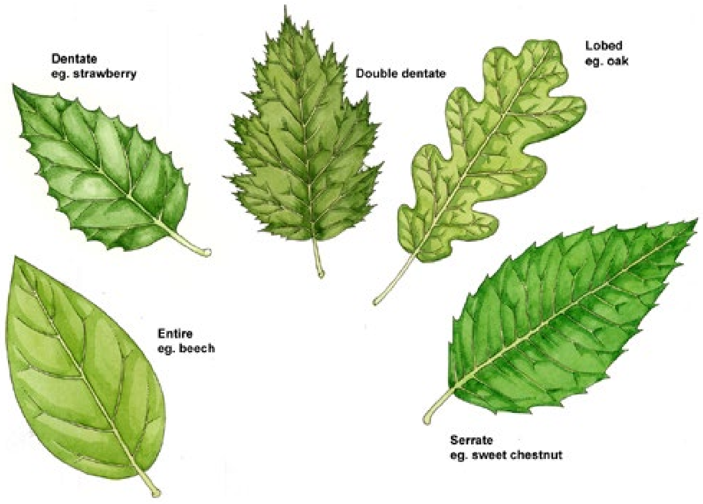


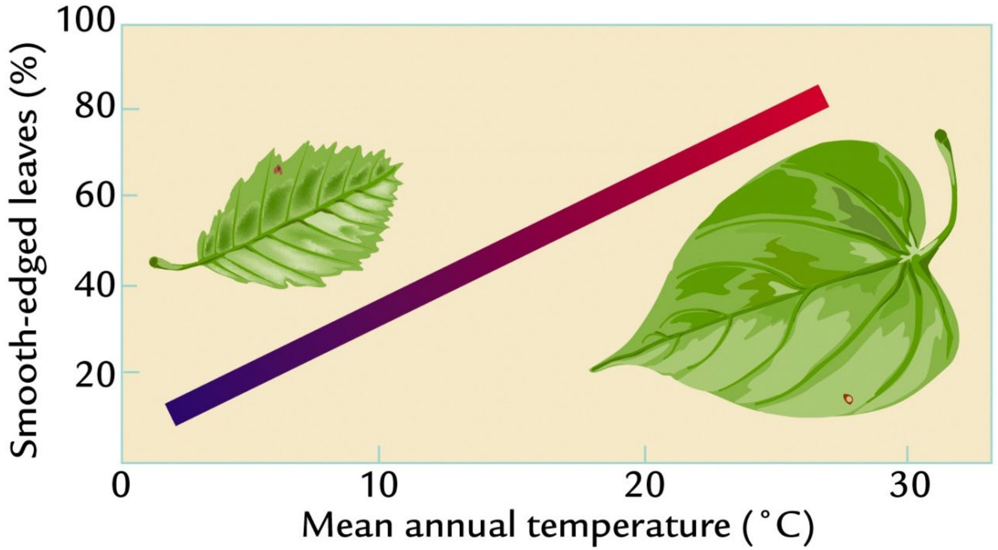
CLIFF DWELLING OF MESA VERDE



Mesa Verde National Park is a protected area of the United States and a UNESCO World Heritage Site. It is located in Colorado, in Montezuma County. It has an area of 211 km^2 and includes an area where there are the remains of numerous settlements built by the Pueblos. These are villages built inside recesses in the rock, called cliff-dwellings (dwellings under the cliff). The best known and largest of these settlements is the one called "Cliff Palace".

MORPHOLOGICAL ANALYSIS OF FOSSIL LEAVES MARGIN

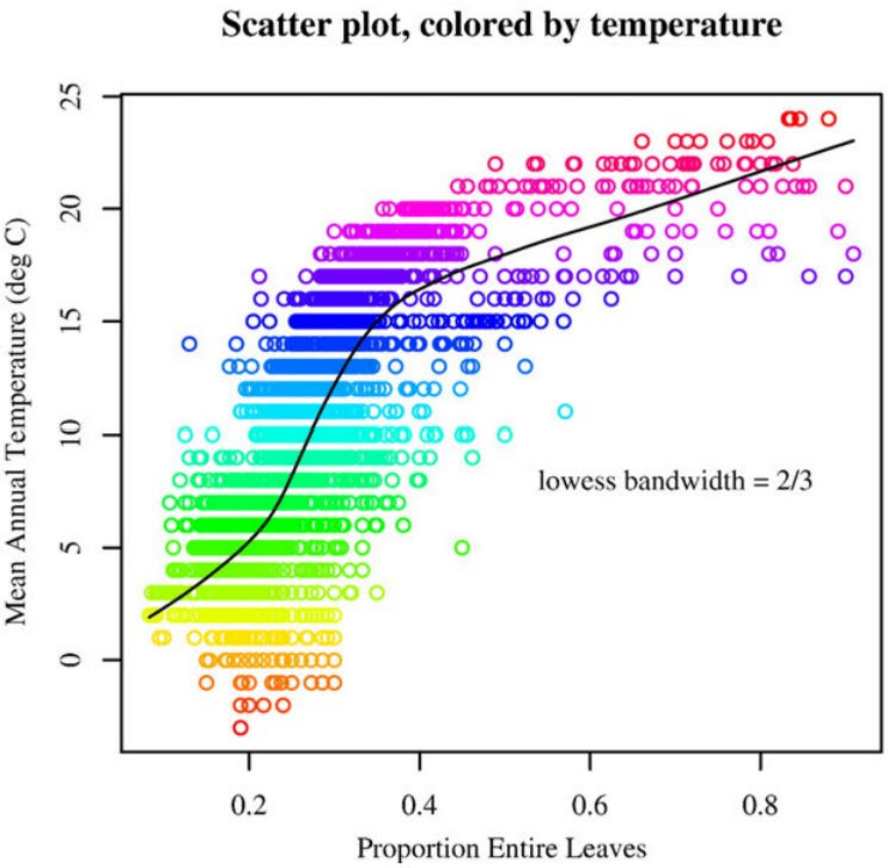


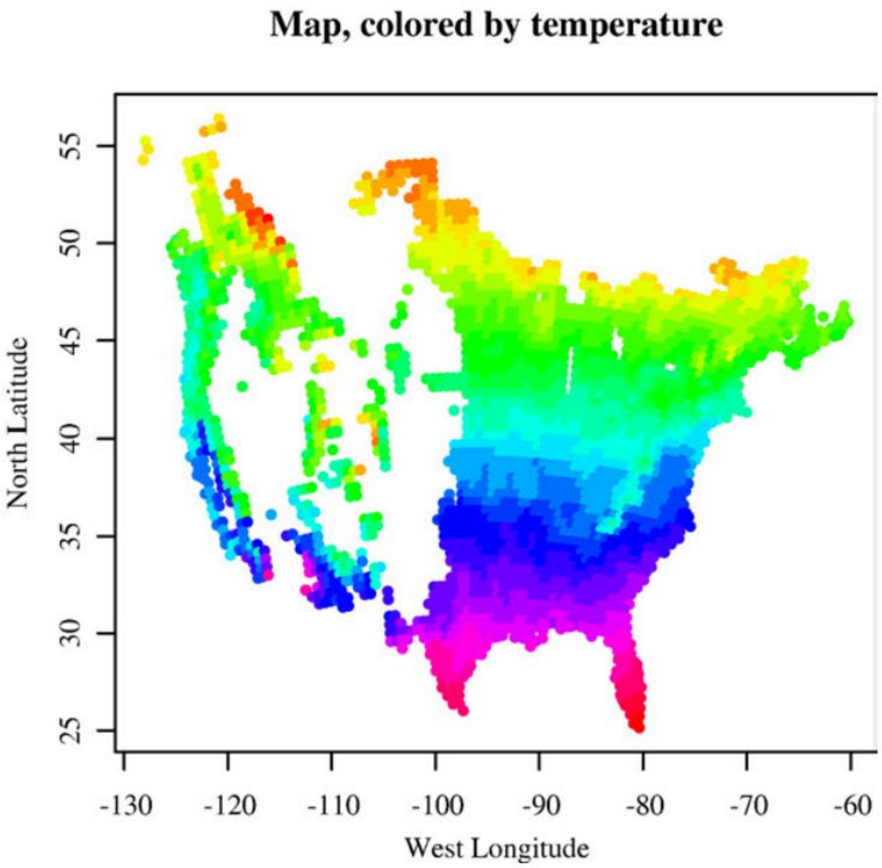


Empirical data show a strong correlation between <u>leaf margin type</u> and <u>average annual temperature</u>:

- In warm climates, smooth-edged leaves (entire-margined, e.g., laurel) are common.
- In cold climates, jagged or serrated leaves (e.g., oak) prevail.

MORPHOLOGICAL ANALYSIS OF FOSSIL LEAVES MARGIN


Scatter plot, colored by temperature


Map, colored by temperature

Adams et al., 2008 Global and Planetary Change

OTHER "CLIMATIC" FOSSILS

On the left is a *Champsosaurus*, a relative of modern crocodiles, found in Cretaceous rock on Axel Heiberg Island (70°N) in the Arctic (CA). This aligns with isotopic data suggesting that 80–90 million years ago, Arctic temperatures averaged above 14°C.

Below (left and center) *Arctica islandica* (Stirone Park, Parma, Italy), a classic "boreal guest" (cold) in the Mediterranean during the Pleistocene; below (right) a mammoth extinct, elephant-like mammals (cold-Pleistocene).

BOREAL (COLD) AND TROPICAL (WARM) GUESTS

Fluctuations between cold and warm periods caused shifts in the distribution of temperature-sensitive marine and terrestrial species, as they migrated with the advancing and retreating glaciers.

Simplified present distribution of fossil mollusks found in the Pleistocene deposits of the Mediterranean Sea.

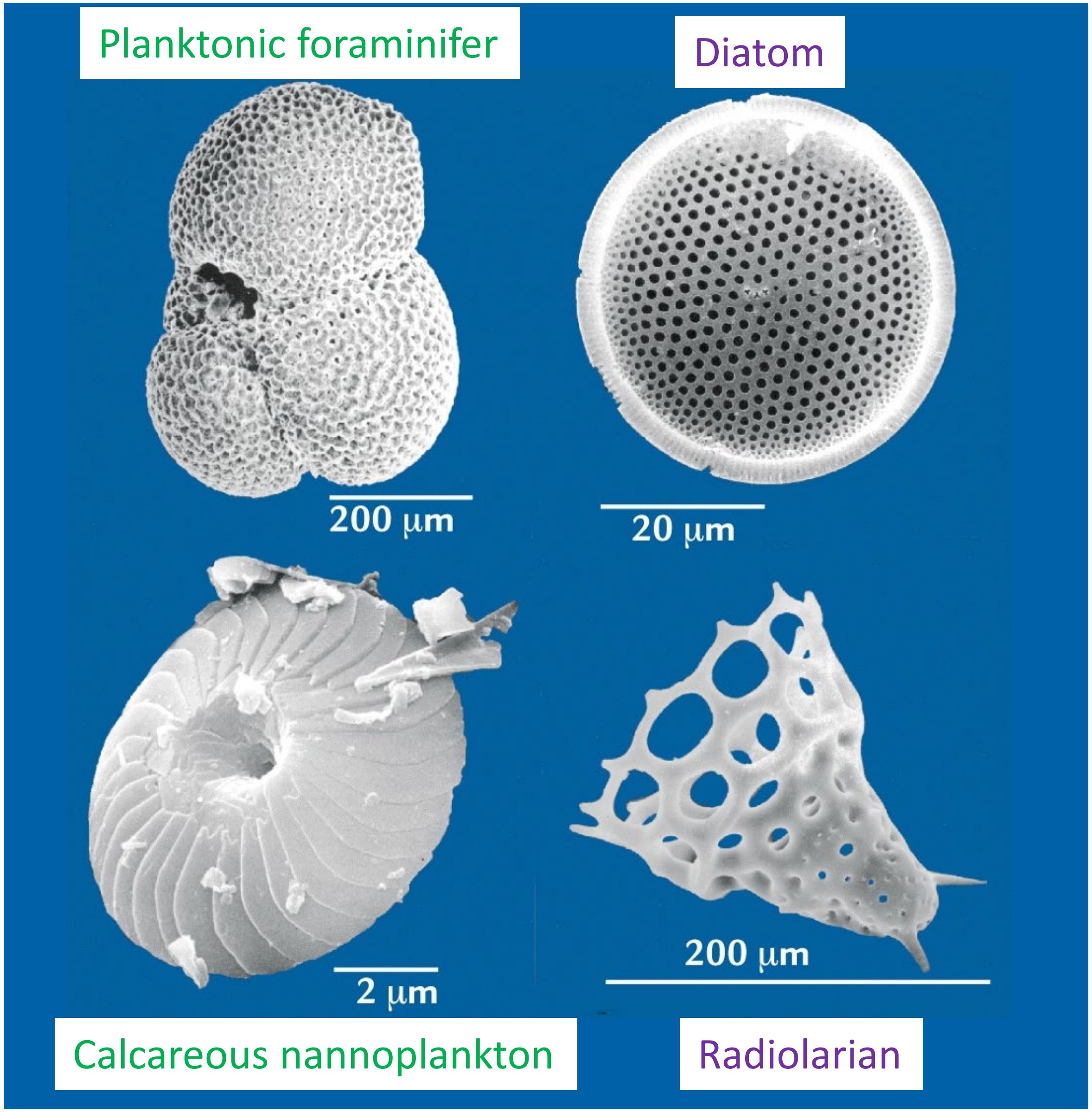
LIGHT BLUE = *Arctica islandica* , *Panopea norvegica*, *Mya truncata* e *Neptunea contraria* (Mediterranean «boreal guest")

ORANGE = *Strombus bubonius* , *Conus testudinarius* , *Brachidontes senegalensis* (Mediterranean «tropical guest").

Mya truncata

Strombus bubonius

MARINE PLANKTON



Why the fossil remains of marine (calcareous and siliceous) plankton (phyto and zoo) - microfossils - are exceptional paleoenvironmental proxies?

- They are abundant

- They have different ecological-environmental affinities at a specific level

- They retain significant information about the chemical and physical conditions of their growth environment within their shell's chemistry.

