Looking into the past to predict the future

The planet is rich of natural archives storing the past climate history

Arctic and Antarctic Ice

Glaciers

Peat bogs and mires

Marine and freshwater sediments

The analysis of sediments make use of many, integrated techniques to:

- Date the sediment layers
- Infer temperatures when the layer was deposited
- Date the organic component of the sediments (both plant and animal)
- Infer air composition
- Detect evidence of volcanic activity
- Reconstruct vegetation and its changes
- Estimate precipitations
- other

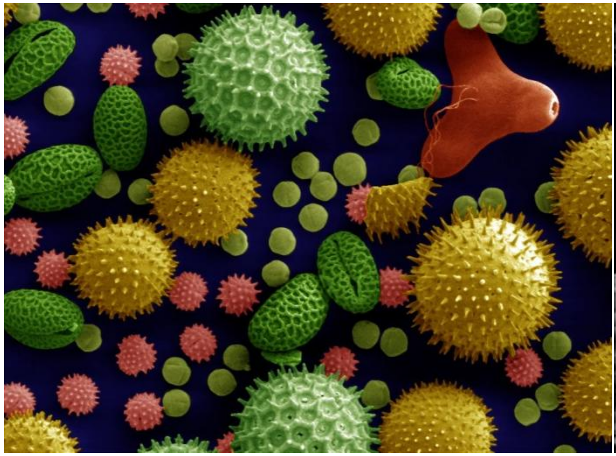
Using plants

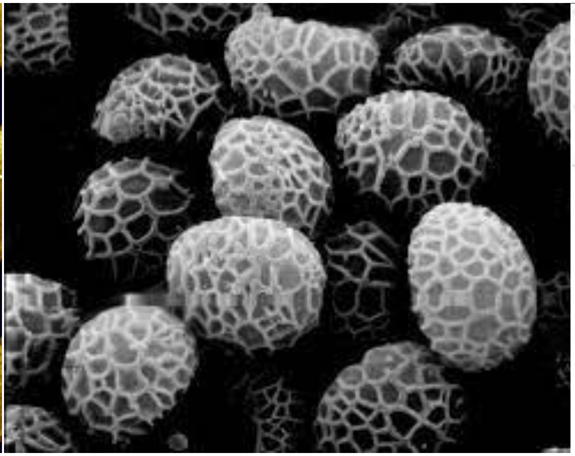
Paleopalynology **Dendrochronology** **Plant fossils and finds**

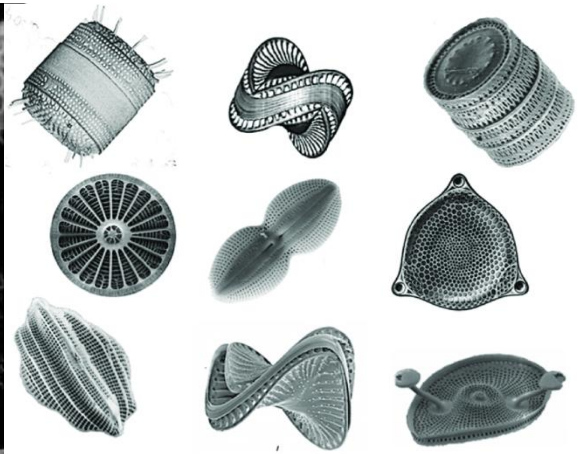
Palynology

Palynology = combination of the Greek verb palunein (παλύνειν, “to strew or sprinkle”), the Greek noun pale (παλη, in the sense of “dust, fine meal”) -> close to the Latin word pollen, meaning “fine flour, dust”) (Hyde and Williams**, 1944**)

Scientific discipline concerned with the study of **plant pollen**, **spores**, and certain **microscopic planktonic organisms**, in both **living** and **fossil form (= Palynomorphs)**.







The field is associated with the plant sciences as well as with the geologic sciences, notably those aspects dealing with stratigraphy, historical geology, and paleontology

Pollen = male microgametophyte

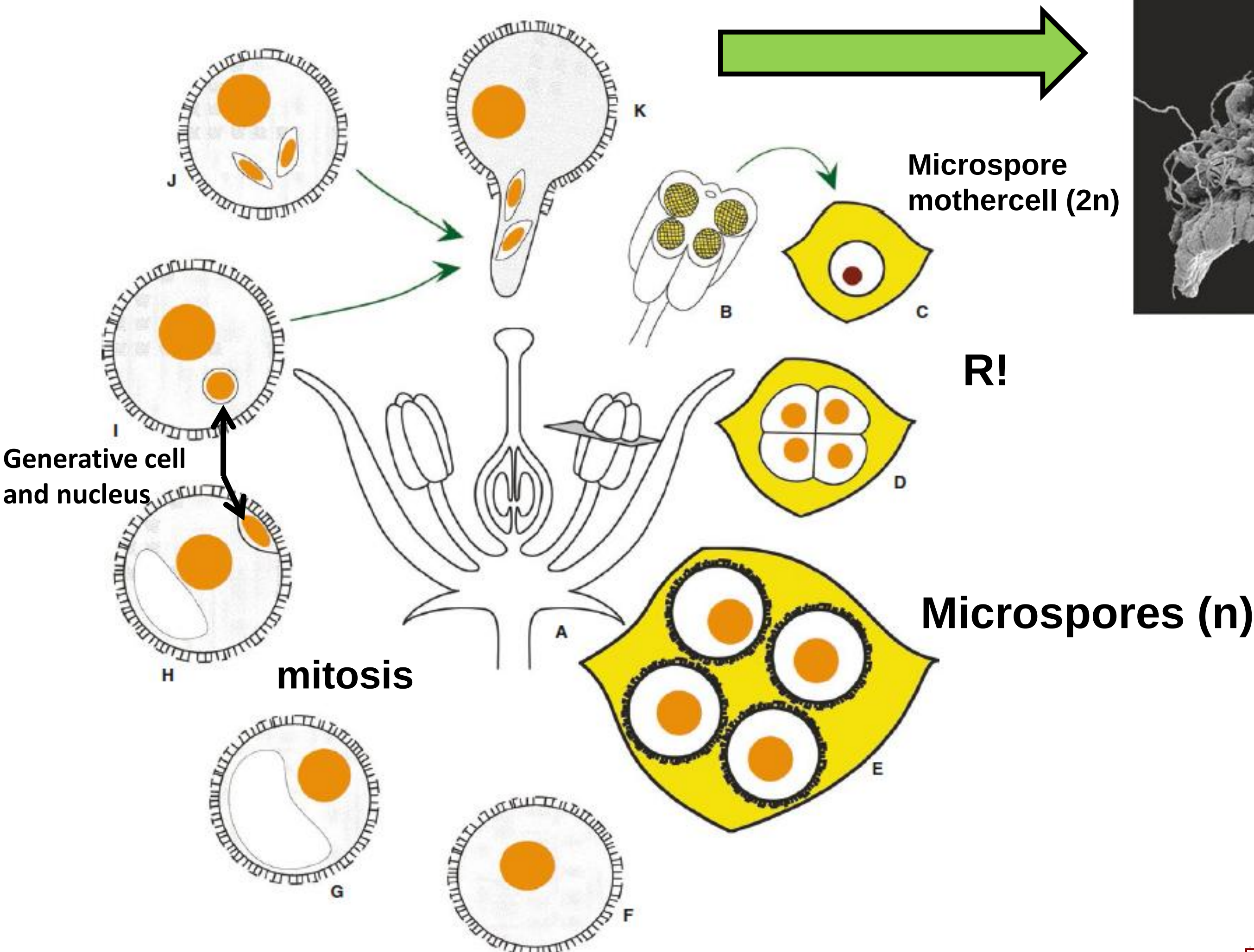
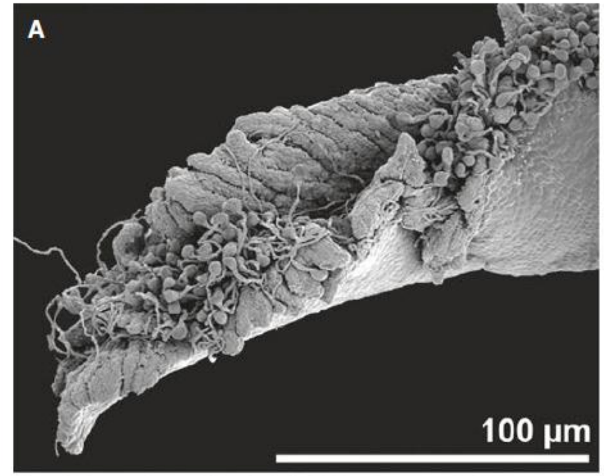
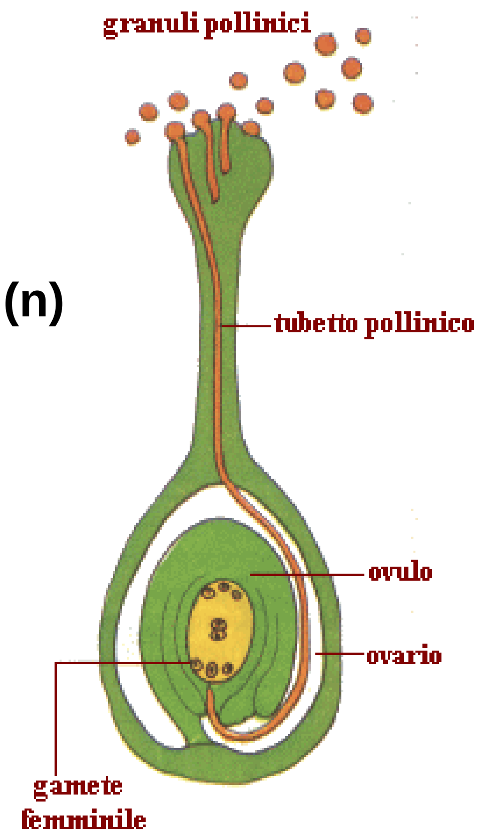


Fig. 1 Pollen development in angiosperms. A. Schematic illustration of an angiosperm flower. B. Cross section of anther. C. Pollen mother cell (PMC) encased in callose (diploid nucleus darkred). D. Tetrad of four haploid microspores encased in callose (haploid nucleus orange). E. Pollen wall formation and separation of microspores. F. A single free microspore with central haploid nucleus. G. Beginning of gametogenesis, formation of a central vacuole (white). H. First pollen mitosis, lens-shaped generative cell with generative nucleus attached to pollen wall. I. Two-celled pollen grain, generative cell detached from pollen wall. J. Three-celled pollen grain after second pollen mitosis, note two sperm cells with sperm nuclei. K. Germination can occur from either a two-celled pollen grain, followed by the formation of sperm cells, or from a three-celled pollen grain (pathways indicated by green arrows)





The development of pollen research follows the history of plant anatomy and morphology in general and is dependent to a large degree on developmental stages of the microscope.

Nehemiah Grew first observed pollen microscopically in Britain about 1640.

About the same time, **Malpighi** (1628 – 1694) noted differences in size and color of pollen.

Various people later studied the biology of pollen and spores, especially with reference to the function of pollen in fertilization of ovules, in the 18th century.

Camerarius R. J. (1665 – 1721) usually gets credit for proving the maleness and fertilizing function of pollen in the late 17th century (De sexu plantarum epistola, 1694).

Curiously, ancient peoples knew what pollen was for, and such **aboriginal** people as **American Indians** have understood the maleness, and the precise function, of pollen, apparently for thousands of years: pollen played a prominent role in some Indian puberty ceremonies.

Western Apache Writing Symbol:

"He who is decorated with and enriched by pollen."

In the **19th century**, with the coming of much improved microscopes, the anatomy of pollen and spores was carefully studied and catalogued by German scientists, e.g., von Mohl (d. 1872), Fritsche (d. 1871) and Fischer (pollen work published in 1889).