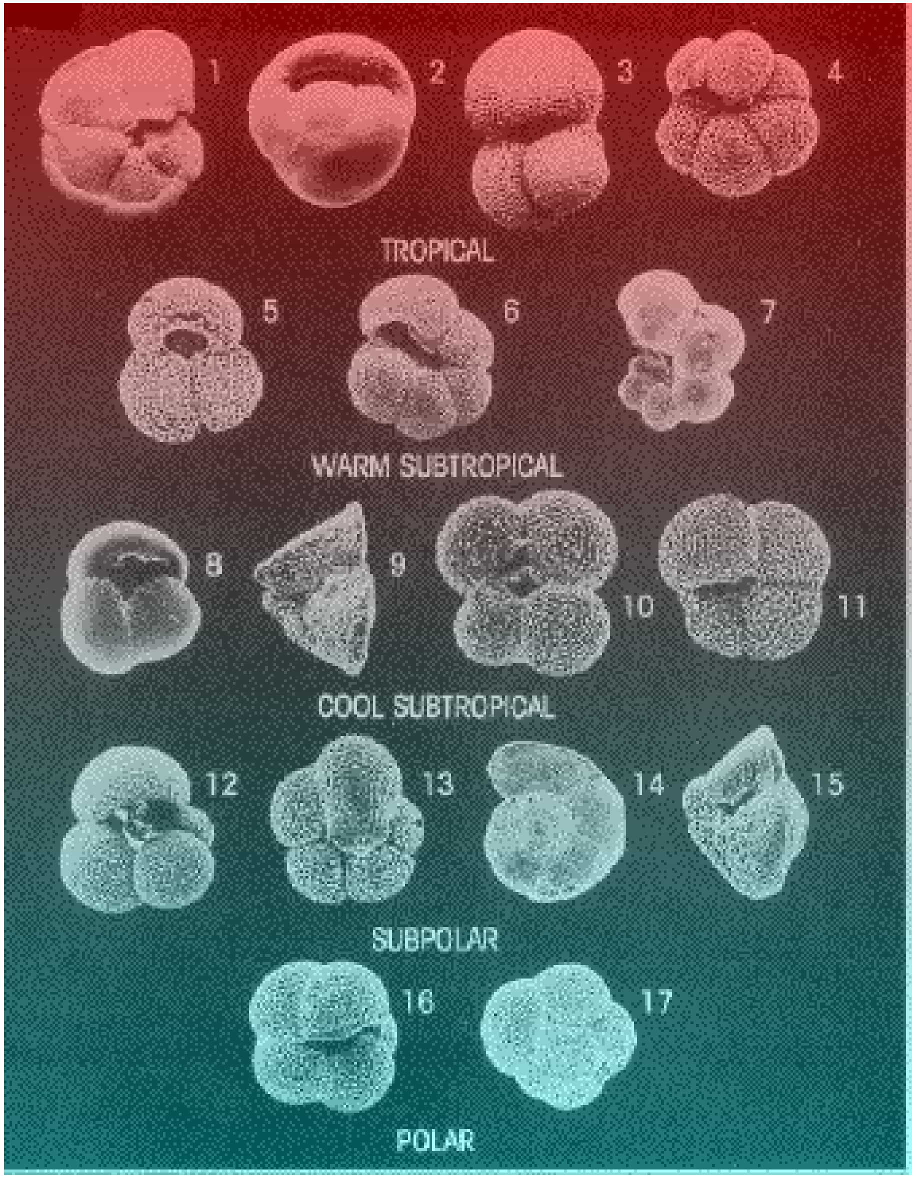
PLANKTONIC FORAMINIFERA

One of the most classically used proxies for T (° C) is **THE RELATIVE ABUNDANCE OF DIFFERENT TAXA WITHIN MICROFOSSIL ASSOCIATIONS.**

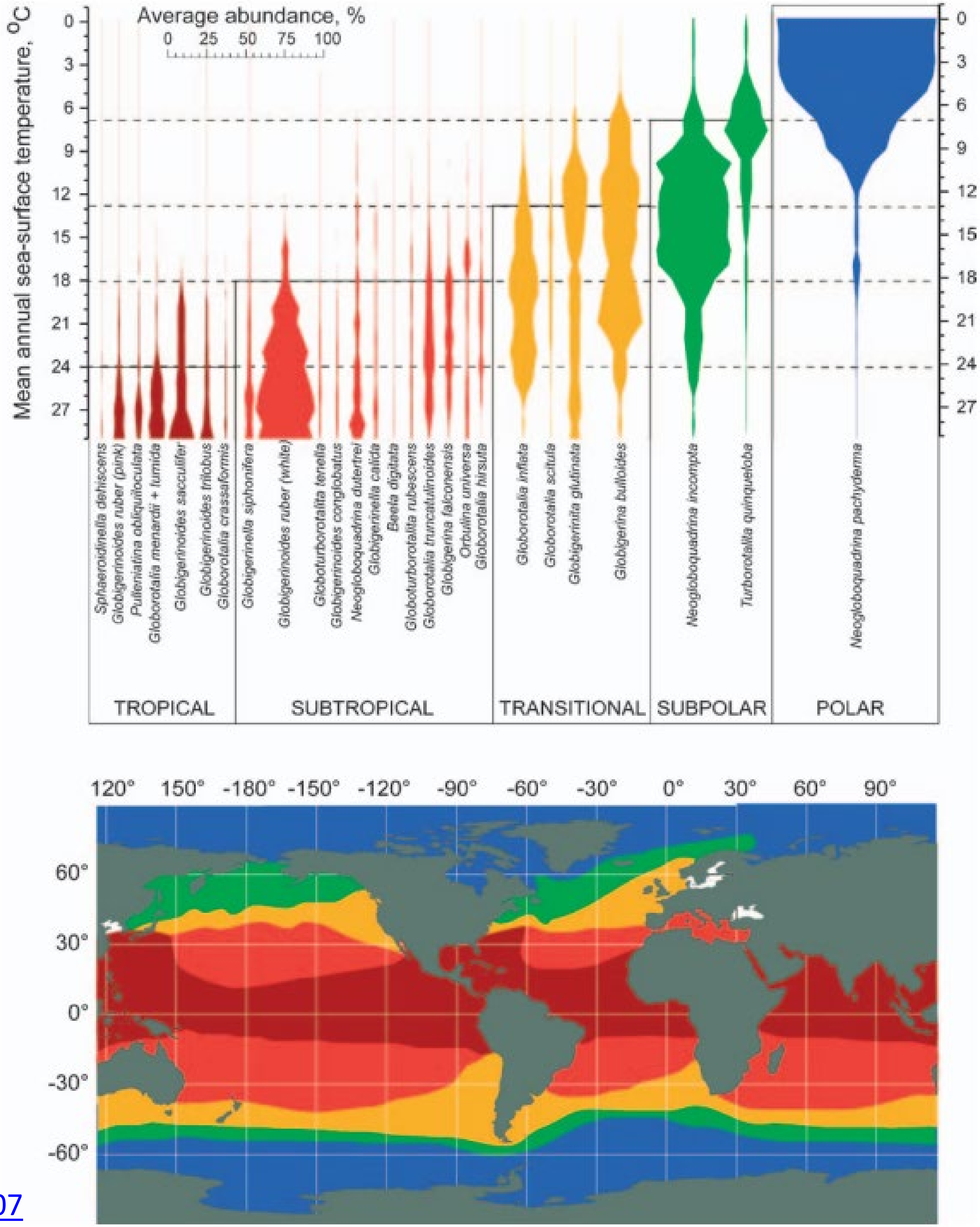
This method has been foundational in paleoceanography since John Murray of the Challenger Expedition (1872-1875) discovered that planktonic foraminifers:

- **form a significant part of seafloor sediments;**
- **different taxa indicate varying temperatures.**

The next advancement is the use of transfer functions.



Planktonic foraminiferal provinces in the modern ocean



Kucera, 2007

TRANSFER FUNCTION (calibration function)

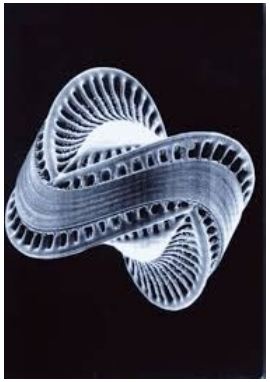
Transfer functions refer to a set of statistical methods used in paleoceanography and in palaeoclimatology in general to express microfossil assemblages in terms of climatic or oceanographic parameters.

Fossil data (e.g. diatoms) 'Proxy data' **Environmental** variable (e.g. pH)

1, ----------------- , *m* taxa

Y_f

t
samples



1 variable

X_f

Unknown

To be estimated or reconstructed

t
samples

To solve for $\mathbf{X}_f$, need modern data about species and pH from *n* samples

modified after Birks

Modern biology (e.g. diatoms)

Modern environment (e.g. pH)

1, ……, *m* taxa

n samples

$\mathbf{Y}_m$

1 variable

n samples

$\mathbf{X}_m$

Model $\mathbf{Y}_m$ in relation to $\mathbf{X}_m$ to derive modern calibration function $\hat{\mathbf{U}}_m$

Apply $\hat{\mathbf{U}}_m$ to $\mathbf{Y}_f$ to estimate past environment $\mathbf{X}_f$

Imbrie & Kipp provided the basic theory and assumptions, a robust method, and modern and fossil data.

Quantitative Transfer Function Approaches in Palaeoclimatic Reconstruction Using Quaternary Ostracods

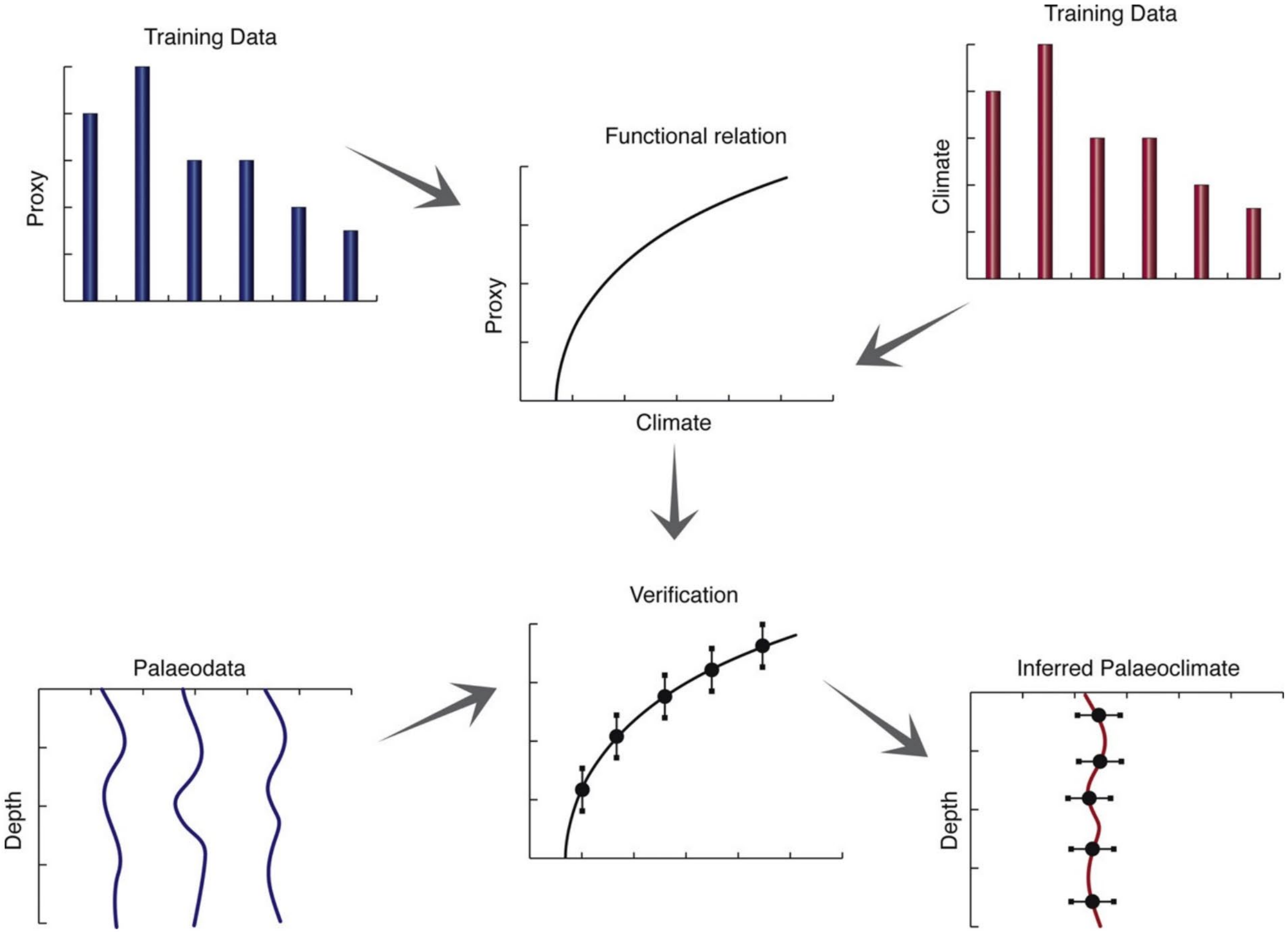


FIGURE 4.1 Illustration of the transfer function approach. Modern faunistic data and physico-chemical parameters of the environment are used for calibration. Regression methods are validated and applied to fossil assemblages to infer indicative parameters quantitatively with error estimations.