Robert Brown noted **in 1809** that pollen could be used to advantage for systematic studies of seed plants, and Brown's illustrator, F. Bauer, described **175 species of pollen** for this purpose (see Graham and Barker, 1981)

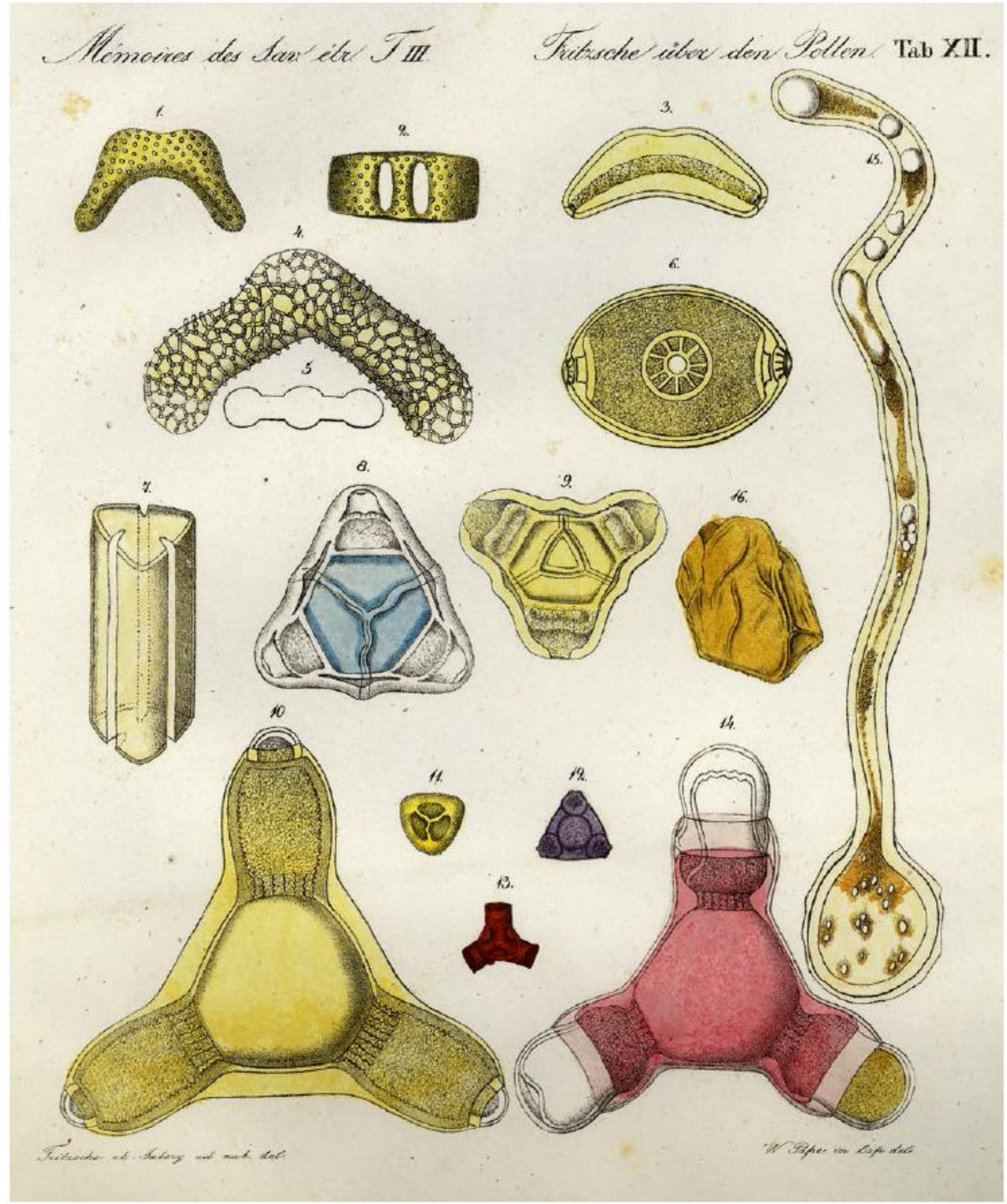
Pollen morphologists of today continue the work of Brown, Fritsche and Fischer, employing better optical microscopes, and especially scanning and transmission electron microscopes (SEM, TEM).

Pollen grains morphology

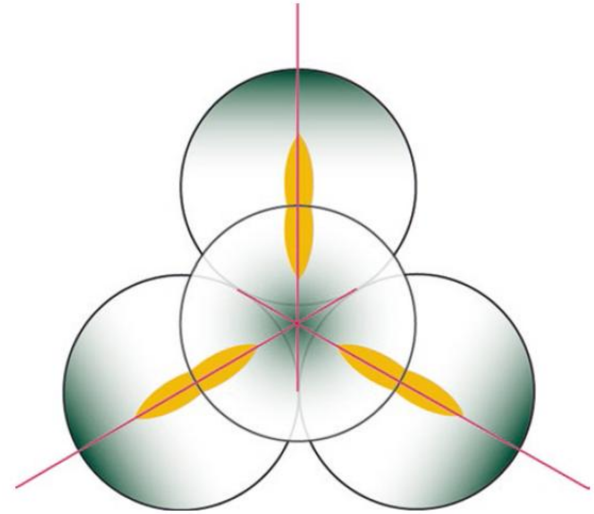
Among taxonomic groups they can exhibit tremendous variability:

- polarity
- shape (dry ≠ wet!)
- dimensions
- apertures
- ornamentation of the pollen wall
- Etc.

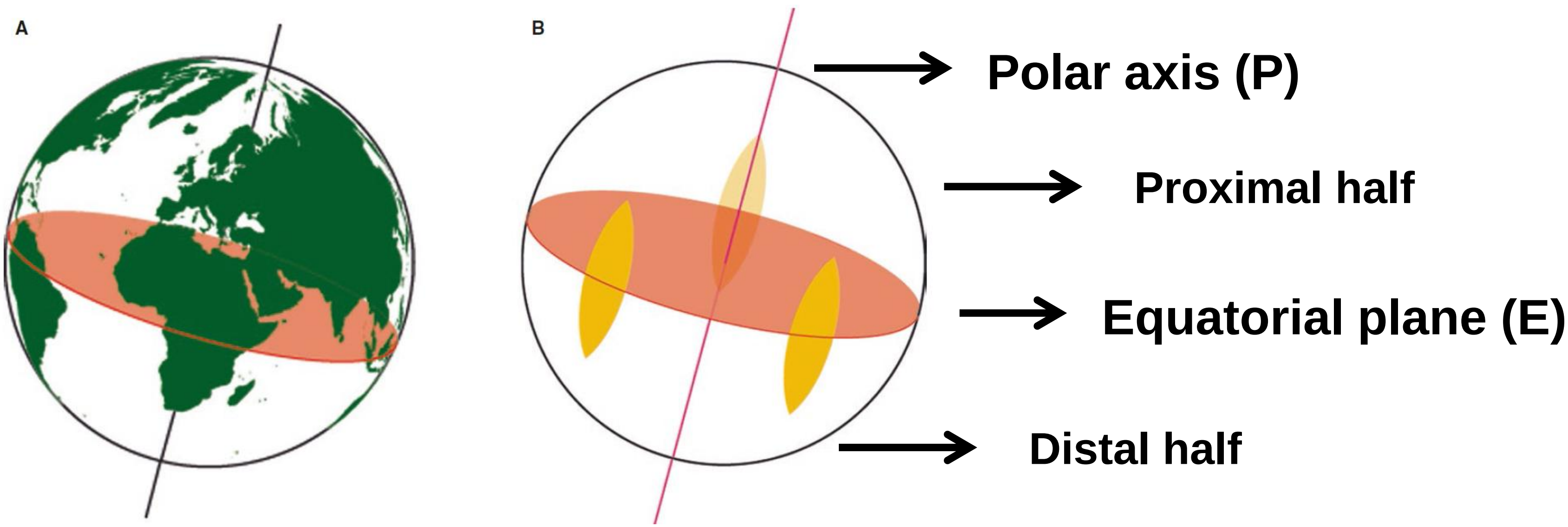
Diagnostic characters used to identify the belonging to a taxonomic group: **family, genus** or even **species**.



Polarity and pollen shape



Pollen shape and aperture location relate directly to pollen **polarity.** The polarity is determined by the spatial orientation of the microspore in the meiotic tetrad and can be examined in the **tetrad stage.**



The **polar axis** of each microspore/ pollen runs from the **proximal pole,** orientated towards the tetrad center, to the **distal pole** of the microspore/pollen. The **equatorial plane** is located at the microspore's center, perpendicular to the polar axis (Fig. 2). Therefore, the **equatorial plane** divides the microspore/pollen into a proximal and a distal half

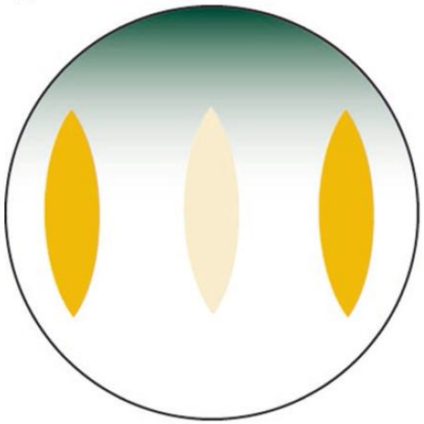
Isopolar pollen

has identical proximal and distal poles, thus the equatorial plane is a symmetry plane.

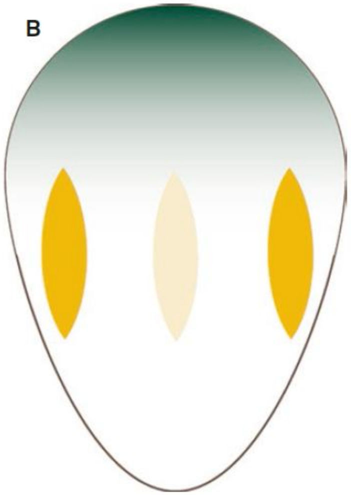
Heteropolar pollen

the proximal and distal halves differ

A

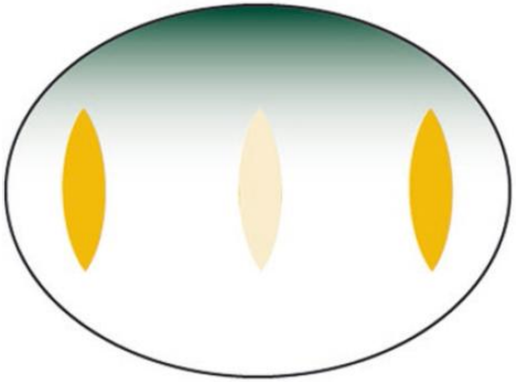


B

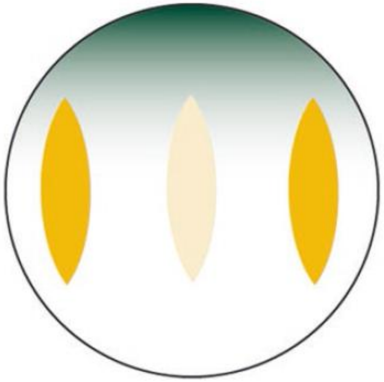


P/E ratio -> type of polarity

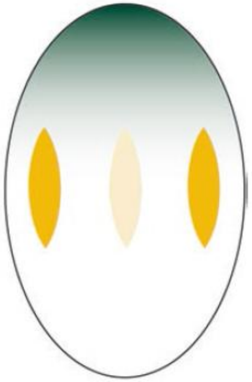
Oblate



Isodiametric



Prolate



Dicots vs monocots

Dicots : Isodiametric pollen; apertures along the equatorial plane

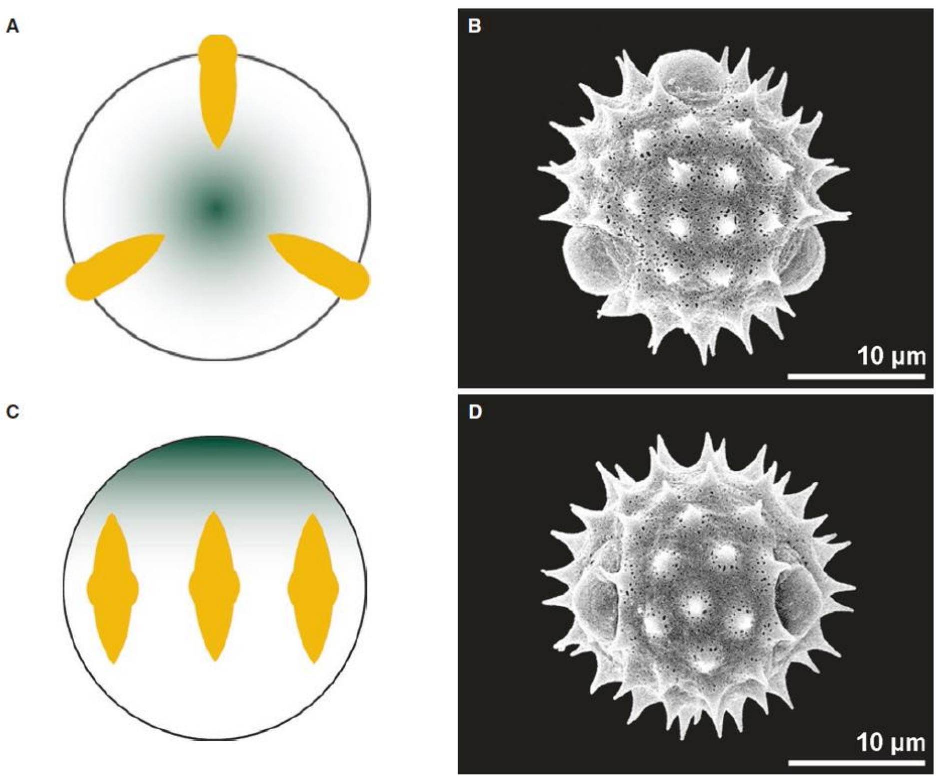


Fig. 3 Polarity of pollen in dicots. **A-B.** *Bellis perennis*, Asteraceae, polar view. **C-D.** *Bellis perennis*, Asteraceae, equatorial view