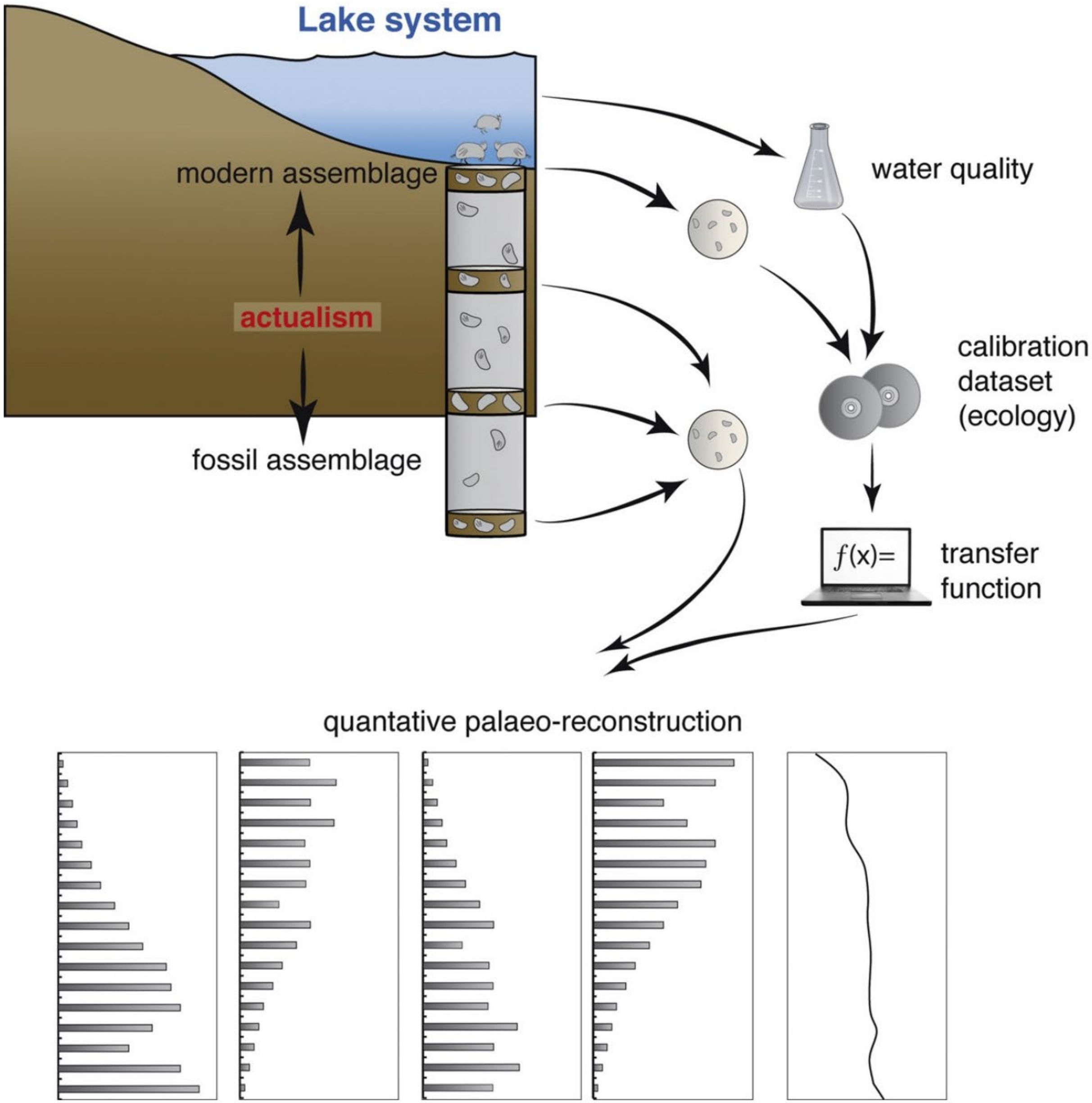
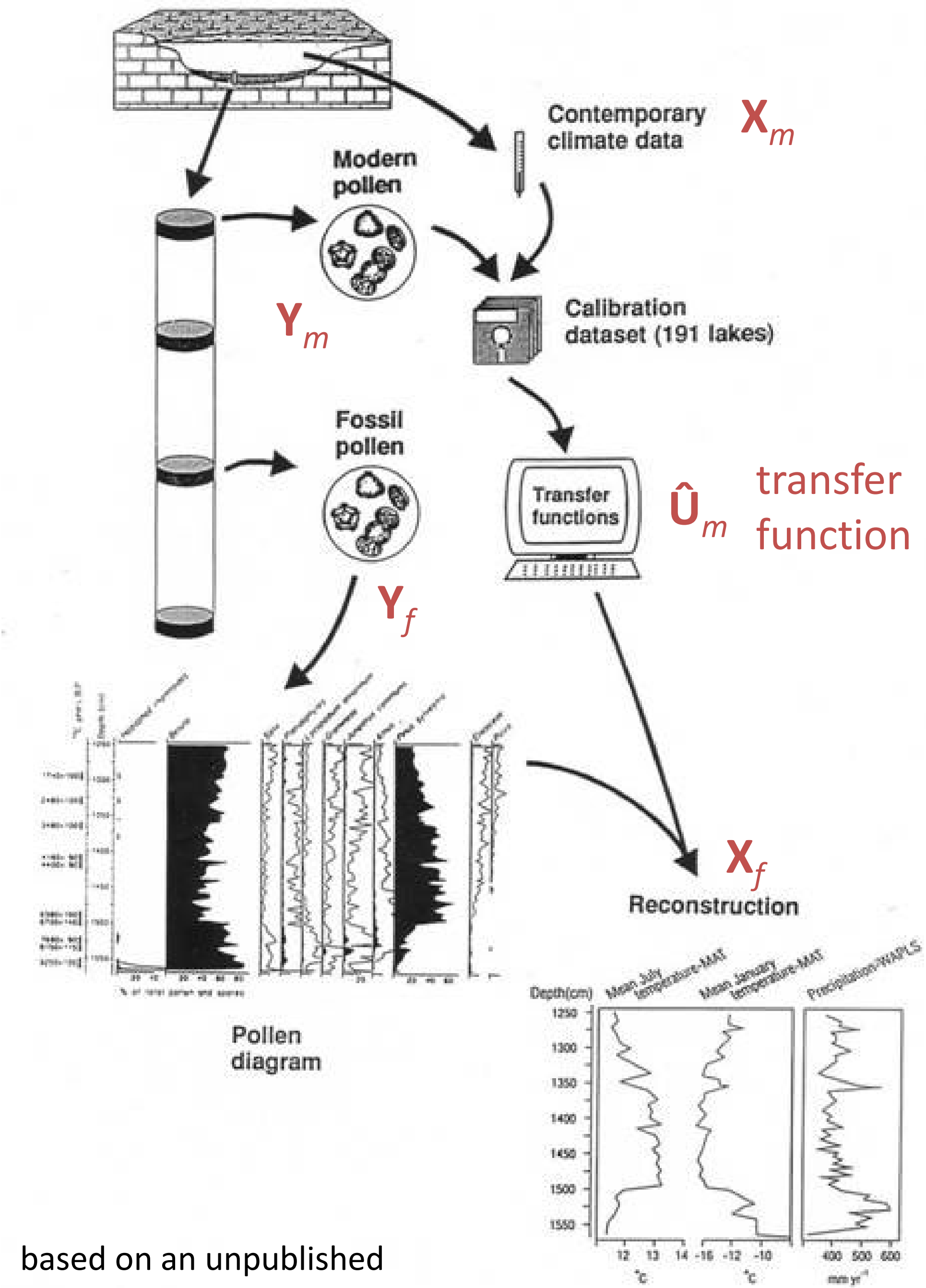


FIGURE 4.2 Schematic workflow to set up a transfer function. Surface samples are analysed from multiple locations. Ecological and faunistic data make a matrix in the calibration dataset. Samples of fossil ostracod assemblages are processed by the transfer function to quantify past environmental changes (redrawn from Juggins and Birks, 2012).

Viehberg, F. A., & Mesquita-Joanes, F. (2012). Quantitative Transfer Function Approaches in Palaeoclimatic Reconstruction Using Quaternary Ostracods. Developments in Quaternary Sciences, 47–64. doi:10.1016/b978-0-444-53636-5.00004-4



$\mathbf{X}_m$

$\mathbf{Y}_m$

$\hat{\mathbf{U}}_m$ transfer function

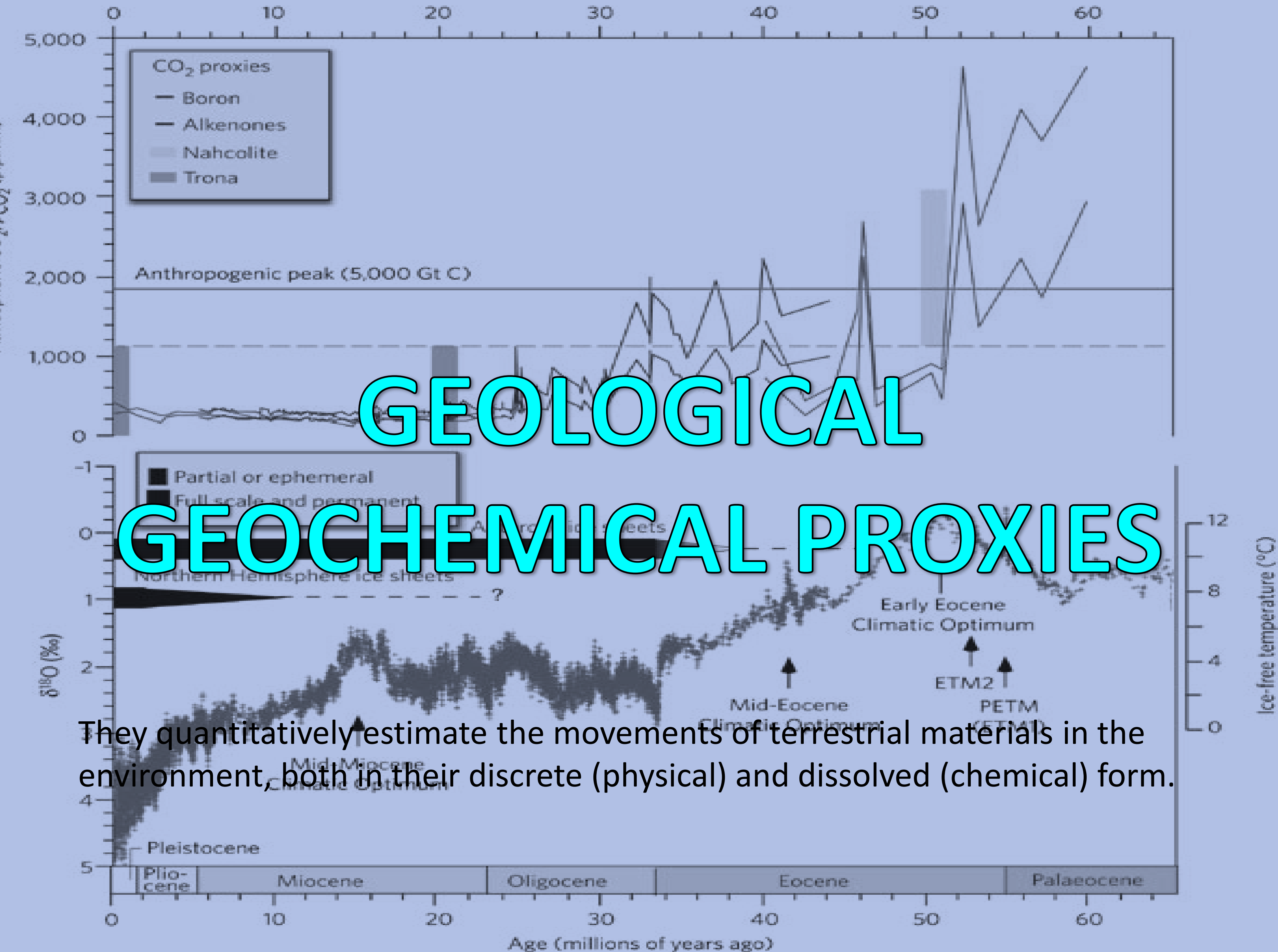
$\mathbf{Y}_f$

$\mathbf{X}_f$

based on an unpublished diagram by Steve Juggins

GEOLOGICAL GEOCHEMICAL PROXIES

They quantitatively estimate the movements of terrestrial materials in the environment, both in their discrete (physical) and dissolved (chemical) form.



THE SEDIMENTARY CYCLE

Sediments are eroded and deposited on continents through:

Physical weathering

Sediments are broken into smaller particles by water, wind, and ice. Examples include:

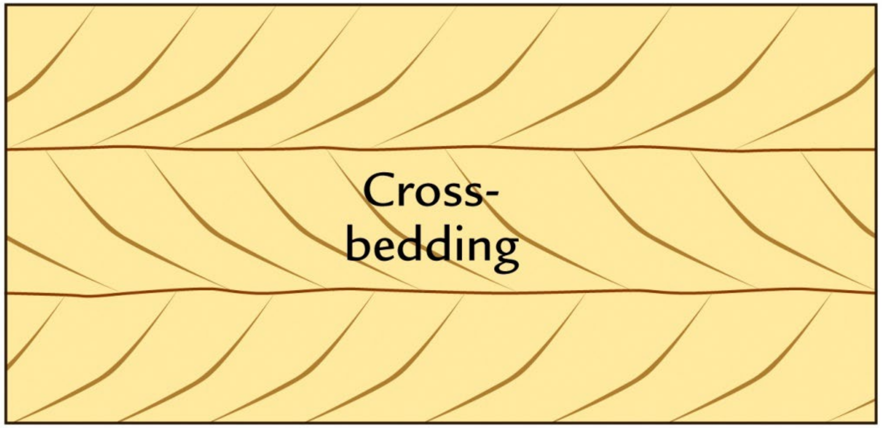
- Ice-Rafted Detritus (IRD)
- Wind-blown sediments (loess)
- River sediments

Chemical weathering

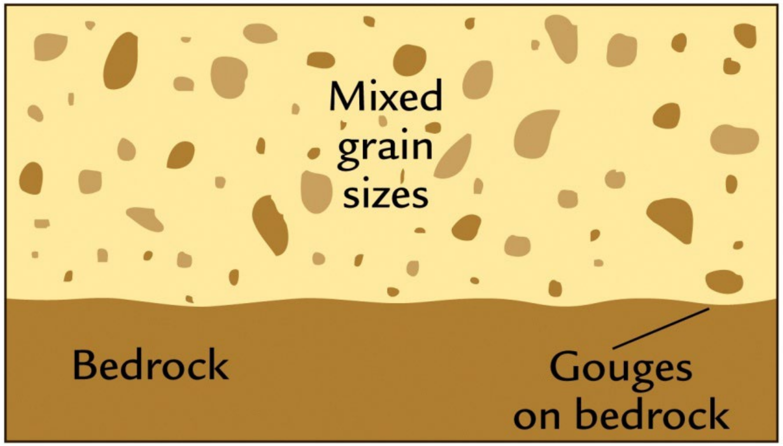
Sediments are dissolved in water as ions and transported to the sea. This occurs through:

- Dissolution of carbonate and evaporite rocks (e.g., $CaCO_3$, $NaCl$)
- Hydrolysis of silicate rocks (e.g., basalts, granites)

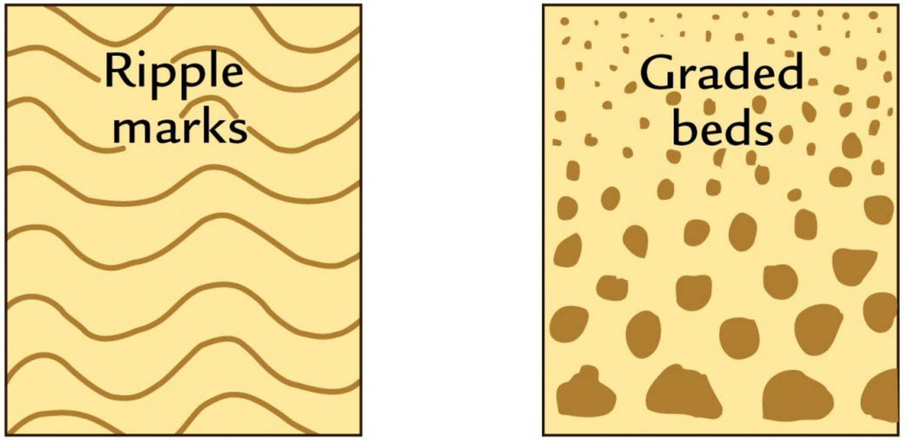
TRASPORT AGENTS☞ TYPE OF SEDIMENTS



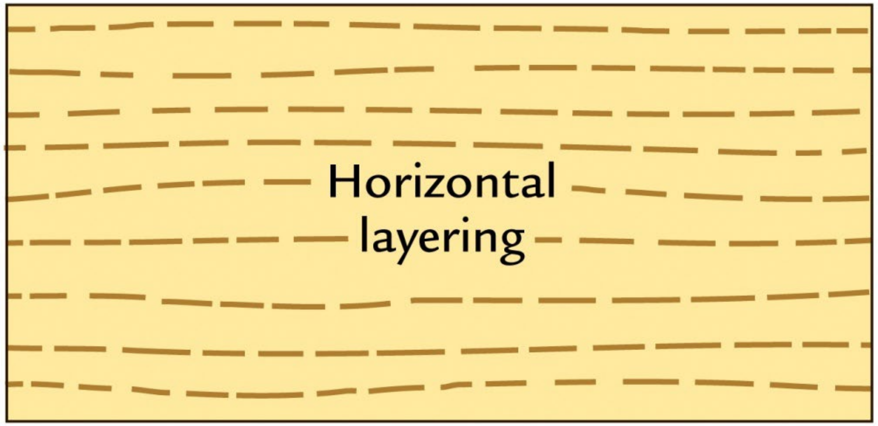
B Deposition by wind



A Deposition by ice



D Deposition by water (poor archive)



C Deposition by water (good archive)

PALEOENVIRONMENTAL INDICATOR

CONTINUOS SIGNAL

ROCKS/SEDIMENTS AS PROXIES

Some rocks, simply by their presence, serve as indicators of the environment and climate conditions in which they were deposited.

EXAMPLES are glacial deposits (moraines, etc.) and periglacial deposits, evaporites in the marine environment (arid climate) and / or coals.

“CLIMATE/ENVIRONMENTAL” SEDIMENTS FROM PHYSICAL WEATHERING

(1) Ice-Rafted Detritus (IRD)
(2) Wind derived sediments
(3) Fluvial derived sediments

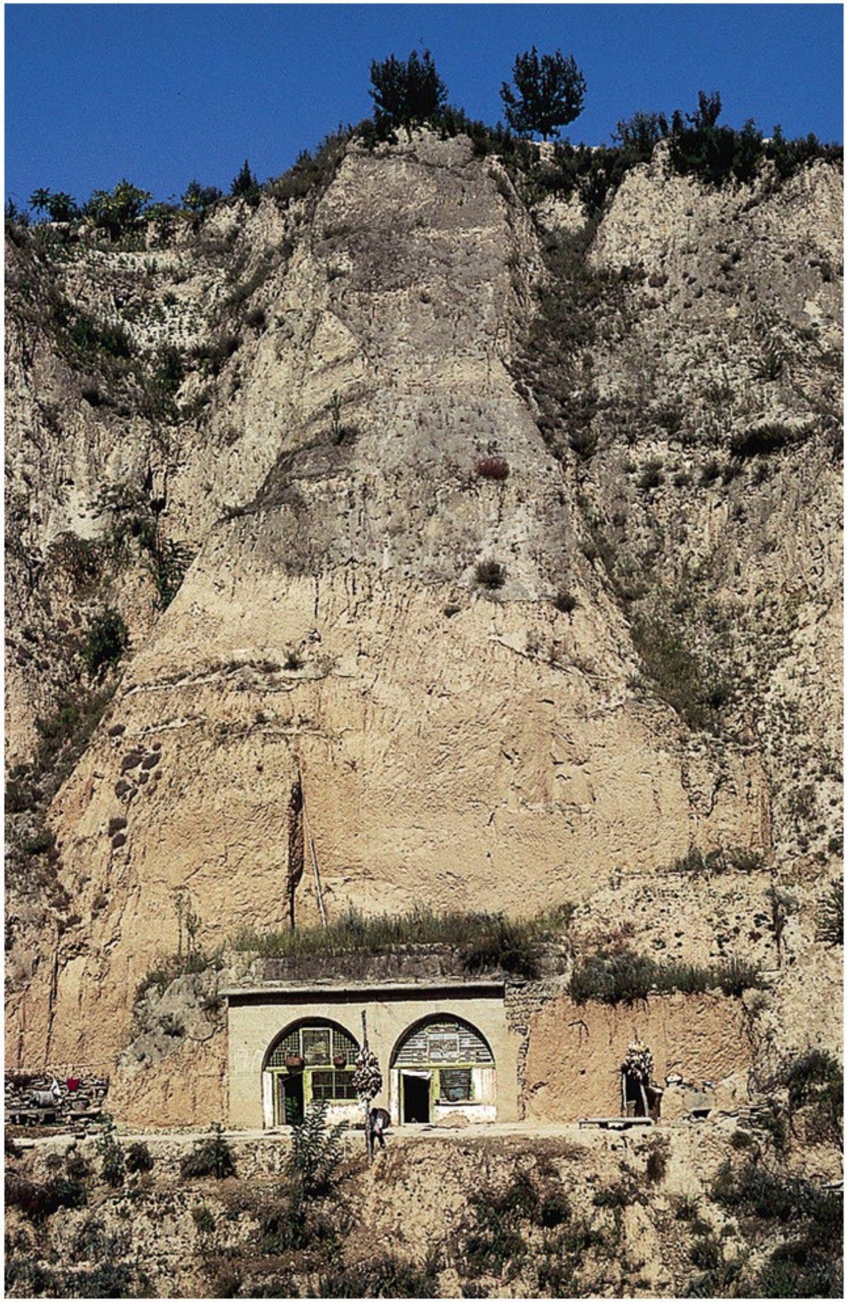
GLACIAL DEPOSITS

Among glacial deposits, the glaciomarine deposits in the oceans are those that derive from the melting of icebergs (i.e., Ice-Rafted Detritus (IRD) or ice rafted deposits).

Alaska's Sheridan Glacier

Ice-Rafted Detritus (IRD)

EOLIAN DEPOSITS - LOESS



DEFINITION
Loess is a wind-blown, silt-sized sediment deposited on Earth's surface, capturing major climate shifts and landscape-forming processes.

These deposits provide insights into the history of wind and surface changes over time.

EOLIAN DEPOSITS - LOESS

Qu et al. 2022

The Loess Plateau in north-central China is one of the largest and most studied loess deposits. Over the last million years, sediments have accumulated in layers up to several hundred meters thick, alternating between loess, formed during dry, glacial periods, and soils developed in warm, humid interglacial periods.

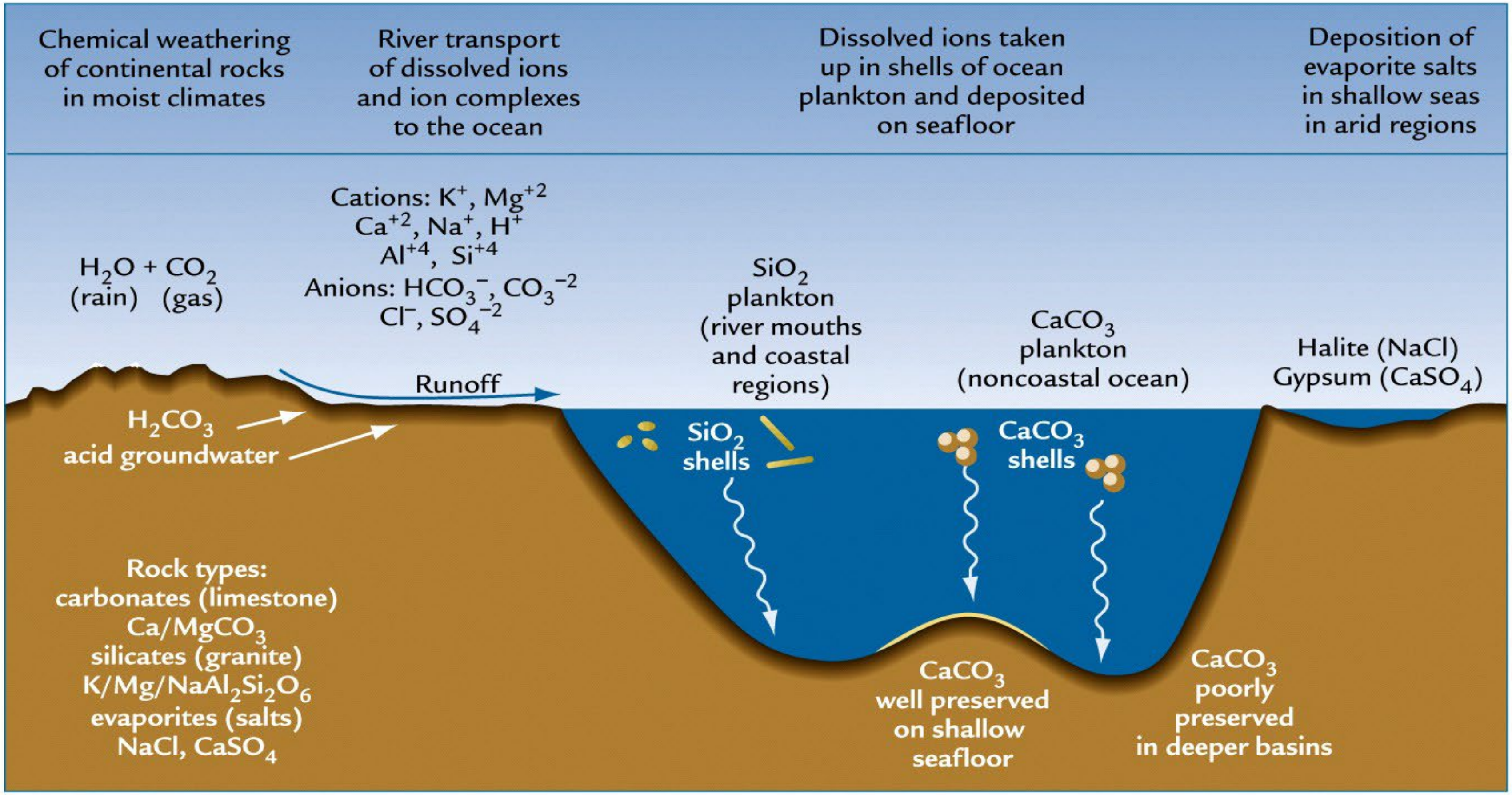
FLUVIAL DEPOSITS

They are significant for sedimentological and basin analysis but less crucial for paleoclimatic reconstructions.

“CLIMATE/ENVIRONMENTAL” SEDIMENTS FROM CHEMICAL WEATHERING

(1) Dissolution of carbonates and evaporites
(2) Hydrolysis of silicate rocks

CHEMICAL WEATHERING



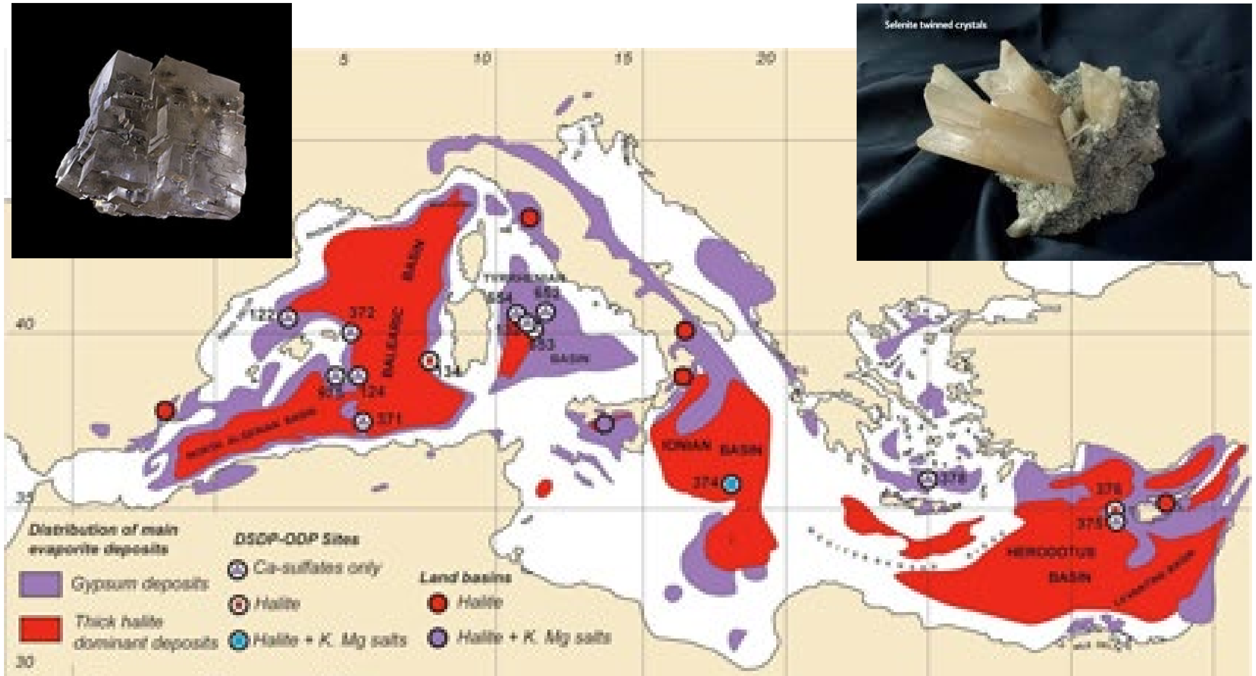
Chemical weathering slowly attacks rocks on land, producing ions that dissolved in river waters and will be carried into the oceans. Many organisms, and plankton in particular, incorporate these dissolved ions into their shells. When they die, they fall to the sea bottom and enter the geological record. Part of these dissolved ions may also chemically precipitate in the continental margins with an arid climate.

Rocks formed by the **weathering** of silicate rocks

- **Laterite**: Produced by intense chemical weathering of silicate rocks in tropical climates, rich in iron and aluminum oxides.

- **Argillite**: Formed by the chemical alteration of silicates, like granites and basalts, which produce clay minerals. **Kaolinite**: A clay mineral primarily formed from the weathering of feldspars in rocks like granite.

EVAPORITES: THE MEDITERRANEAN MESSINIAN CRISIS

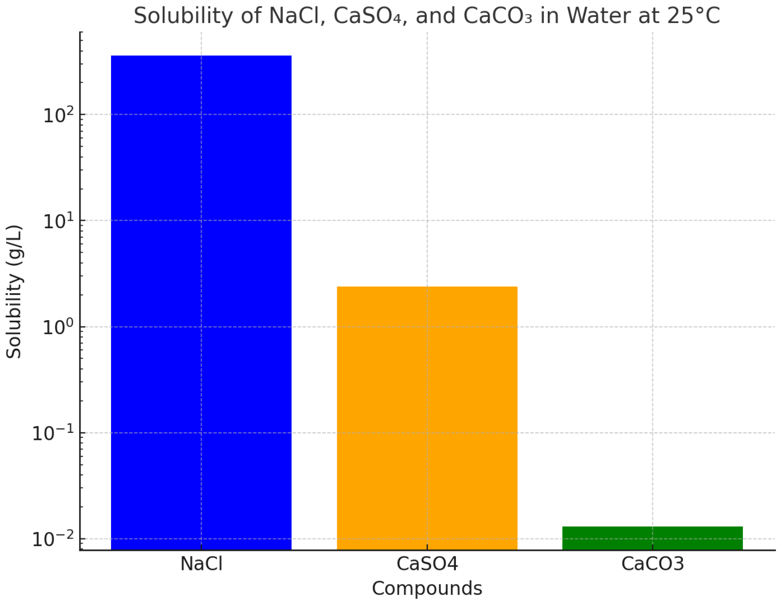


About 6 Ma ago (Late Miocene), the Strait of Gibraltar closed and the Mediterranean evaporated and turned into a predominantly dry depression.