Monocots: Oblate pollen; aperture at the distal pole

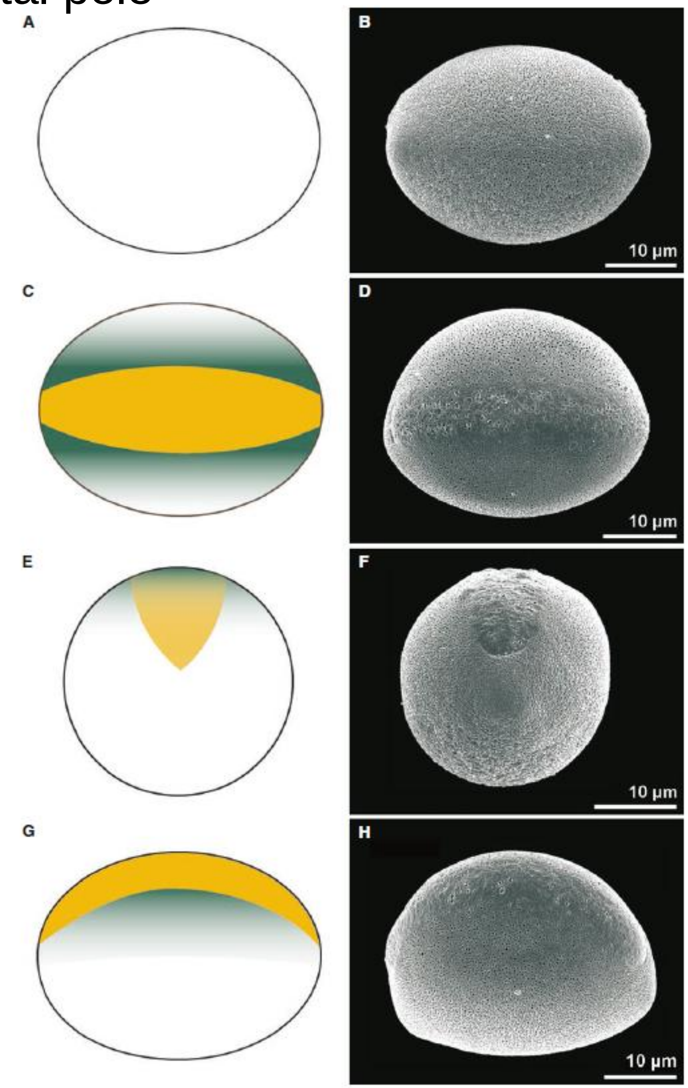


Fig. 4 Polarity of pollen in monocots (*Allium paradoxum*, Alliaceae). **A-B.** Proximal polar view. **C-D.** Distal polar
E-F. Equatorial view (short axis). **G-H.** Equatorial view (long axis)

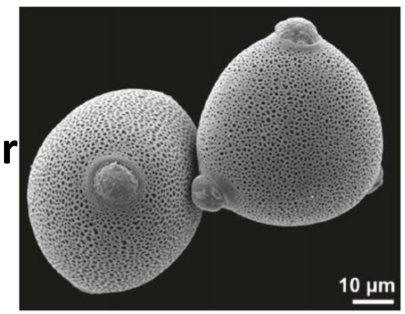
Apertures

An **aperture** is a region of the pollen wall that differs significantly from its surroundings in morphology and/or anatomy. The aperture is presumed to function as the site of germination

Circular apertures | **Elongated apertures** | **Hybrid apertures**

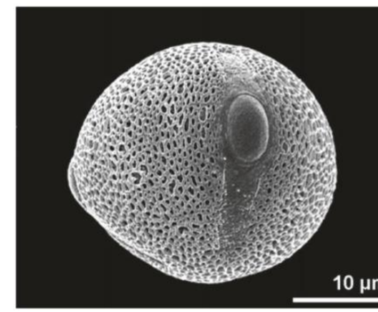
Positioned equatorially or globally

Porus/Porate



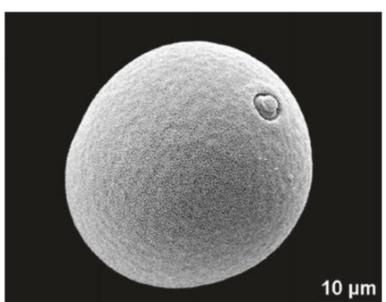
Colpus/Colpate

Colporus/Colporate

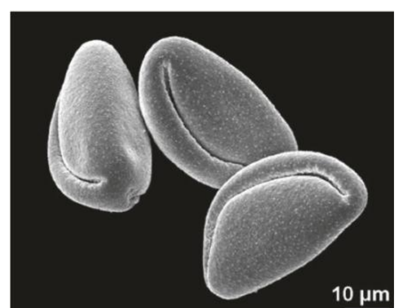


Positioned distally

Ulcus/Ulcerate

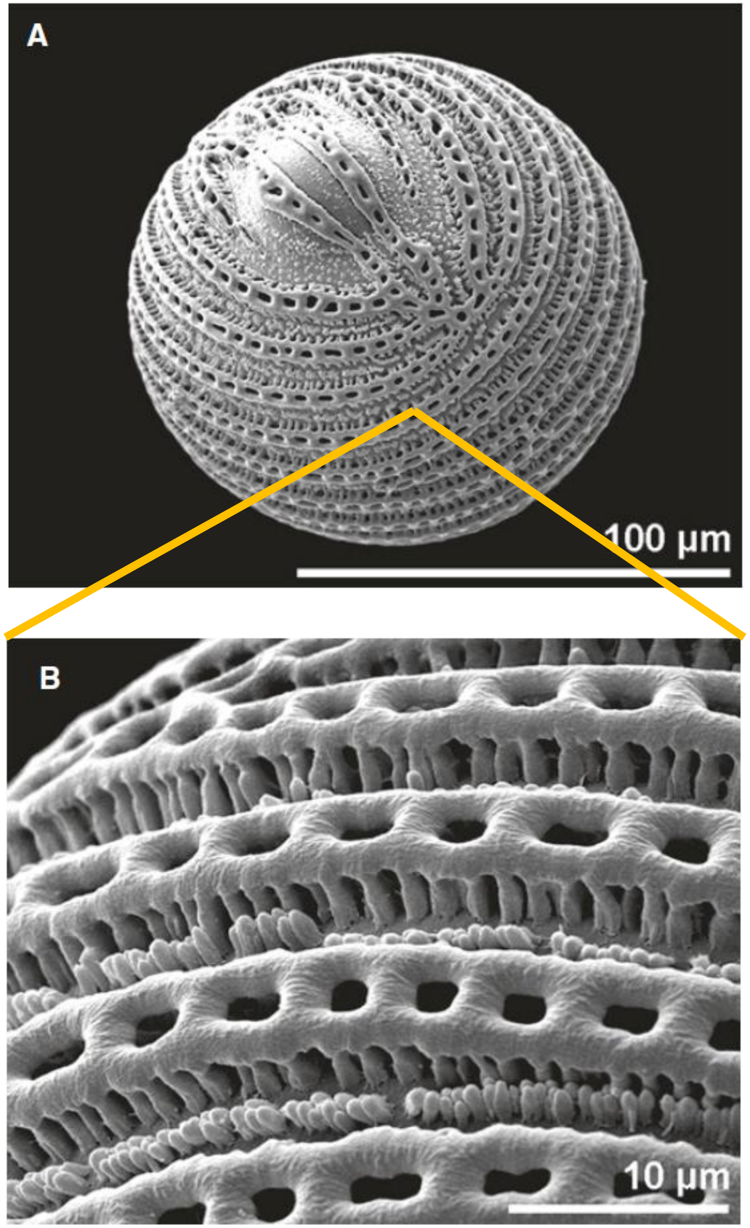


Sulcus/Sulcate

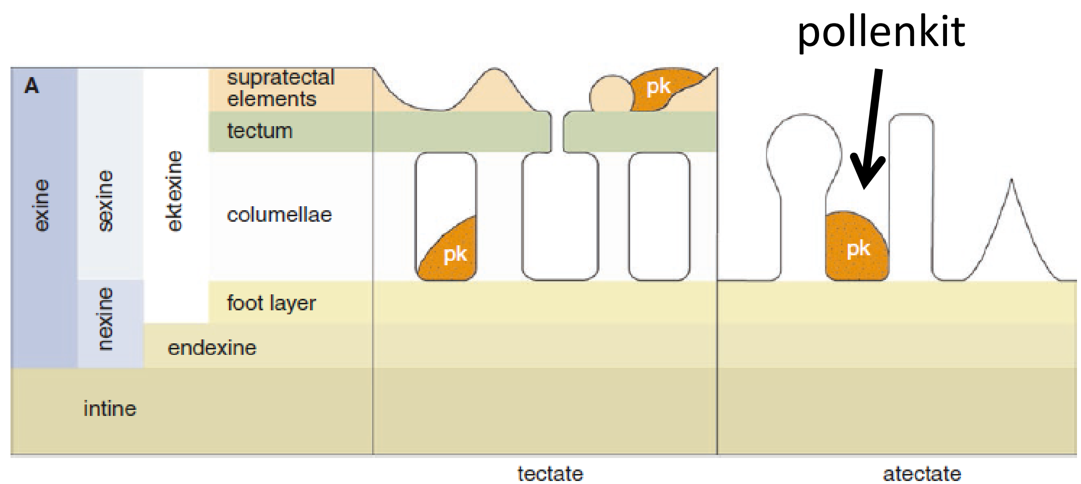


Inaperturate (without apertures) pollens are also present as well as **Heteroaperturate** pollens (different types of aperture on the same pollen grain)