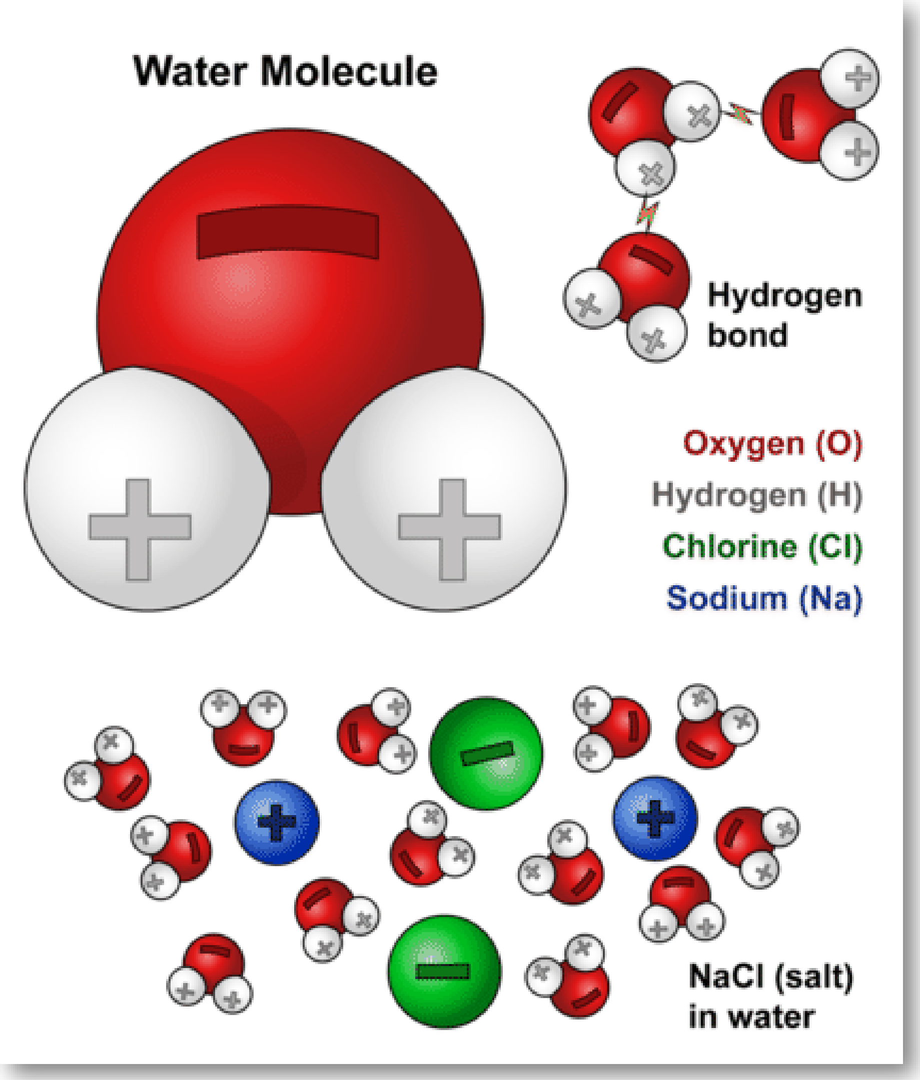
https://www.youtube.com/watch?v=B5uW7Qg6rXM

Salt /Water Solution

A salt solution is a type of solution in which **a salt (the solute) is dissolved in a solvent, typically water**.



NaCl (Sodium chloride):Highly soluble in water. Solubility: ~360 g/L at 25°C.
$CaSO_4$ (Calcium sulfate):Moderately soluble in water. Solubility: ~2.4 g/L at 25°C.
$CaCO_3$ (Calcium carbonate):Poorly soluble in water. Solubility: ~0.013 g/L at 25°C.
Solubility ranking (from highest to lowest):NaCl > $CaSO_4$ > $CaCO_3$.



OTHER SEDIMENTS

(1) Hard coals

HARD COALS


PEAT


LIGNITE
$C>70\%$


LITANTHRACE
$75\%< C< 90\%$


ANTHRACITE
$C>90\%$

The process of hard coal formation is known as *carbogenesis* or ***CARBONIZATION***.

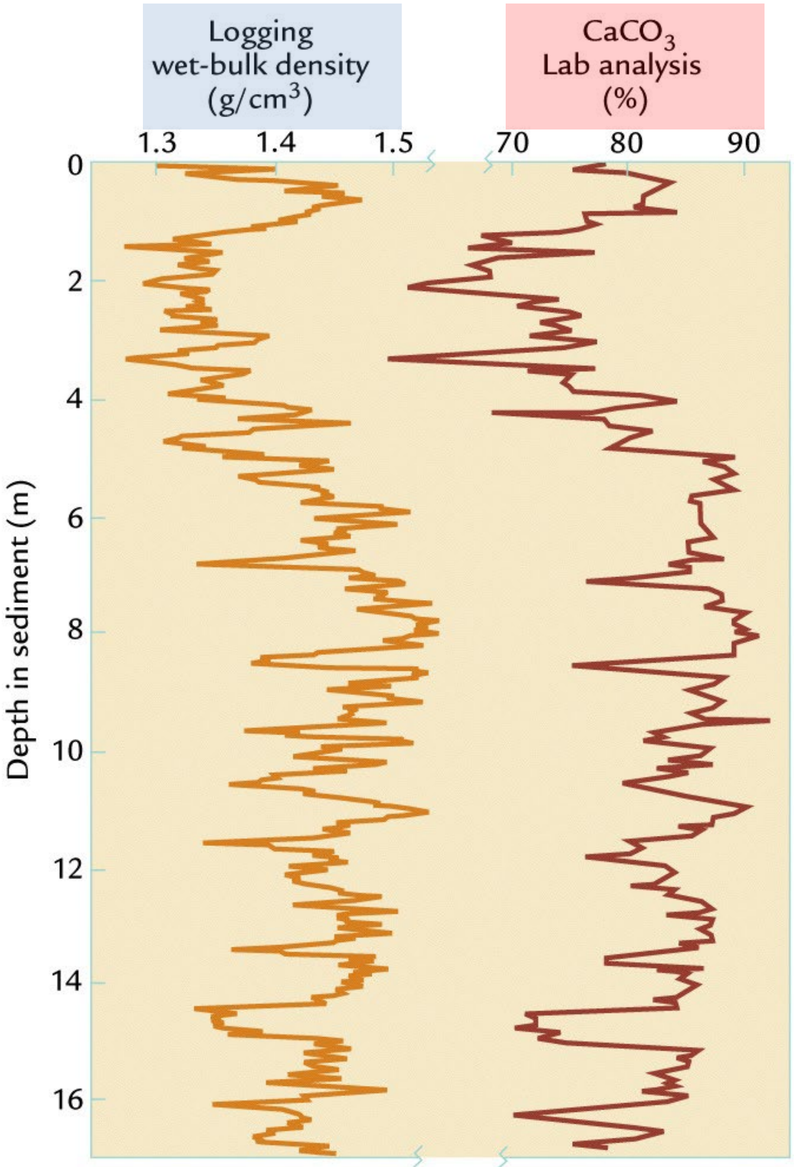
The composition and characteristics of coal differ greatly from reservoir to reservoir. This difference is attributable
to the different types of plants from which coal originates;
the depth of their burial (T and P);
the length of the period of formation and
the composition of the water and rocks.

A Prolonged carbogenesis leads to a decrease in H, O and N, with a consequent increase in the carbon content.

Having made these qualitative premises, hard coal is classified, in ascending degree of alteration, as follows: PEAT, LIGNITE, LITANTHRACE, ANTHRACITE.

GEOLOGICAL-GEOCHEMICAL PROXIES

PHYSICAL AND CHEMICAL PROPERTIES - 1



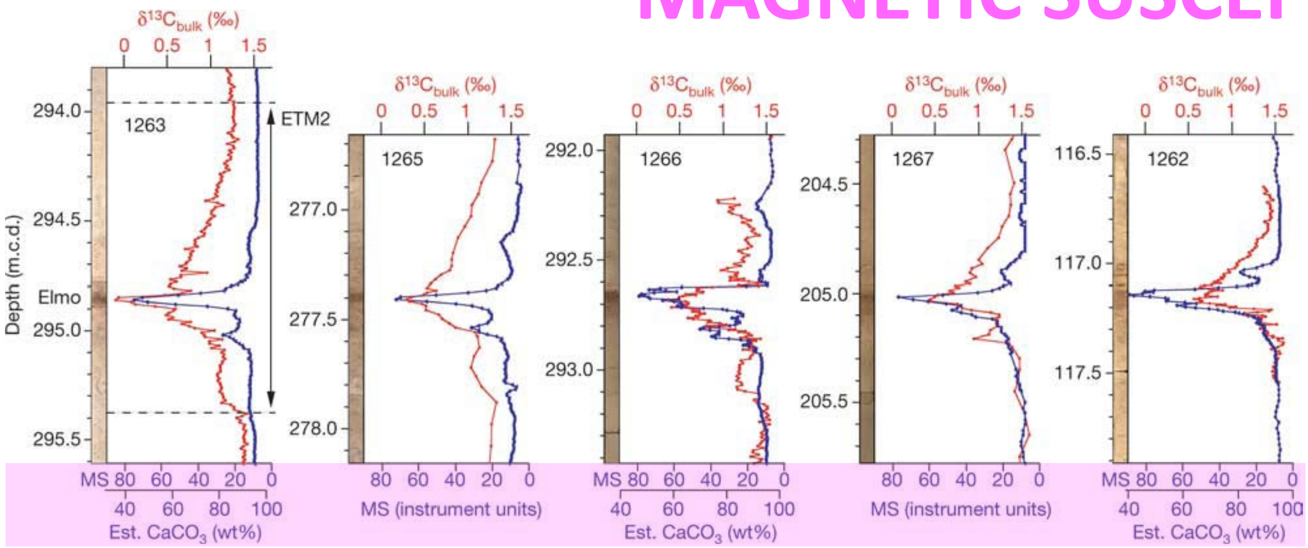
PROXIES IN THE SEDIMENTS

THE CONTENT IN $CaCO_3$ and other components (SiO_2, trace elements such as Ba, P, Fe, Cr, etc.) and the DENSITY provide important information. These data are collected routinely.

Information is also provided by properties SUCH AS MAGNETIC SUSCEPTIVITY, COLOR OF SEDIMENTS, ect ...

PHYSICAL AND CHEMICAL PROPERTIES -2

MAGNETIC SUSCEPTIVITY



COLOR OF SEDIMENTS

35m

45m

70ka

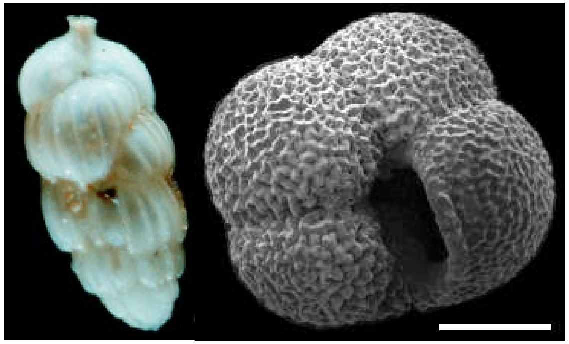
140ka

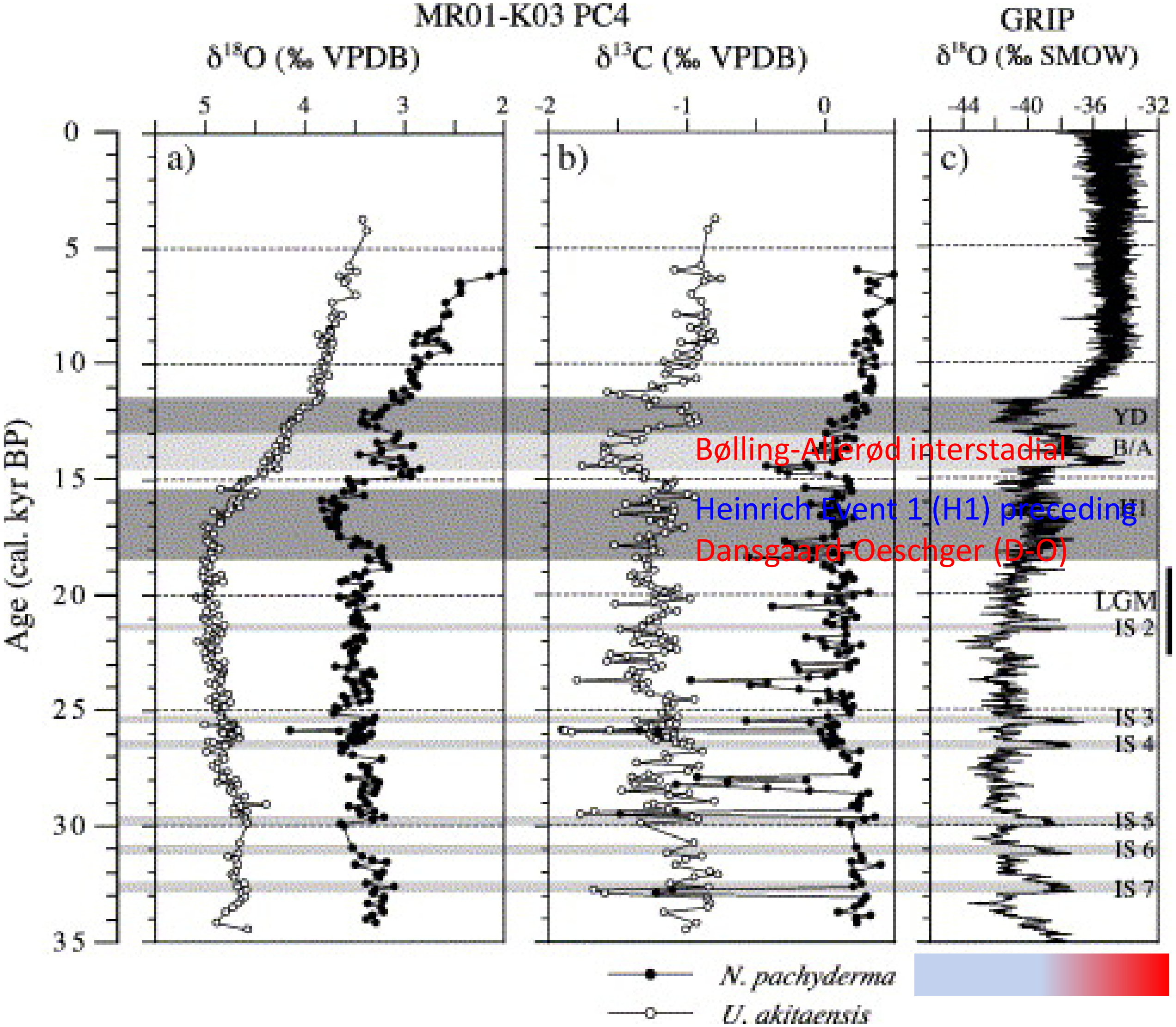
Color variations in the MD95-2036 core from 35 to 45m. Recorded period 70-40 Ka. The color changes represent changes in $CaCO_3$ (light-dark) and hematite (red). These are climate-controlled changes and indicate extreme variability in climate at the scale of hundreds of years.

PHYSICAL AND CHEMICAL PROPERTIES -3

Within the category of geological-geochemical proxies, we encounter the light stable isotopes.

We will delve into the analysis of oxygen and carbon isotopes extensively.





Bølling-Allerød interstadial

Heinrich Event 1 (H1) preceding

Dansgaard-Oeschger (D-O)

PALEOENVIRONMENTAL PROXIES AND PARAMETERS

To reconstruct ancient environments, it's crucial to know numerous environmental factors (along with their corresponding proxies). Some of the most vital ones include:

- **TEMPERATURE (CONTINENTS AND OCEANS)**
- **O_2 CONCENTRATION (ATMOSPHERE AND OCEAN)**
- **CO_2 CONCENTRATION (ATMOSPHERE AND OCEAN)**
- **CHEMICAL STATE OF THE OCEAN (pH, saturation, alkalinity, ..)**
- **NUTRIENTS AVAIBILITY AND MARINE PRODUCTIVITY**
- **OCEAN CIRCULATION**
- **VOLUME OF THE CRYOSPHERE**
- **………..**

The cross-checking between proxies of the same parameter allows an evaluation of the quality of the various proxies

PALEOTEMPERATURE - 1

The estimate of the paleotemperature is a fundamental factor to reconstruct the climate of the past. A bit of history….