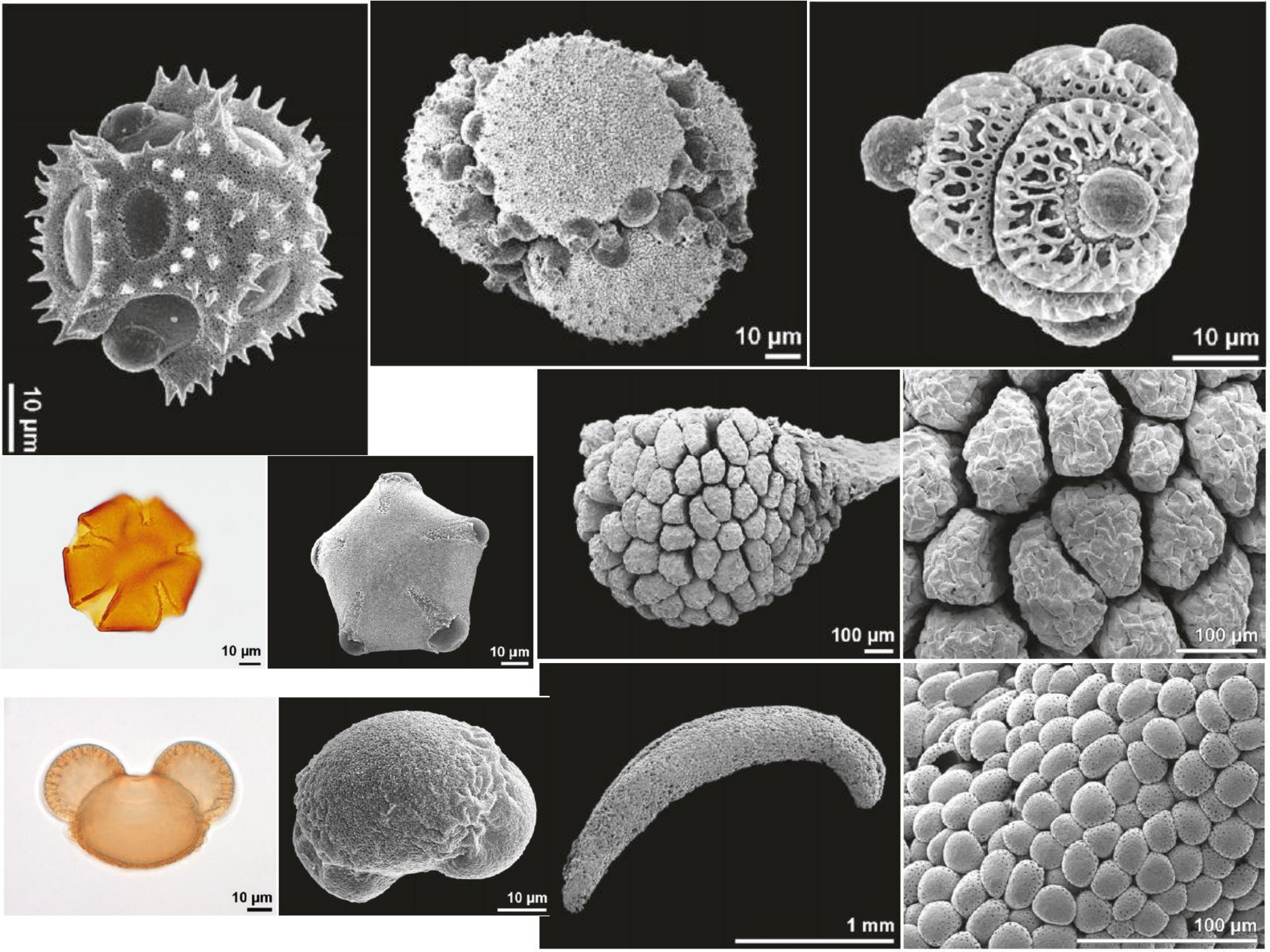
Pollen wall and ornamentation



The **pollen wall** (**sporoderm**) of seed plants is formed by two main layers: the outer **exine** and the inner **intine** (Fig. 15).



The exine consists mainly of **sporopollenin**. The intine is mainly composed of cellulose and pectin. Aperture regions are characterized by the reduction of exine structures or by a deviant exine, and a thick, often bilayered intine.


10 µm
10 µm
10 µm
10 µm
10 µm
100 µm
100 µm
10 µm
10 µm
1 mm
100 µm

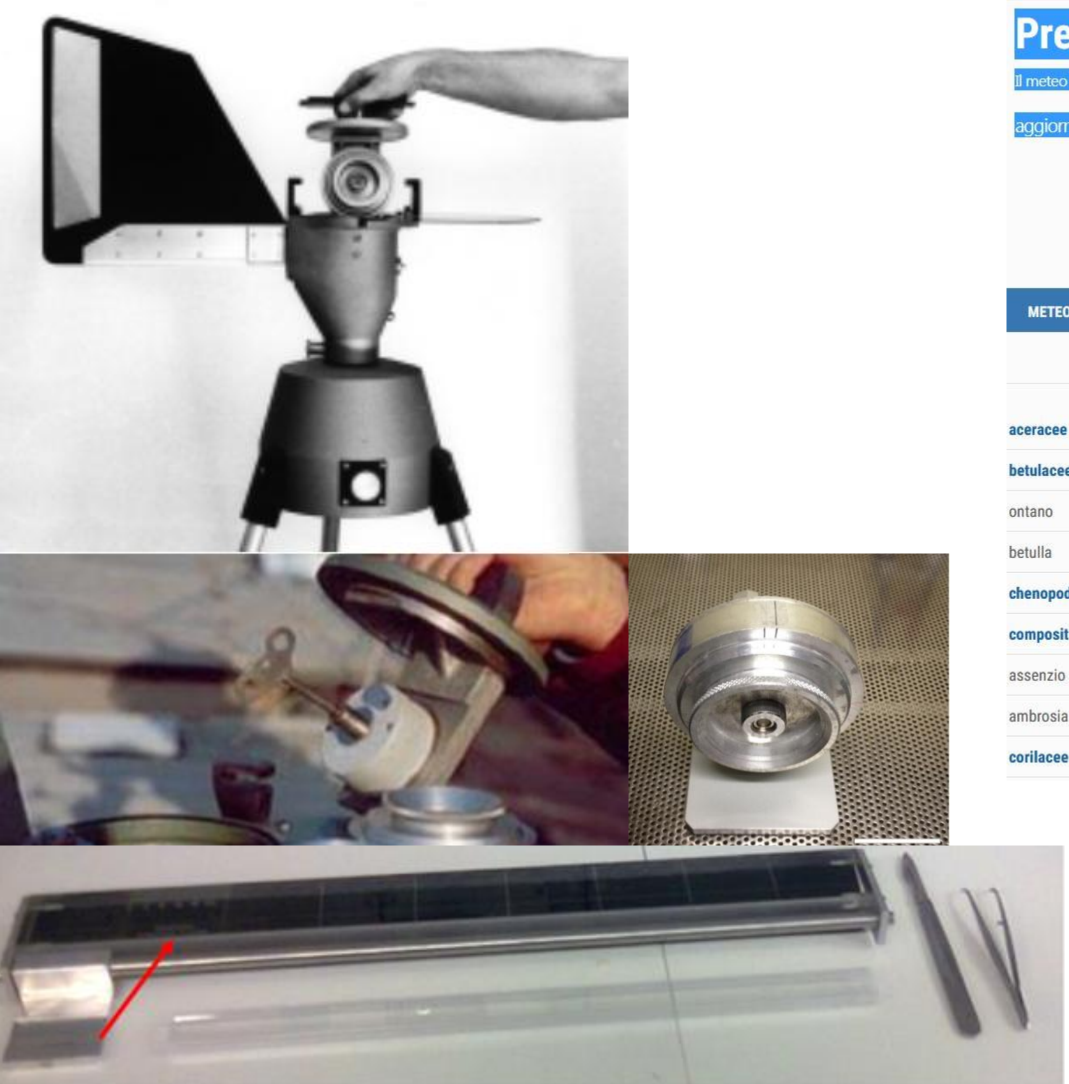
Palinology involves:

a) Base research -> morphology, taxonomy, physical and chemical properties of pollen wall, correlation of palynology with other branches of biology, such as cytology, taxonomy, etc.; **e.g.** the analysis of morphology leads to the determination of pollen types (taxonomic comparisons) and identification keys (Morphopalinology).

b) Applied research -> taxonomic determination of pollen grains recovered from various substrates. Taxonomic identification aided by pollen atlases or libraries made of reference material.

Applications of Palynology:

a) **Aeropalynology**, study of the airborne pollen -> pollen bullettins -> human allergies;



Previsioni pollini a Trieste

Il meteo pollini è un servizio sperimentale. Inviaci le tue osservazioni

aggiornate il **31 agosto alle ore 12:17**

METEO | WEEKEND | MESE | STORICO | ALLERTE | WEBCAM | POLLINI | ARIA

	gio 31	ven 01	sab 02	dom 03	lun 04	mar 05	mer 06
aceracee	Assente	Assente	Assente	Assente	Assente	Assente	Assente
betulacee	Assente	Assente	Assente	Assente	Assente	Assente	Assente
ontano	Assente	Assente	Assente	Assente	Assente	Assente	Assente
betulla	Assente	Assente	Assente	Assente	Assente	Assente	Assente
chenopodiacee/amarantacee	Bassa	Bassa	Bassa	Bassa	Bassa	Bassa	Bassa
composite	Bassa	Bassa	Bassa	Media	Media	Media	Media
assenzio	Bassa	Bassa	Bassa	Media	Media	Media	Media
ambrosia	Bassa	Bassa	Bassa	Media	Media	Media	Media
corilacee	Assente	Assente	Assente	Assente	Assente	Assente	Assente

Applications of Palinology:

b) **Briopalynology**, study of the pollen landing on mosses and lichens and other plant organisms playing as natural traps;

c) **Melissopalynology**, study of the pollen ending in honey (or in other bees' products) -> compliance of the honey with the label;

Are we sure it is a Dandelion (*Taraxacus sp*.) honey?

d) **Pharmacopalynology**, study of pollen grains in drugs and herbal products;

Applications of Palinology:

f) **Forensic palynology**, determination of pollen grains recovered from samples of crime scenes or related samples;

g) **Archeopalynology**, study of pollen diversity from site inhabited by humans

Fig. 1. The equestrian statue of Cangrande (Castelvecchio Museum, Verona).

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A medieval case of digitalis poisoning: the sudden death of Cangrande della Scala, lord of verona (1291–1329)

Gino Fornaciari [a, b], Valentina Giuffra [a, b, *], Federica Bortolotti [c], Rossella Gottardo [c], Silvia Marvelli [d], Marco Marchesini [e], Silvia Marinozzi [f], Antonio Fornaciari [a, b], Giorgio Broccο [g], Franco Tagliaro [c]

"**Palynological analyses** demonstrated the presence of **pollen grains of Digitalis sp.**/foxglove **in the rectum content**, **along with Matricaria chamomilla/chamomille and Morus nigra/black mulberry.**"

f) **Paleopalynology**, the study of the organic microfossils that are found in maceration preparations of sedimentary rocks, freshwater sediments, peat bogs, soils, i.e. “What my net catches is a fish” .

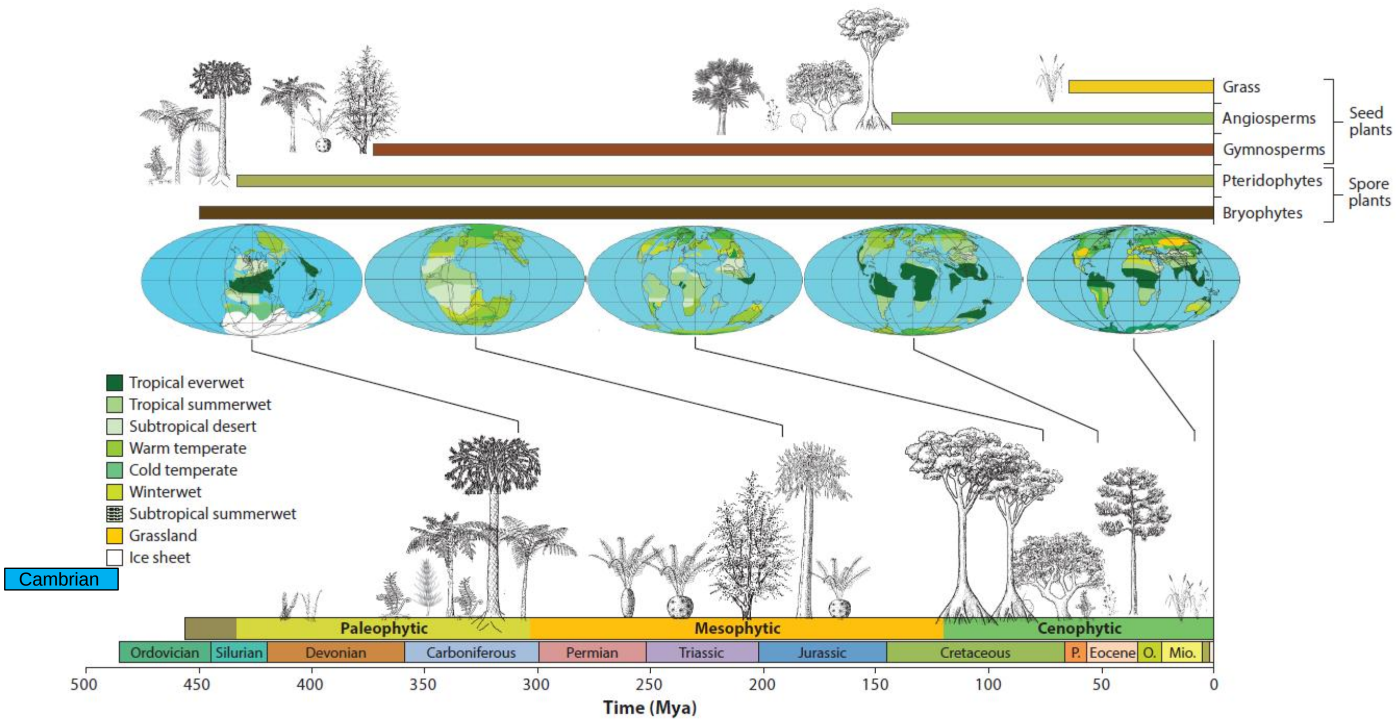


Figure 1

Time line of plant evolution demonstrating the estimated first occurrences of major plant groups [bryophytes, based on the time of origin of land plants, >450 Mya (139); pteridophytes, based on the time of origin of vascular plants, 433.5 Mya (139); gymnosperms, based on the time of origin of seed plants, 373.8 Mya; angiosperms, 143.8 Mya (139); and grasses, 65 Mya (148)], biomes through time (166), and the timing of the phases of plant evolutionary floras (Paleophytic, Mesophytic, and Cenophytic), modified from Reference 30. Plant illustrations from Reference 166 by Marlene Hill-Donnelly; used with permission. Geological timescale from the 2013 update by the International Commission on Stratigraphy. Abbreviations: Mio., Miocene; O., Oligocene; P., Paleocene.