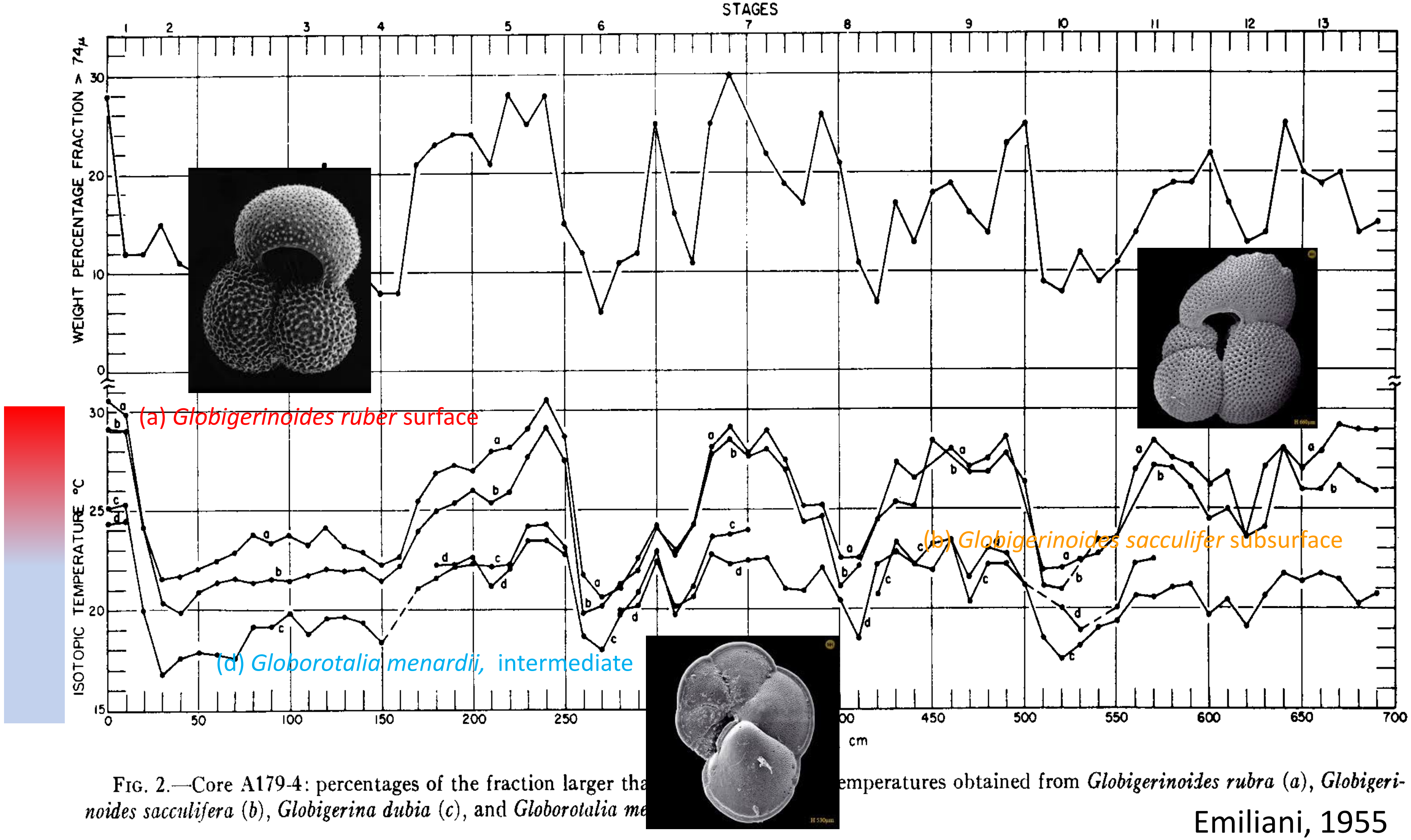


FIG. 2.—Core A179-4: percentages of the fraction larger tha emperatures obtained from *Globigerinoides rubra* (*a*), *Globigerinoides sacculifera* (*b*), *Globigerina dubia* (*c*), and *Globorotalia me*

Emiliani, 1955

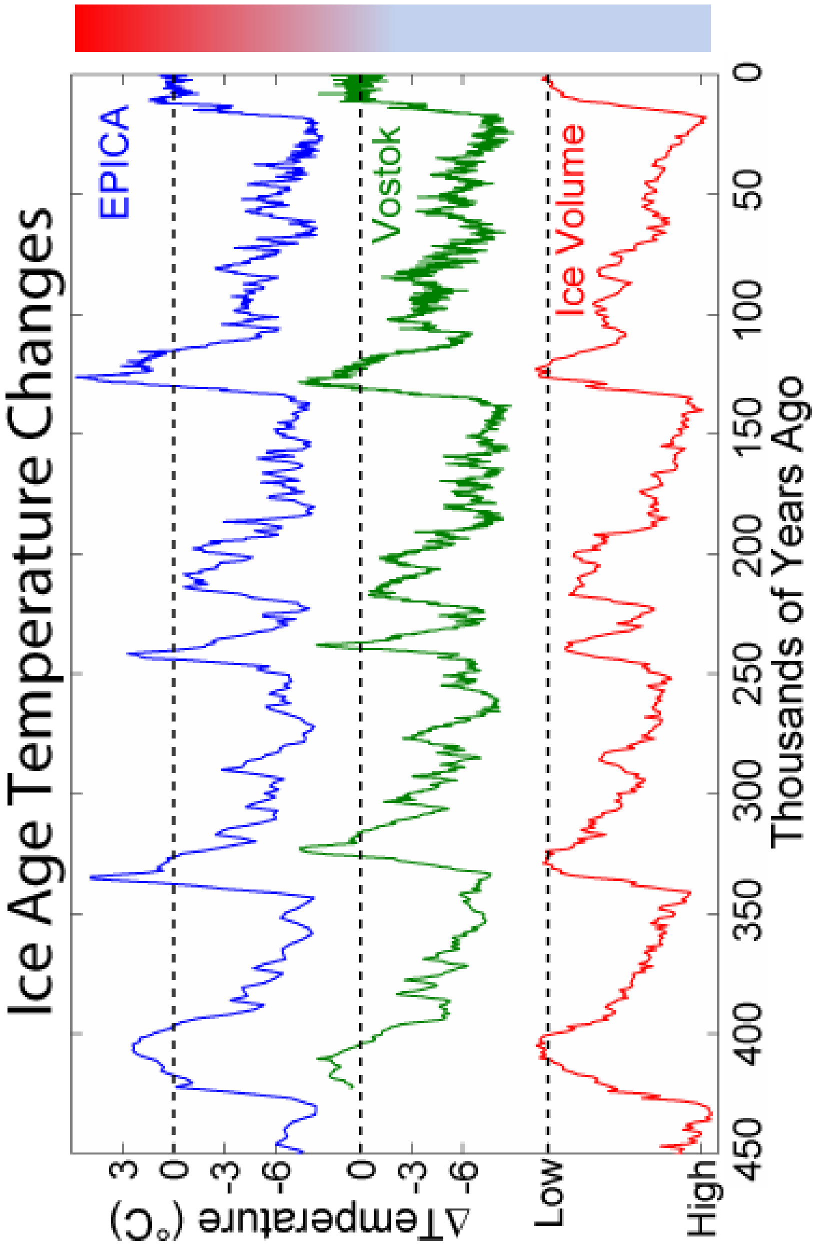
PALEOTEMPERATURE - 2

The results obtained are astonishing, encompassing both marine and terrestrial settings.

The most notable (quantitative) findings predominantly pertain to the more recent geological era, primarily the Cenozoic.

Specifically, temperature trends (and, consequently, climate) are well-documented in the Holocene and late Pleistocene, often with extensive geographical coverage.

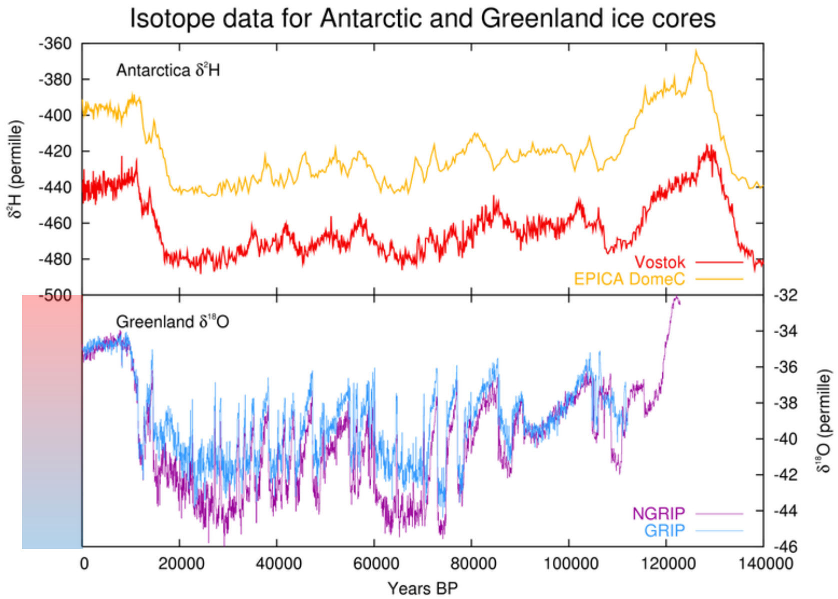
The methods utilized and the feasibility of determining paleotemperatures are contingent on the depositional environment and the specific time frame being studied

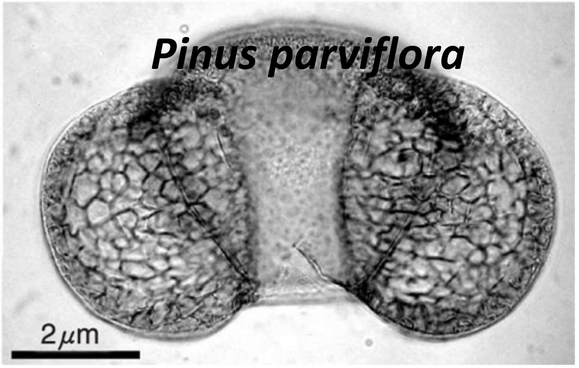


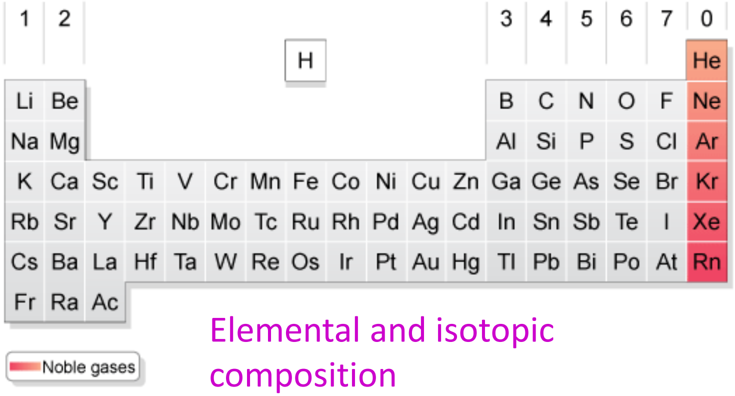
PALEOTEMPERATURE ON CONTINENTS

To reconstruct paleotemperature:

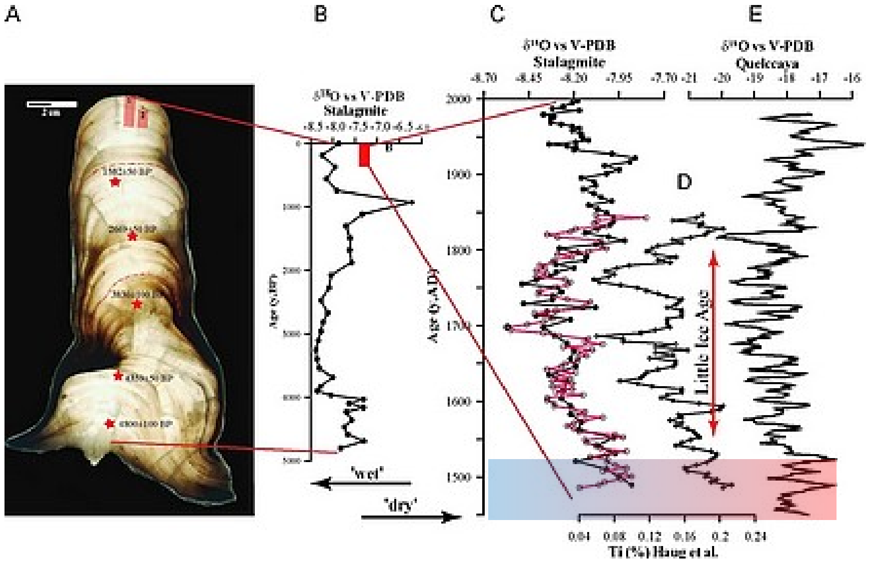
- stable isotopes in ice cores
- pollens in lake and marine sediments
- stable isotopes in speleothems
- noble gases in fossil waters







Elemental and isotopic composition

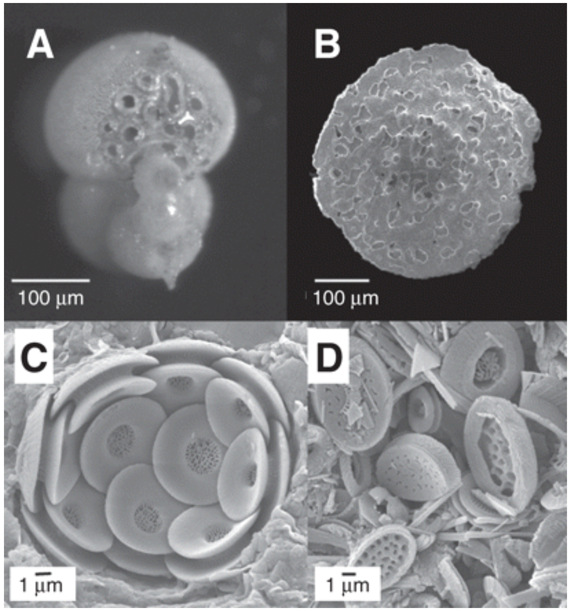


PALEOTEMPERATURE IN THE OCEAN - 1

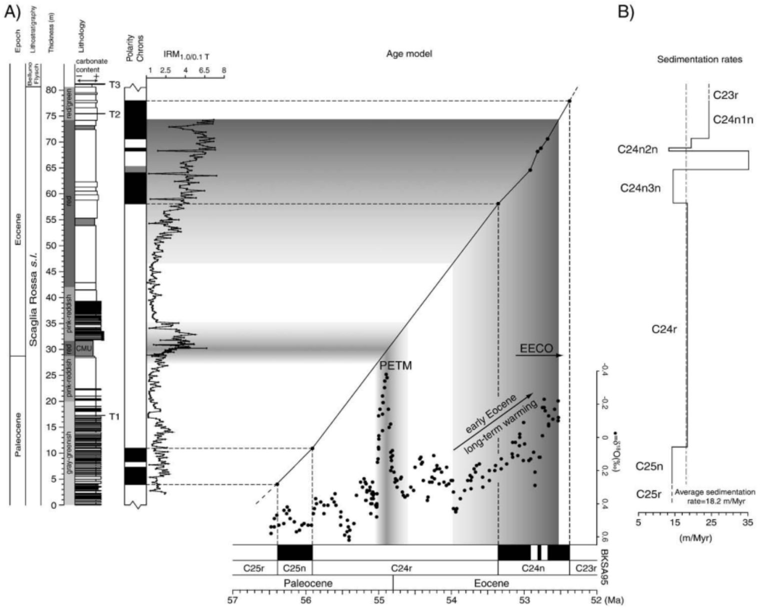
The most valuable records are located in ocean sediments for the following reasons:

- **MICROFOSSILS ARE IN EXCELLENT PRESERVATION CONDITION** (without diagenesis);
- There is **CONTINUOS SEDIMENTATION**, providing continuous documentation of the geological history;
- These sediments offer **HIGH TEMPORAL RESOLUTION**, although only in exceptional cases this is at the level of the years (bioturbation).

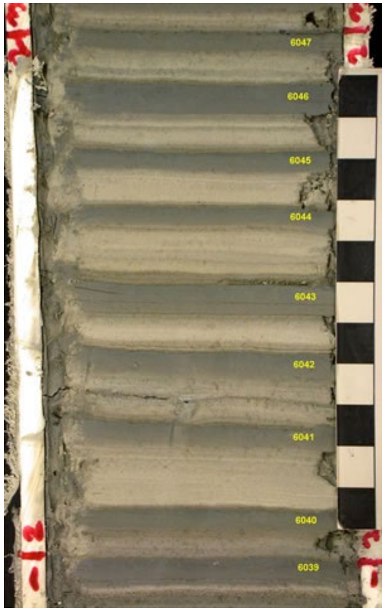
GOOD PRESERVATION



CONTINUOS SEDIMENTATION



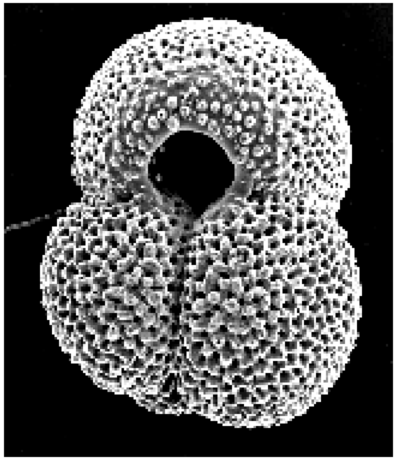
HIGH LSR



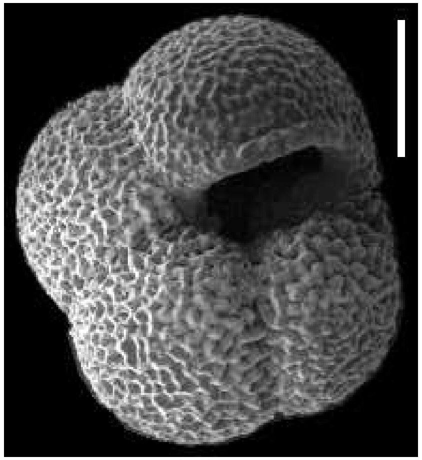
PALEOTEMPERATURE IN THE OCEAN - 2

The primary indicators for reconstructing past ocean temperatures include:

- **FOSSILS** based on the principle of taxonomic uniformitarianism, qualitative information (hot-cold) is obtained. In certain cases, it is possible to derive semi-quantitative and quantitative estimates.
- **STABLE ISOTOPES** (oxygen), **ELEMENTAL COMPOSITION** and **BIOMARKERS** in the calcite of the shells of many fossils (in particular foraminifera and corals).



Globigerinoides ruber

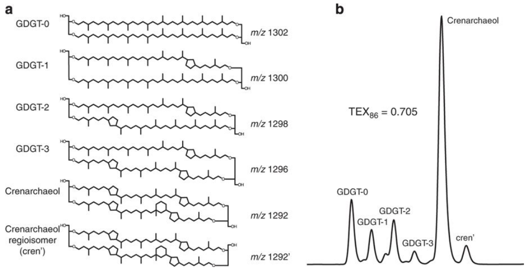


Neogloboquadrina pachyderma

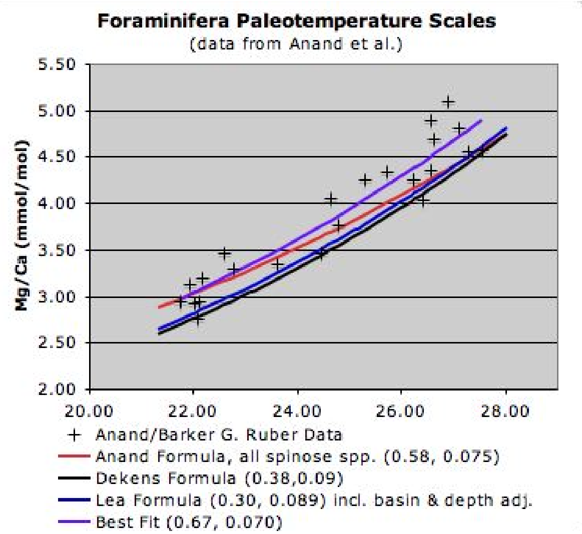
Uvigerina peregrina

PALEOTEMPERATURE IN THE OCEAN - 3

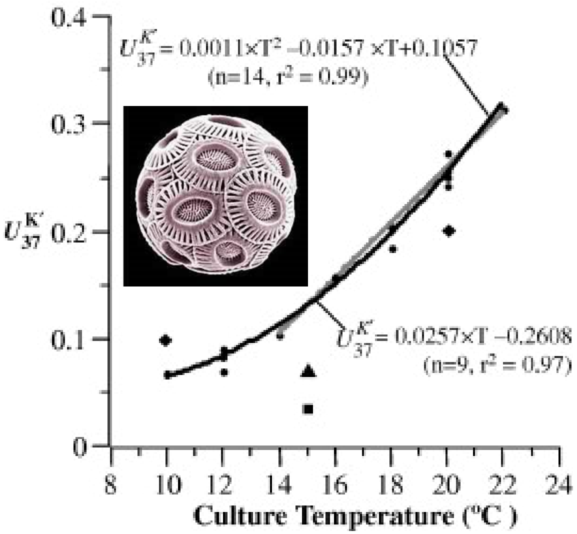
- **MG / CA RATIO** in foraminiferal tests
- **SR / CA RATIO** in corals and foraminifera
- **ALKENONES** are very resistant organic compounds (ketones) produced by phytoplankton (class Prymnesiophyceae).
- **TEX86** is based on the composition of the picoplankton lipid membrane (Crenarchaeota). TetraEther indeX of lipids with 86 carbon atoms.



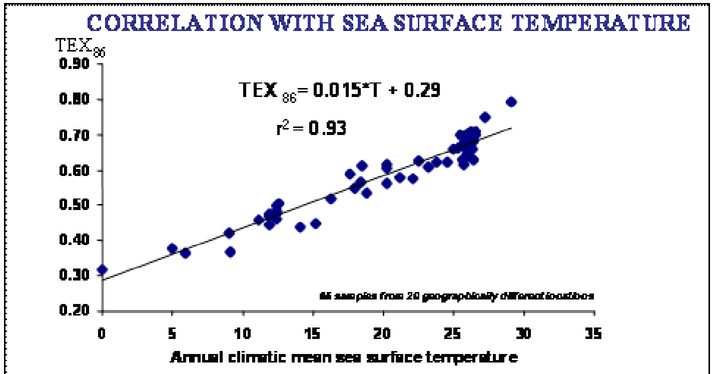
Mg/Ca ratio



Alkenones



TEX86

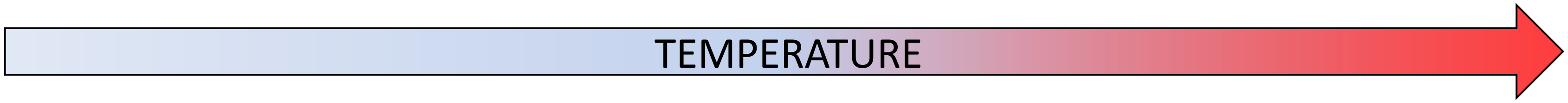


A TetraEther indeX of lipids with 86 carbon atoms

$$TEX_{86} = \frac{[2]+[3]+[4']}{[1]+[2]+[3]+[4']}$$

(numbers indicate no. cyclopentane rings)

Updated from Schouten et al. (2002), *Earth and Planetary Science Letters* **204**, 265-274

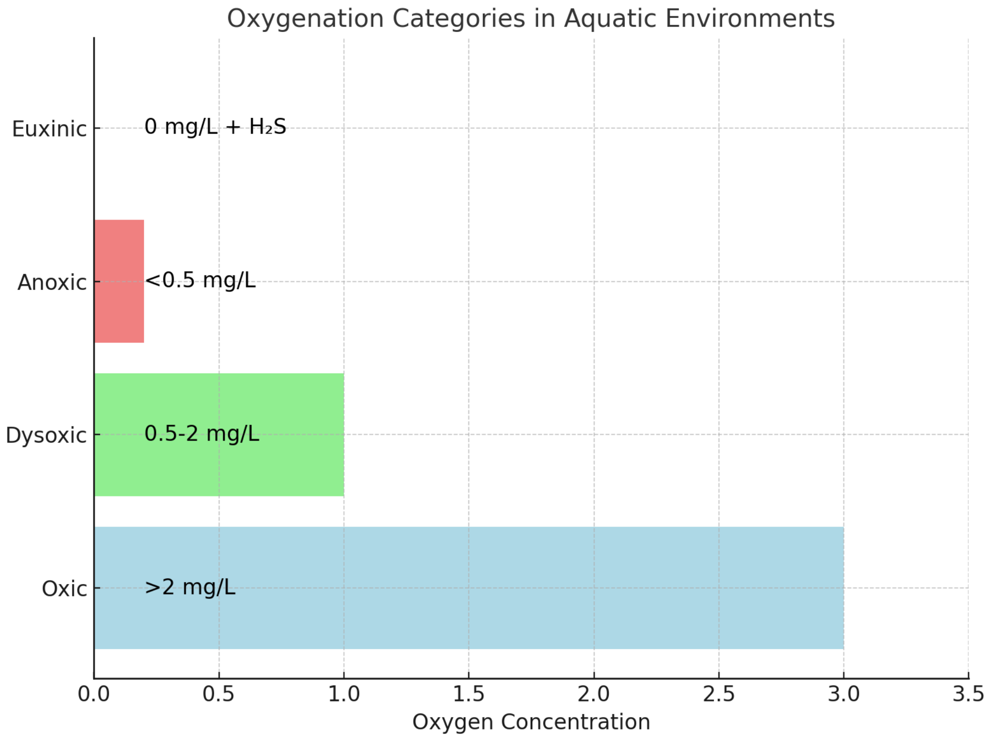


TEMPERATURE

PAST O_2 CONCENTRATION IN THE OCEAN

The main biotic indicators (proxies) used to reconstruct oxygen concentration are:

- Sediment lamination
- Dark color of the sediments
- Types of trace fossils (eg. Chondrites)
- Quantity and type of organic matter
- Taxonomic uniformitarianism (cf. benthic foraminifera)
- Taxonomic diversity
- Opportunistic species
- Only plankton and neckton
- Paper *Pecten*



PAST O_2 CONCENTRATION IN THE OCEAN

The main geochemical indicators (proxies) used to reconstruct oxygen concentration are:

- **Redox-Sensitive Elements**: The concentrations of certain elements, like iron (Fe), manganese (Mn), and sulfur (S), can be used to infer past oxygen levels. In sediments. The presence of reduced forms FeO of these elements suggests low oxygen. (Fe_2O_3 => oxidized form)
- **Lanthanide Anomalies**: Lanthanides are a group of elements with distinct behavior in response to varying redox conditions. The ratio of certain lanthanides (e.g., cerium to europium) in sediments or rocks can provide insights into the prevailing oxygen levels during deposition.
- **Sulfur Isotopes**: The isotopic composition of sulfur ($\delta^{34}S$) can be used to trace changes in microbial sulfate reduction, which is an anaerobic process. Variations in $\delta^{34}S$ values in sedimentary sulfur minerals can reflect fluctuations in oxygen levels.
- **Molybdenum and Uranium Isotopes**: The isotopic compositions of molybdenum (Mo) and uranium (U) in sedimentary rocks can provide information about the presence of oxygen in ancient oceans. These elements are sensitive to changes in redox conditions.
- **Trace Metal Concentrations**: Changes in the concentrations of certain trace metals (e.g., vanadium, nickel) in sedimentary records can reflect variations in oxygen.

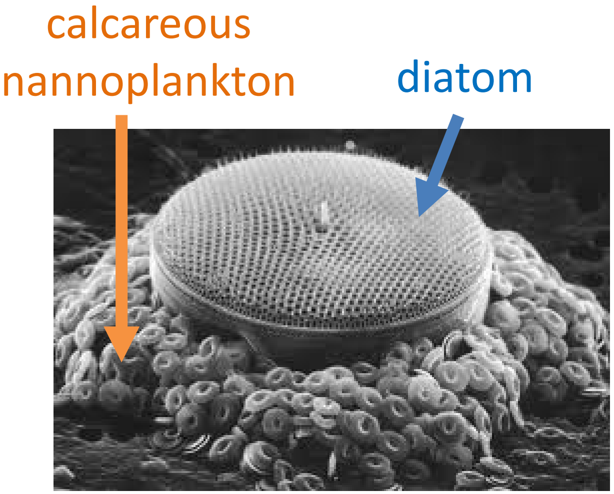
MARINE PALEOPRODUCTIVITY - 1

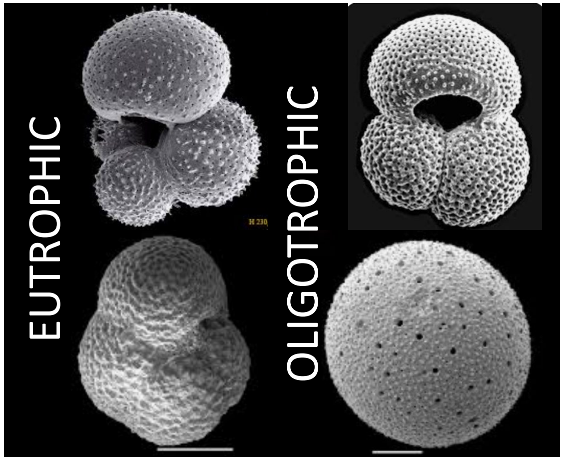
Taphonomic processes can significantly alter original paleoproductivity values, making it difficult to assess them quantitatively.
However, due to the importance of this parameter, qualitative or semi-quantitative estimates are still made using sedimentological, geochemical, and paleontological methods.