<u>**Identification**</u> of pollen and spore microfossils has greatly aided delineation of the geographical distribution of many plant groups from early Cambrian time (some 541 million years ago) to the present

Paleopalynomorphs other than pollens and fungal spores

Acritarchs: “of undecided or doubtful origin”. The “hystrichosphaerids” which could not be shown to be dinoflagellate cysts were then left as “acritarchs.” The term now includes a very large range of presumably algal bodies, mostly marine (but there are many brackish-water or freshwater forms including probable green algae) mostly 15–80 µm. The wall contains **sporopollenin** or a very similar compound. From Proterozoic to present, highest abundance in the Paleozoic.

Scolecodonts: **chitinous** mouthparts of polychaetous, mostly marine annelid worms. Although they range from Cambrian to the present, they have been mostly studied in Paleozoic rocks.

Chitinozoans: **pseudochitinous** palynomorphs of uncertain origin. Hyp. Graptolites, *i.e.* marine colonial organisms with chitinous exoskelon; The suggestion of fungal origin is very unlikely, the experts on the topic will go only so far as “…eggs of soft-bodied marine metazoans.” They first appear in Cambrian rocks, are most abundant in the Ordovician and become extinct by the end of the Devonian time.

Dinoflagellates: Sporopolleninous <u>cysts</u> of dinoflagellates are common from Late Triassic rocks to present, mostly in marine environments, but also in sediments deposited in fresh and brackish water. Temporal range: Cambrian (?) – Late Triassic to present. Difficulty in the determination of the oldest specimens because of the absence of the typical dynoflagellates morphological features.

Foraminiferal inner tests (= shells): These frequently occur in paleopalynological preparations of marine rock, especially in Cenozoic sediments. They represent the **chitinous** inner tests of foraminifera, almost always of planispiral forms. Temporal Range: Devonian (?) to present.

Palynodebris and Varia: Palynological preparations always contain more-or-less organic "junk" not referable to specific palynomorph classes. Four categories of such particles are especially common and are occasionally useful to paleopalynologists: (1) wood (tracheids, wood fibers, vessel elements), (2) cuticular-epidermal leaf fragments, (3) Ubisch bodies (orbicules), and (4) variously degraded algal and other plant tissues. Ubisch bodies, also called orbicules, are tiny bits of sporopollenin about 1–5 μm, which consist at least in part of **sporopollenin** left over by the tapetum in laying down the exine of spores and pollen. Proterozoic to present. Other "organic junk" can be arthropods **chitinous** parts.

The study of the paleopalynomoprhs is possible thanks to molecules letting palynomorphs to overcome ages, such as

<u>Sporopollenin and chitin</u>… but only if conserved at specific conditions because it is not indestructible**: fungi and bacteria**, **(UV-) light**, **pH**, **high temperatures and O_2** can oxidize its chemical composition damaging the exine morphology with the final loss of the pollen.

However: under **anaerobic conditions** the sporopollenin remains stable:

Glaciers

Vulcanic eruptions (ashes coverings)

Peat bogs and mires

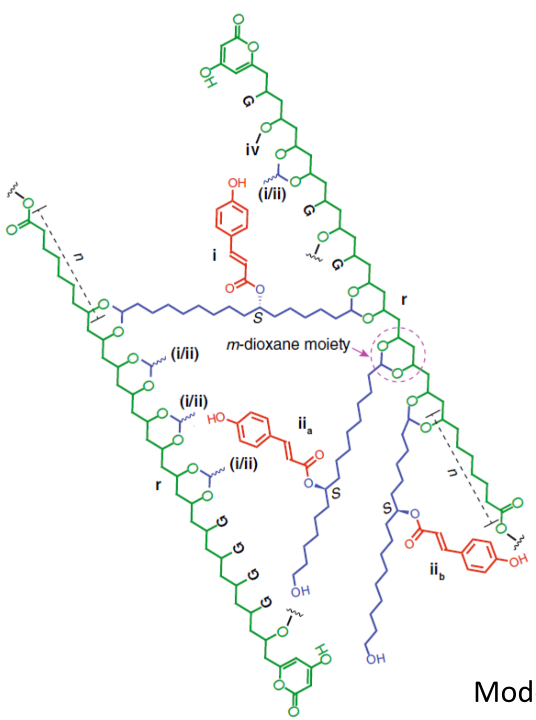
Marine and freshwater sediments

Molecules letting palynomorphs to overcome ages

Sporopollenin

Zetzsche et al. (1931) coined the term "sporopollenin", from the previous terms "pollenin" and "sporonin" used to indicate the resistant exine material of pollen and spores, respectively.

Sporopollenin is a complex biopolymer and **extremely resistant** to decay as well as to chemical and mechanical damage.



Its structure is composed by **aliphatic compounds** and **oxygenated aromatic compounds** including:

- carotenoids
- polyunsaturated fatty acids
- conjugated phenols

The term "**sporopollenins**" is the one commonly used because there are **many variation** in the structure, e.g. **between** sporopollenins of **angio-** , **gymnosperms** (in pollens) and **pteridophytes** (in spores).

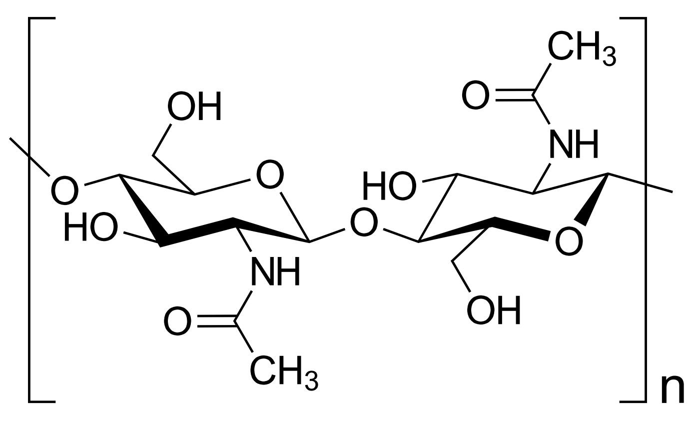
Model of sporopollenin from *Pinus rigida* (Li et al. 2019)

Molecules letting palynomorphs to overcome ages

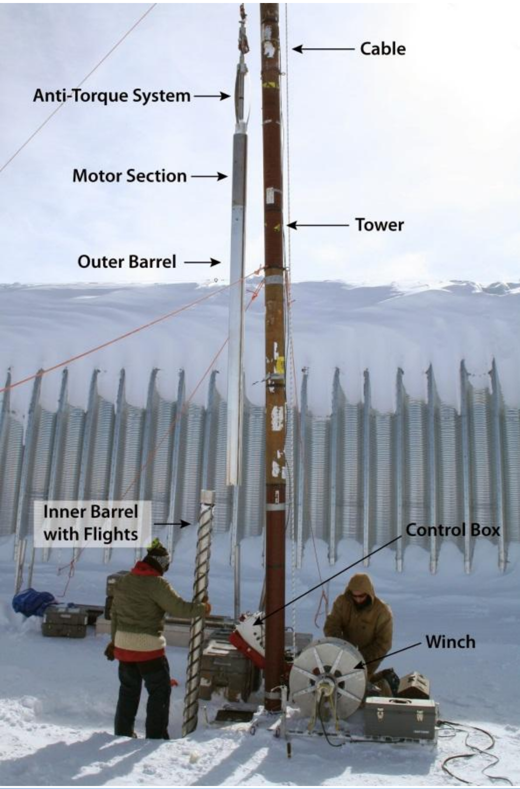
Chitin

The English word "chitin" comes from the French word *chitine*, which was derived in 1821 from the Greek word χιτών (*khitōn*) meaning covering.

Chitin $(C_8H_{13}O_5N)_n$ is a long-chain polymer synthesized from units of N-acetyl-D-glucosamine (to be precise, 2-(acetylamino)-2-deoxy-D-glucose), an amide derivative of glucose. Chitin is the second most abundant polysaccharide in nature (behind only cellulose). It is a primary component of cell walls in fungi (especially filamentous and mushroom forming fungi), the exoskeletons of arthropods such as crustaceans and insects, the radulae, cephalopod beaks and gladii of molluscs and in some nematodes and diatoms.

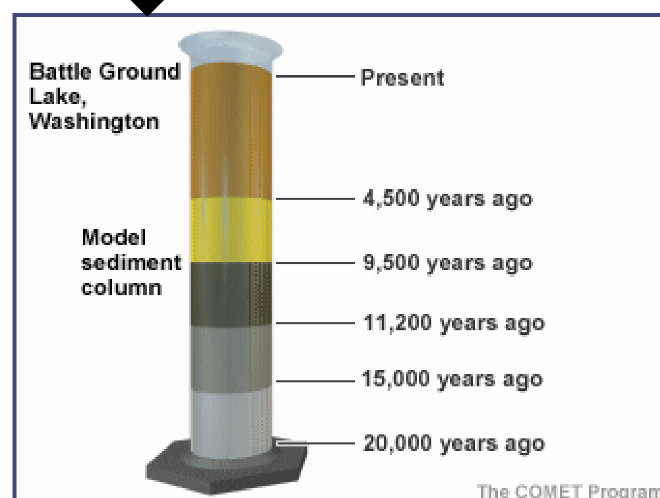


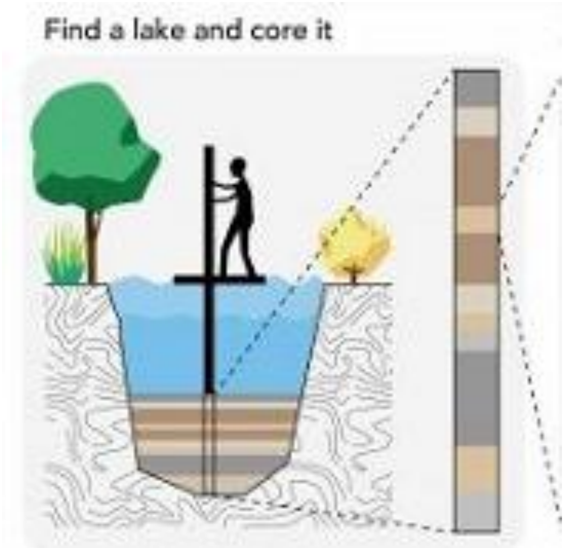
Fossil pollen is extracted from sediments