PALEONTOLOGICAL METHODS:

TYPE OF PHYTOPLANCTON:

Diatoms dominate high-productivity areas, while calcareous nannoplankton is typical of oligotrophic regions. This pattern helps identify past productivity gradients, with siliceous fossils indicating eutrophic environments.





TAXONOMIC COMPOSITION: Some species within different groups prefer eutrophic environments (*Globigerina bulloides, Neogloboquadrina* spp., Etc.), other oligotrophic environments (*Globigerinoides ruber, Orbulina universa*).

MARINE PALEOPRODUCTIVITY - 2

OTHER METHODS:

- Carbonate content and sedimentation rates: consists in calculating the quantity of carbonate deposited per unit of time in a given surface [(g / m^2 / Ma] => FLUX. The method must take into account the fact that the carbonate FLUXES are a function of soil dilution and dissolution, as well as productivity.
- Silica content (opal): for the reasons explained in the previous slide.
- Content of nitrates and phosphates in sediments.
- C_{org} content of sediments: The result can be altered by the fact that the C_{org} content depends on the preservation conditions (which depend on the sedimentation rates and on the oxygen concentration) as well as on the productivity.
- Stable Carbon Isotopes (^{13}C and ^{12}C)
- Ba content
- Ca / Ba ratio in benthic foraminifera
- Sedimentological and paleontological evidence of bottom anoxia

RECONSTRUCTION OF $pCO_{2\ ATM}$

The Intergovernmental Panel on Climate Change (IPCC, 2007) has identified a range of proxies/methods for the reconstruction of CO_2 levels:

ice core record data

Continental proxies:

-Stomatal index

-$\delta^{13}C$ paleosol

a

37:2 Me heptatriaconta-15E, 22E-dien-2-one

b

37:3 Me heptatriaconta-8E, 15E, 22E-trien-2-one

Marine Proxies:

-Boron stable isotope- $\delta^{11}B$ (^{11}B /^{10}B)

-$\delta^{13}C$ di 37:2 Alkenones – organic compounds. Alkenones are long chained (C37-C39) unsaturated ethyl and methyl ketones produced by a few species of Haptophyte algae in the modern ocean.

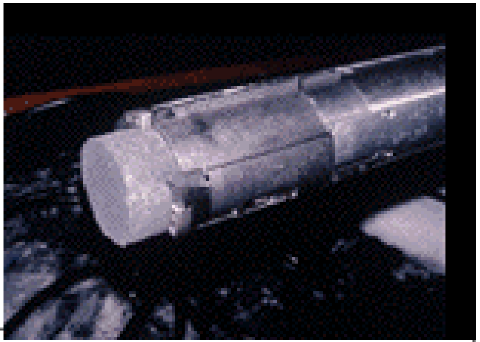
$U^{K'}_{37} = C_{37:2}/(C_{37:2} + C_{37:3})$ ☞ $T\,[°C] = (U^{K'}_{37} - 0.039)/0.034$

Altri

Nahcolite - $NaHCO_3$

Trona - $Na_2(CO_3)(HCO_3)\cdot 2(H_2O)$

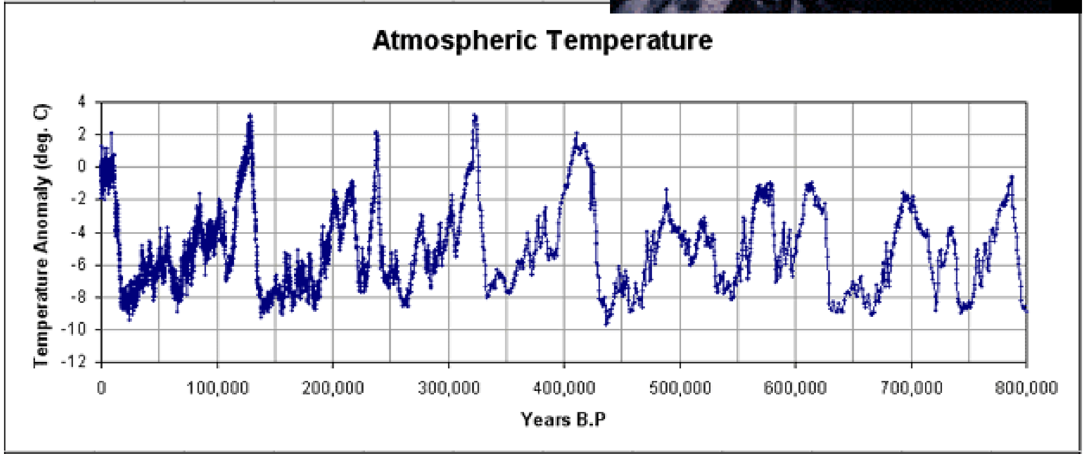
Ice Core record



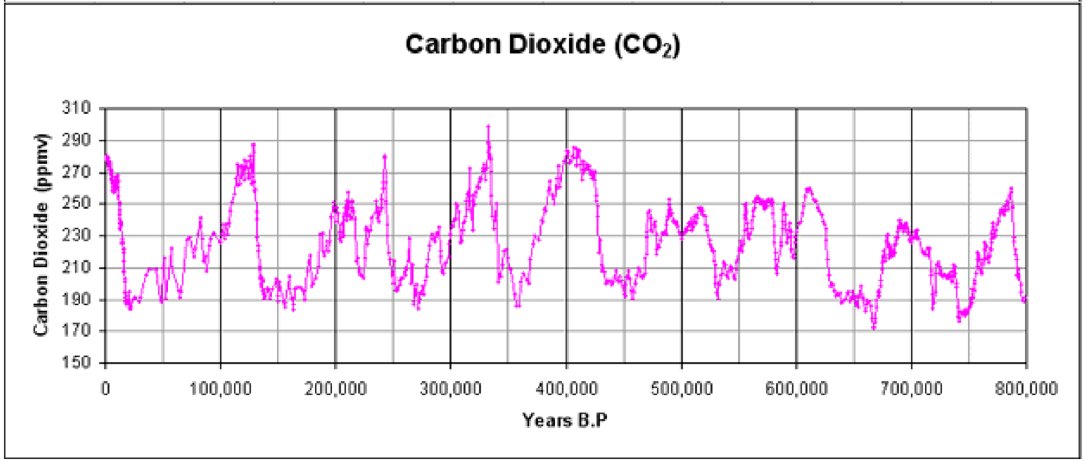
Ice cores recovered by drilling into permanent ice caps in Antarctica and Greenland represent a formidable archive for measuring CO$_2$ levels in the past.

Limits: short-term changes (10 – 10^2anni)

The burial of the ice produced on the ice caps takes 10^2 years (or more) to be completely buried and therefore isolated from the atmosphere.
This isolation is achieved at depths of about 120 m (at the South Pole). The P and T conditions that characterize these depths facilitate gas exchanges, which can modify the chemistry of the "air bubbles" present.
At greater depths (900-1200m) the P is such as to destroy the "air bubbles" that recombine with liquids and ice. This type of process tends to flatten the variability in the recorded CO$_2$ levels.



Atmospheric Temperature

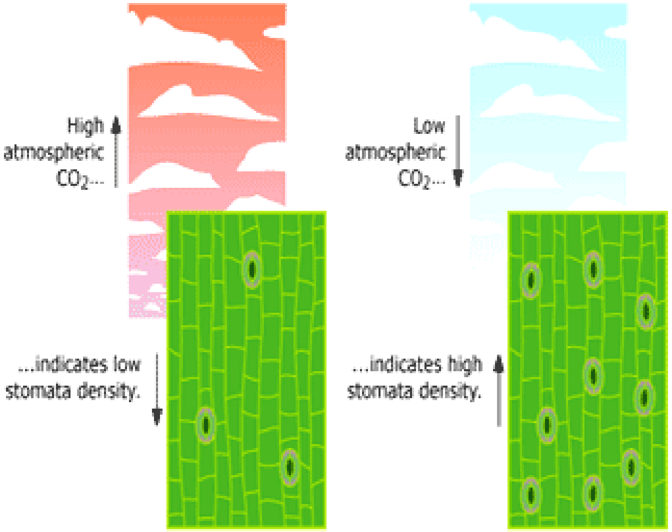


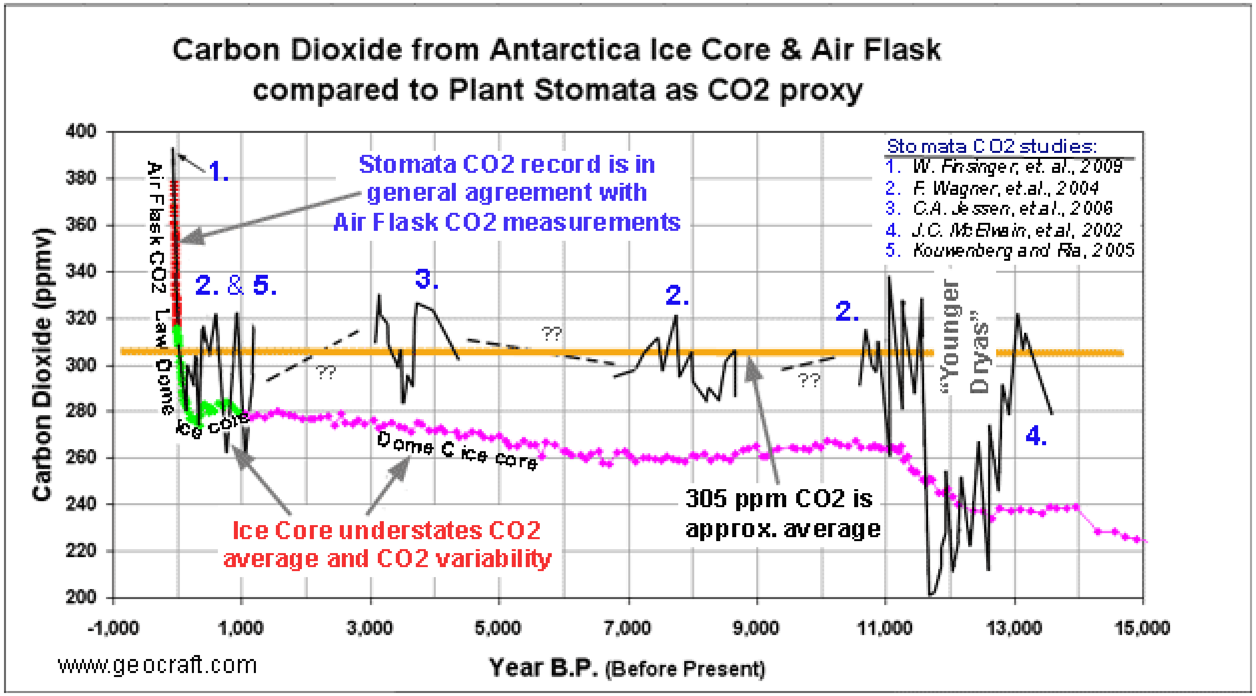
Carbon Dioxide (CO$_2$)

Plant stomata

PROXY:
SD (Stomata density) = number of stomata
SI (Stomata index) = number of stomata
+ size of the epidermal cells.

Rationale:
The number of stomata **decreases** with **high** values in pCO_2, while it **increases** when the pCO_2 is **low**.




Carbon Dioxide from Antarctica Ice Core & Air Flask compared to Plant Stomata as CO2 proxy

Stomata CO2 studies:
1. W. Finsinger, et. al., 2009
2. F. Wagner, et.al., 2004
3. C.A. Jessen, et.al., 2006
4. J.C. McElwain, et.al, 2002
5. Kouwenberg and Ra, 2005

Stomata CO2 record is in general agreement with Air Flask CO2 measurements

Ice Core understates CO2 average and CO2 variability

305 ppm CO2 is approx. average

www.geocraft.com

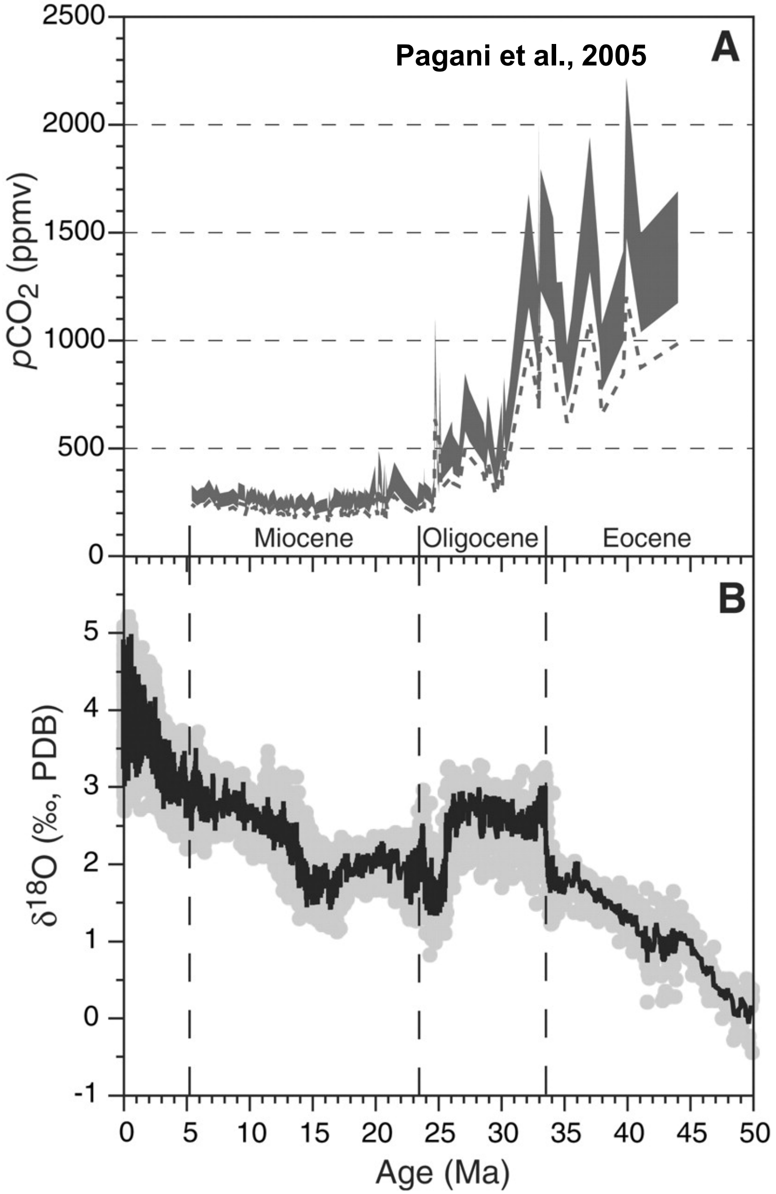
Stomata are small openings, typically found on the surfaces of plant leaves, stems, and other plant parts. **They play a crucial role in the exchange of gases**, such as carbon dioxide and oxygen, between the plant and the surrounding environment.

Alkenones

Proxies:
$\delta^{13}C_{(37:2)}$
$\varepsilon_{p(37:2)}$

Rationale:
The pCO_2 estimates are based on the fractionation that occur in the C isotopes during marine photosynthesis (which leads to carbon fixation).

Experiments conducted under controlled nutrient conditions indicate that εp (fractionation factor εp37: 2) varies as a function of the aqueous concentration of CO_2 [CO_2aq] and the specific growth rate.



pCO_2 proxies Summary