Cores

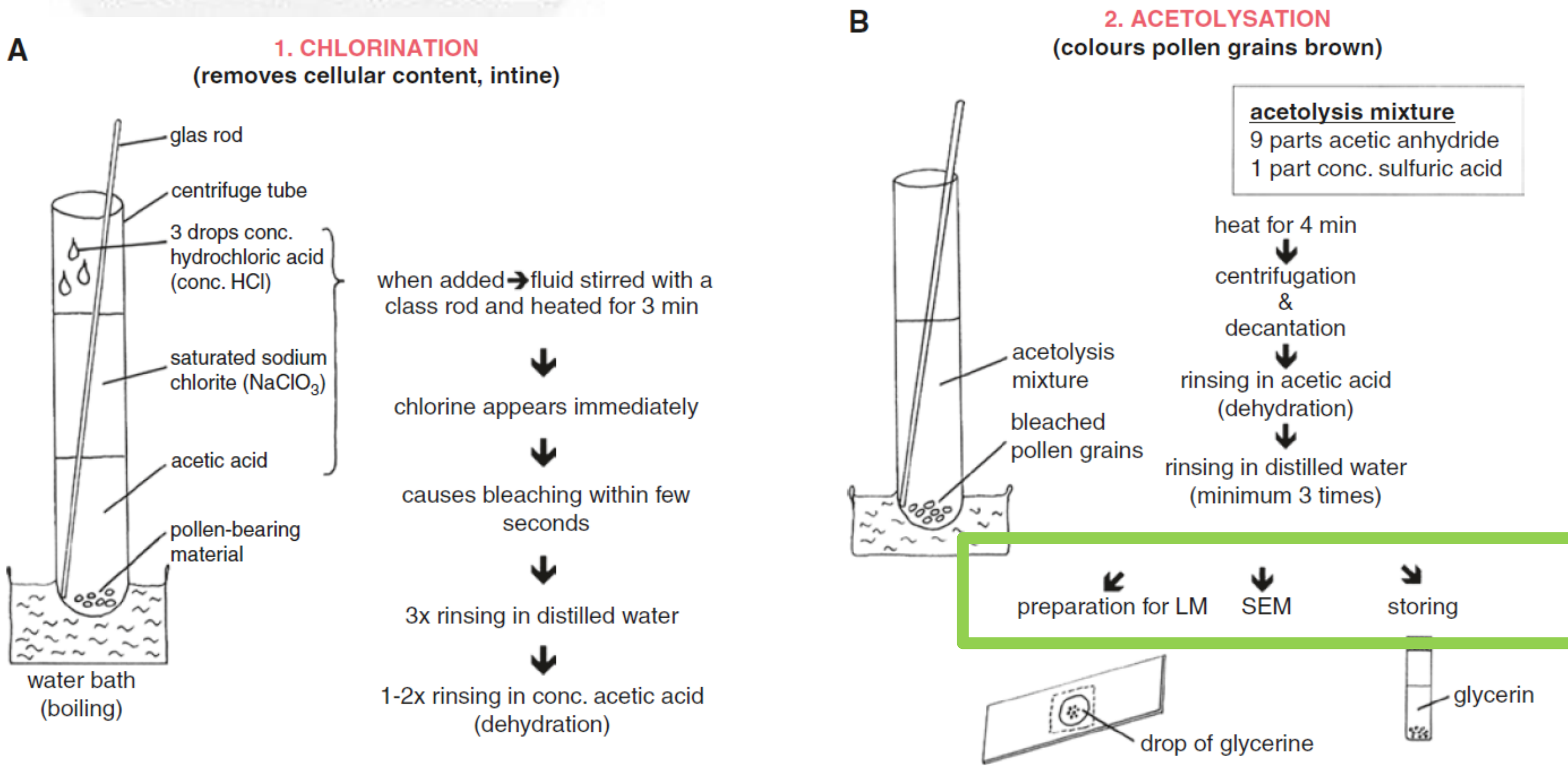
Dating



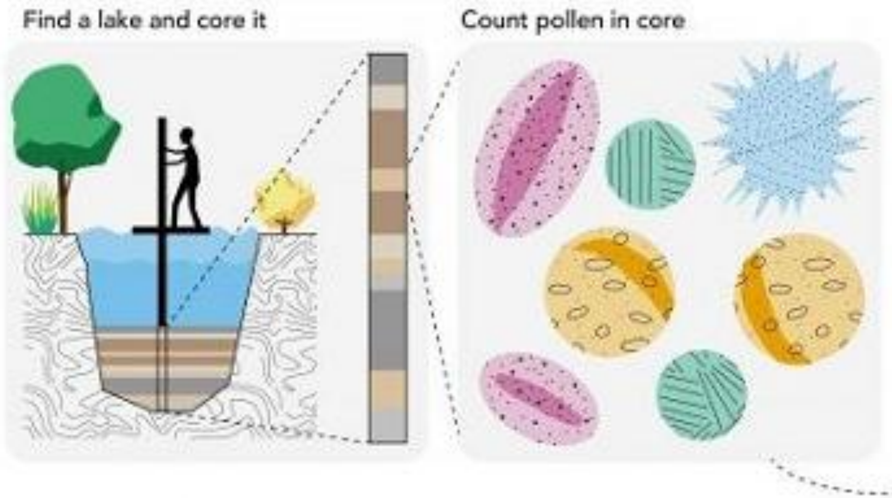


Preparation of fossil pollen: Acetolysation

Used to remove cellular content and intine while preserving and colouring exine and making more evident ornamentation (taxonomic character)

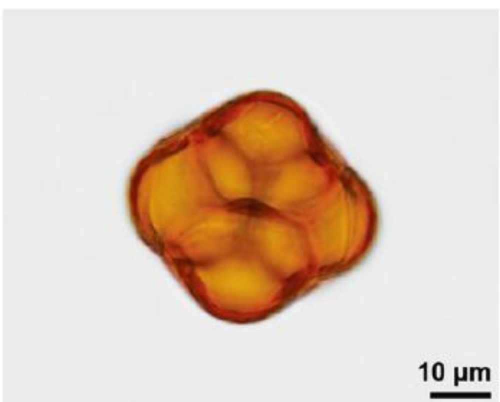


1+2 -> fossil pollen; **only 2** -> recent pollen



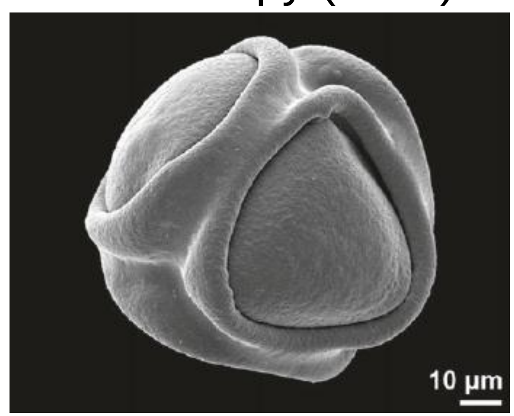
For each stratigraphic layer pollens are taxonomically determined and counted

Light microscopy



- Allows the comparison between hydrated and dehydrated pollen
- Provides information on endoapertures
- Only details at low magnifications

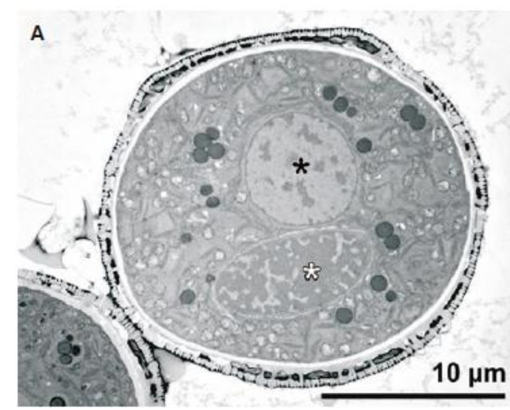
Scanning Electron Microscopy (SEM)



- Allows the observation of the ornamentation at high magnifications
- No insights on endoapertures

Only recent pollens

Transmission Electron Microscopy (TEM)



- Allows the observation of the pollen wall and cellular ultrastructure
- Very high magnifications

Pollen data from cores allow a time-resolved reconstruction of past vegetation

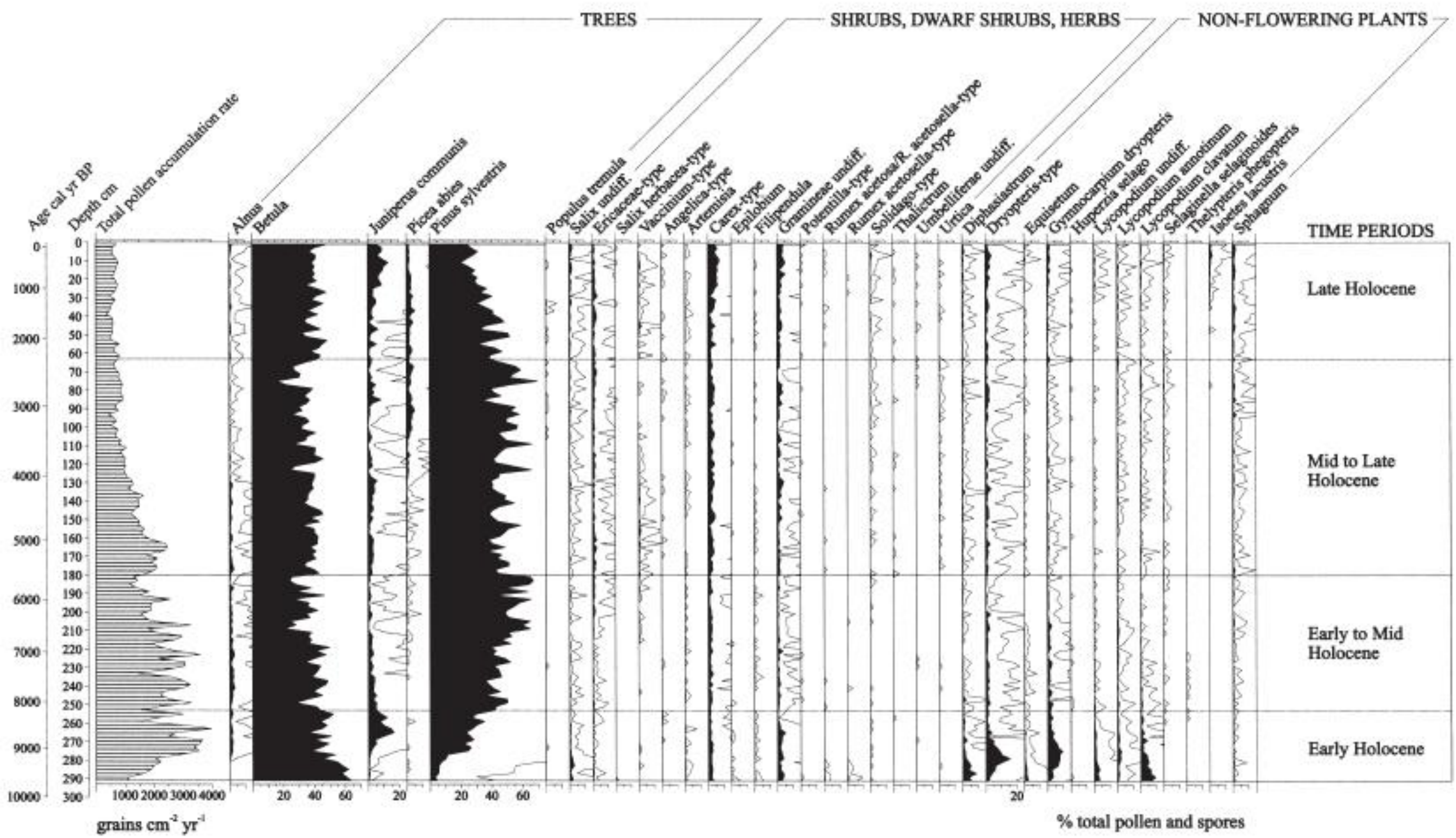
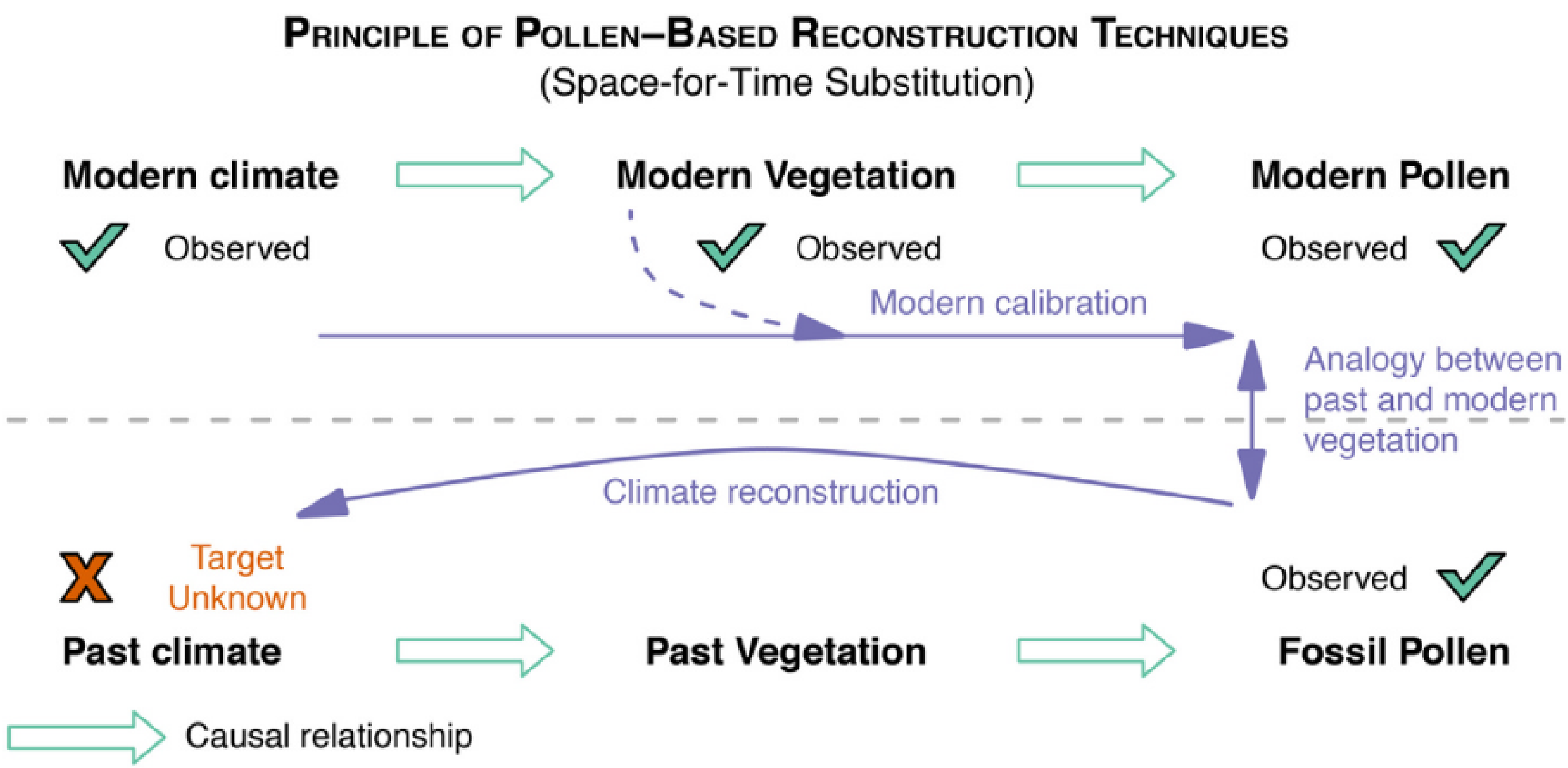


Figure 5 Summary pollen diagram from Tsuolbmajavri. The age scale in modelled calibrated years BP is shown along with the four phases discussed in the text. The total pollen- and spore-accumulation rate (grains·cm^{-2}·yr^{-1}) is also shown. The hollow silhoutte curves denote the 10 × exaggeration of the percentages.

Paleopalynology for past climate reconstruction

The uniformitarian principle

Most pollen-based climate reconstruction techniques aim at modelling/extracting the relationships between vegetation and climate from modern observations to reconstruct past climates, **under the assumption that the relationship between vegetation and climate has remained constant through time**



Assumptions for a reliable past climate reconstruction

1. **The taxa observed in both modern and past samples are systematically related to the climate in which they live.** This assumption assumes approximate dynamic equilibrium between the observed pollen assemblage and climate.

2. **The climate variables to be reconstructed are important determinants, or systematically related to important determinants of the vegetation and the associated pollen**. This assumption assumes that the relationship has remained stable throughout the record (i.e. the uniformitarian principle).

3. **Unstudied environmental variables have had a minor influence on the fossil data** over the studied period of time and at the spatial scale of the pollen record, **or their relationship with the variable of interest remained the same as in the calibration dataset**.

Assumptions for a reliable past climate reconstruction

4. **The taxa in the modern calibration dataset are the same biological entities as in the fossil data**, and their ecological responses have not changed over the studied period of time (**uniformitarian principle**).

5. The specified mathematical model has sufficient flexibility to represent the complexity of the ecological responses to the climate variables of interest.

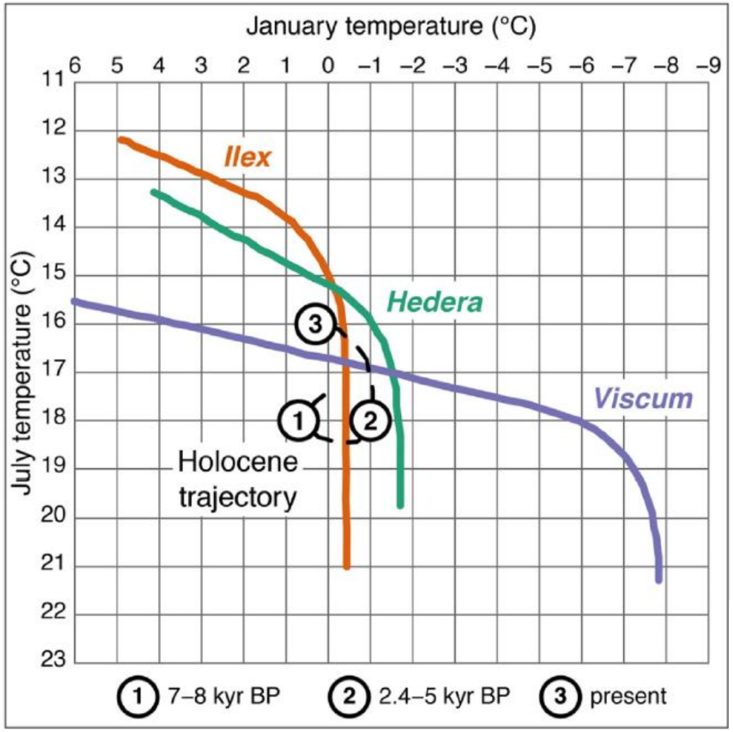


Fig. 2. Classic figure by Iversen (1944) representing the thermal niches of *Viscum*, *Hedera* and *Ilex* and how the combination of their presence (below their respective curve) or absence (above and to the right of their respective curve) in modern environments could be used to estimate past temperatures for the 'Atlantic' (1: 7–8 ka BP), 'Sub-Boreal' (2: 2.4–5 ka BP) and modern (3) phases of the Holocene.

A good comprehension of **the processes that govern the composition of pollen assemblages and their relationship with climate and the environment** is necessary

Pollen grains are produced in all environments where spermatophytes (*i.e.* seed-bearing plants) grow.

Each plant species adopts specific production and dispersal strategies, which can influence the representation and abundance of taxa in fossil pollen records.

Wind pollinated plants generally produce high amounts of pollen

Pinus sp.

vs

Populus sp.

Larix sp.

It can dominate the pollen assemblage even if it they are not the prominent species

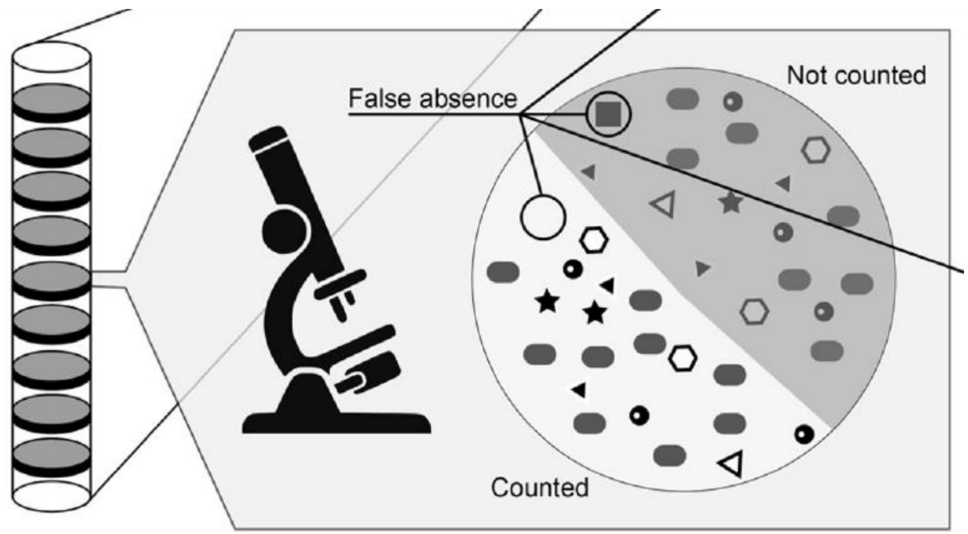
They can be under-represented even if they are prominent in their environment

Contrary to plant macroremains that can generally only be used as presence/absence data, pollen grains are much more abundant in sediments and can be used to derive relative proportions of pollen taxa (eg. % of x taxon on the total pollen counted), which enables more refined statistical inferences about past climates.

The reliability of these percentages directly depends also on the number of counted pollen grains being counted

↓

The optimal number of grains depends on the research aim, AIM of the study



Over representative taxa **might mask** the signal of rare but climatically informative taxa

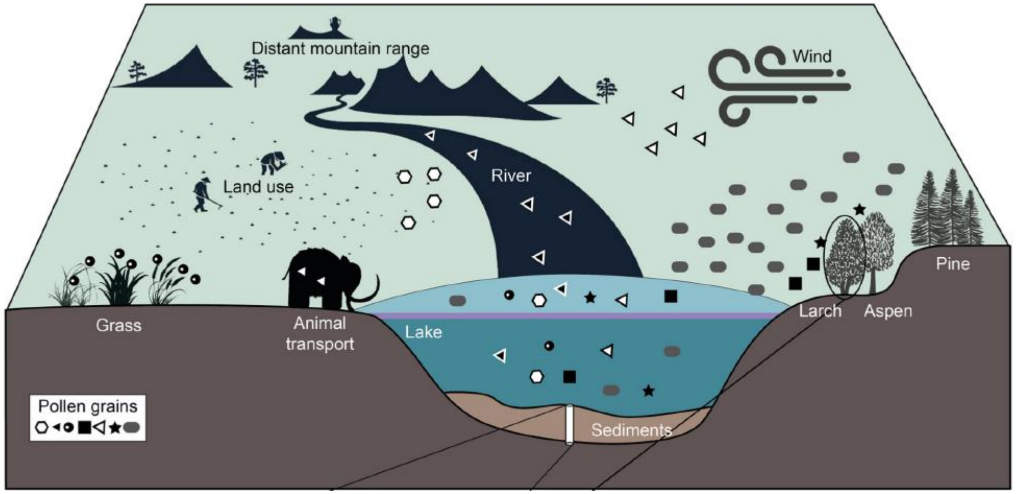
Counting 300 – 500 pollens is a good number but not always possible depending in certain environments or sediment types due to preservation or other taphonomic issues

Representativeness of a pollen sample

A pollen assemblage is not a direct measure of local vegetation composition, as many biological, climatic and environmental processes influence the production, dispersal and preservation of pollen grains

Pollen grains are transported by:

- Wind (mixes pollens)
- Streams and rivers
- Animals (foraging signal, rare)



Pollen assemblages thus represent a mix of locally and remotely produced pollen grains whose chances of being observed decrease with increasing distance of the plant source to the sampling location

The relative proportion of local and distant taxa is related to the catchment characteristics of the studied archive (site were pollen-containing cores are sampled).

The environmental setting of a pollen archive can strongly influence the scale of climatic inferences that can be derived from a pollen record because…

Usually contain a stronger local signal (small pollen source area)

Act as regional integrators of pollen sources potentially very far

extreme endmembers of local vs regional pollen ratios as most of the pollen in these archives is not produced locally

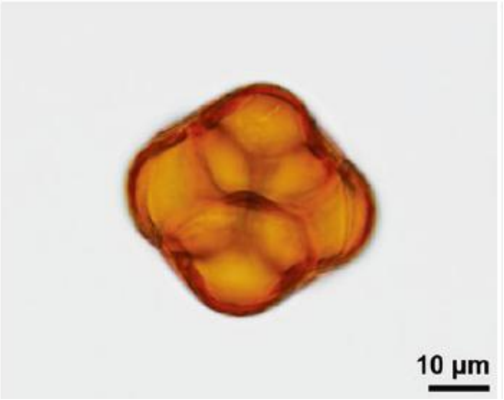
When possible, characterizing the source archive and the likely area represented by pollen assemblages is important to defining the type and scale of climate inferences that can be drawn from a fossil pollen record

Environments with low pollen productivity can also be highly influenced by remote pollen producers

High arctic tundra

In such cases, **separating local from extra-local taxa can reduce the noise** of the pollen data **and improve the local climate signal**

Taxonomic resolution



Pollen grains are rarely identifiable to the species level using light microscopy

Increasing the taxonomic resolution of pollen analyses is useful for paleoecological studies, especially in hotspots of botanical diversity where tens to hundreds of plant species with different climatic/ecological niches produce indistinguishable pollen grains (e.g. in Amazonia)

However, most reconstruction techniques use large compilations of modern pollen samples to estimate the relationship between pollen and climate
-> taxonomic improvements cannot be back-propagated to the existing compilations of modern pollen sample -> records with higher taxonomic resolution needs to be simplified or new compilations need to be produced

Human impact

Most terrestrial environments are or have been influenced to some extent by humans.

Human activities (*e.g.* deforestation or agriculture) modify vegetation structure, composition and diversity (*e.g.* replacement of a forested area by a field), which can obscure the observed relationships between pollen and climate

Note: <u>climate reconstruction inferences are based on the relative abundances of pollens in the fossil records as compared to modern ones</u>

The impact of human activity (e.g. land-use) on the pollen-climate relationship is expected but it is difficult to quantify

However, many reconstructions from such regions have been supported by non-botanical palaeoclimate proxies, indicating that modern climate reconstruction methods can – to some extent – cope with human impact

An example of quantification of human impact effect…

PLOS | ONE

RESEARCH ARTICLE

The Bias and Signal Attenuation Present in Conventional Pollen-Based Climate Reconstructions as Assessed by Early Climate Data from Minnesota, USA

Jeannine-Marie St. Jacques[1]*, Brian F. Cumming[2], David J. Sauchyn[1], John P. Smol[2]

In the American Midwest, **logging**, **fire suppression**, **deforestation** and **agriculture** have **greatly changed vegetation composition and the composition of its pollen rain** since Euro- American settlement in **the mid-1800s**

Minnesota is uniquely rich in **<u>early climate stations</u>** (instrumental recordings) from military forts which **predate** large-scale Euro-American settlement, allowing a rare opportunity to test whether or not the pollen-climate relationship is stationary in time, as has generally been assumed.

Fort Snelling (Minnesota)

An example of quantification of human impact effect…

To assess the significance of low-frequency signal distortion and bias introduced by human settlements

The climate reconstruction based on the modern pollen set was compared to the one obtained using an early post-settlement calibration set **for which instrumental data were available thanks to the recordings of the military fort**

The conventional inference method, based on modern pollen set, **produced significant low-frequency (centennial-scale) signal attenuation** and **positive bias** in the temperature pattern reconstruction of **0.8-1.7°C**

⬇

Considering that the analysis involved a back propagation of the bias in the time frame covered by the sediment analyzed (back to 1116 AD)

⬇

Little Ice Age (1300 – 1850 AD) **temperature was overestimated** and likely the extent and rate of anthropogenic warming in this region was underestimated.

Climate variable(s) that can be reconstructed from a fossil record

Plant growth, survival and reproduction and ultimately the presence/abundance or absence of plant species at a site are determined by a broad range of bioclimatic variables, such as:

- Min and Max temperatures
- Number of growing degree and frost days
- Length of the dry period or seasonality of rainfall and/or temperature

Correlated to ↓ ↑ **Proxies of**

Climate variables:
Temperature and **precipitation**
(monthly, seasonal, annual, etc.)

→

Provide common scales with other biotic and abiotic paleoclimatic sensors (e.g. isotope, other biomarkers)

↓

Improve comparability among palaeoclimate datasets, instrumental data, and climate model simulations

Palaeogeography, Palaeoclimatology, Palaeoecology 425 (2015) 14–40

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Late Miocene vegetation dynamics under monsoonal climate in southwestern China

Shu-Feng Li [a,b], Li-Mi Mao [d], Robert A. Spicer [e], Julie Lebreton-Anberrée [a,b], Tao Su [a], Mei Sun [a,b], Zhe-Kun Zhou [a,c,*]

mean annual temperature (**MAT**), maximum temperature of warmest month (**MTWM**), minimum temperature of coldest month (**MTCM**), mean temperature of wettest quarter (**MTWETQ**), mean temperature of driest quarter (**MTDRYQ**), mean temperature of warmest quarter (**MTWQ**), mean temperature of coldest quarter (**MTCQ**), mean annual precipitation (**MAP**), precipitation of wettest month (**PWETM**), precipitation of driest month (**PDRYM**), precipitation of wettest quarter (**PWETQ**), precipitation of driest quarter (PDRYQ), precipitation of warmest quarter (**PWQ**), and precipitation of coldest quarter (**PCQ**).

Climatic parameter	Wenshan	
	Late Miocene	Modern
MAT (°C)	16.6–17.5	18.1
MTWM (°C)	27.5–29.7	27.2
MTCM (°C)	2.4–5.5	6.5
MTWETQ (°C)	20.9–21.3	23
MTDRYQ (°C)	9.3–11.6	11.6
MTWQ (°C)	22.6–22.7	23
MTCQ (°C)	7.5–10.3	11.6
MAP (mm)	1432.3–1598.9	1038
PWETM (mm)	228.7–266	205
PDRYM (mm)	21.7–48.1	12
PWETQ (mm)	608.3–729.9	551.3
PDRYQ (mm)	76.1–178.9	45
PWQ (mm)	515.5–721.4	551.3
PCQ (mm)	89.5–192.6	45
MSI	11.3.–17.1	18.6

Each paleofossil represents an entity or group of entities that has specific climate and environmental requirements (**environmental niche concept**).

↓

For paleofossils, climate requirements are derived from ecology of the same species or from that of the Nearest Living Relative

↓

The zone of **climatic-profile-overlap** which covers the most of fossil pollen taxa defines the most likely climate space for palaeoflora

Final consideration on the method

One consequence of Assumptions 2 and 3 is also that reconstructing climate is not always possible when **non-climatic factors** leave a stronger impact on the pollen assemblages than climate itself, e.g. **sea-level changes** at a coastal site that change the vegetation composition, **land use**, **levels of CO_2** as low [CO_2] increases the water use of plants.

The techniques to reconstruct climate will always provide estimates of the climatic variables and they do not identify those that drove the observed ecological changes

Performance indexes related to the techniques used, e.g. **spread of uncertainties associated with the fitted reconstruction model** can identify whether a variable is a poor predictor of the pollen data

Issue of covariate variables as they can be a source of bias if the relation is non-analogous between past and present (e.g. present vs past January and July T)

A last case study: alternative natural archive

Geophysical Research Letters

RESEARCH LETTER

10.1029/2018GL080832

Vegetation and Climate Change in Southwestern Australia During the Last Glacial Maximum

J. M. K. Sniderman[1], J. Hellstrom[1], J. D. Woodhead[1], R. N. Drysdale[2], P. Bajo[1,2], M. Archer[3], and L. Hatcher[4,5]

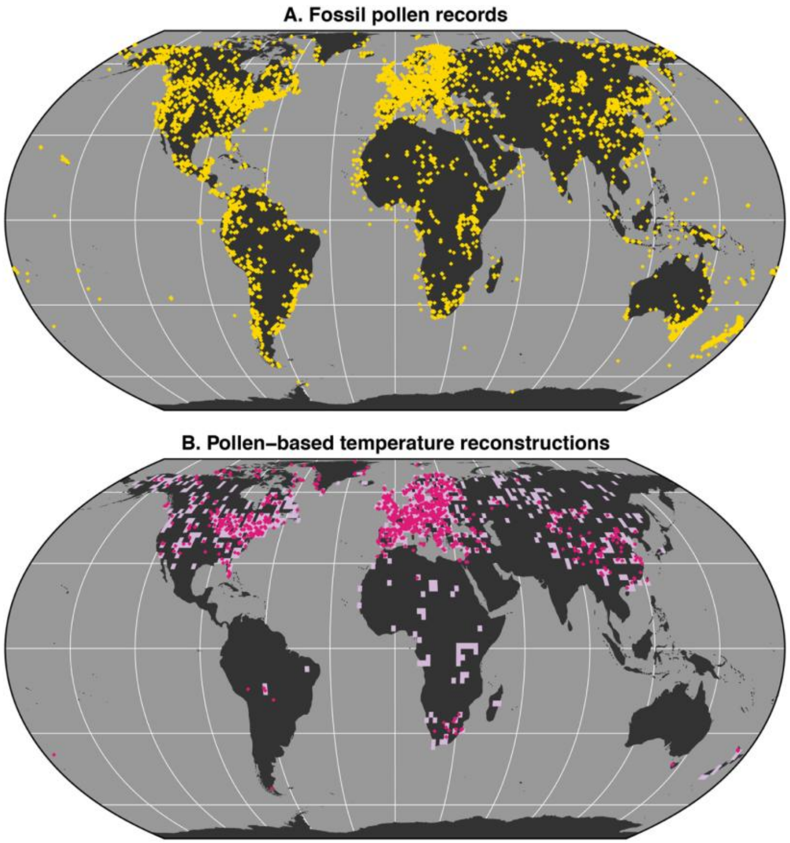
[1]School of Earth Sciences, University of Melbourne, Melbourne, Victoria, Australia, [2]School of Geography, University of Melbourne, Melbourne, Victoria, Australia, [3]School of Biological, Earth and Environmental Sciences, University of New South Wales, Kensington, New South Wales, Australia, [4]CaveWorks, Margaret River, Western Australia, Australia, [5]Deceased 30 October 2017

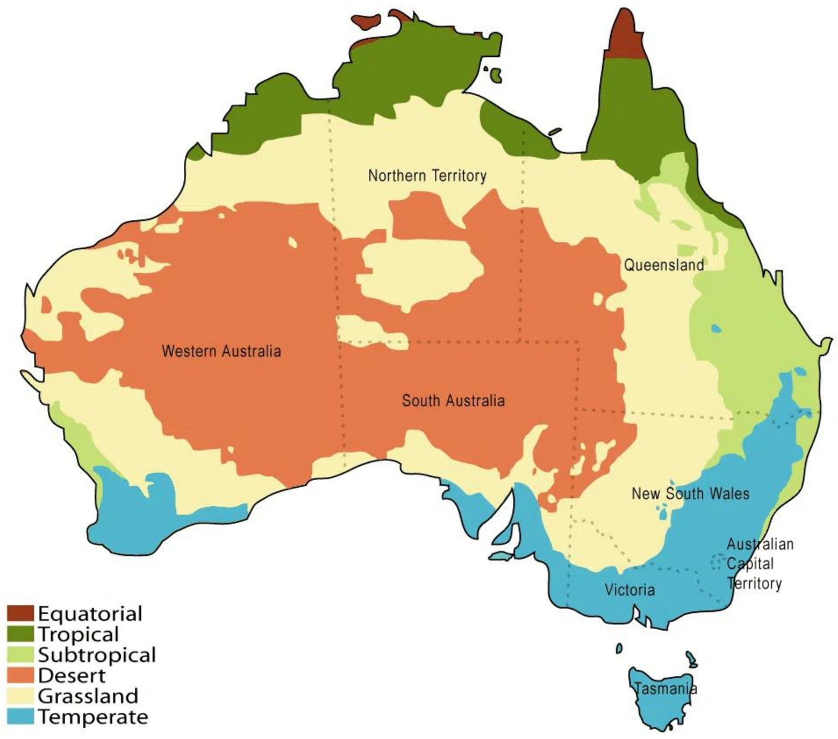
Key Points:

- U-Th dated speleothem palynology illustrates the timing and duration of the Last Glacial Maximum (LGM) in Western Australia
- Between 28 and 18 ka, the forested far southwest of Western Australia was essentially a treeless shrubland
- The pattern of LGM climate change is coherent with records from other

Aim: describe the vegetation change during the Last Glacial Maximum (**between 28 and 18 ka BP**) and to verify if the climatic conditions caused a synchronized vegetational change in the southern hemisphere

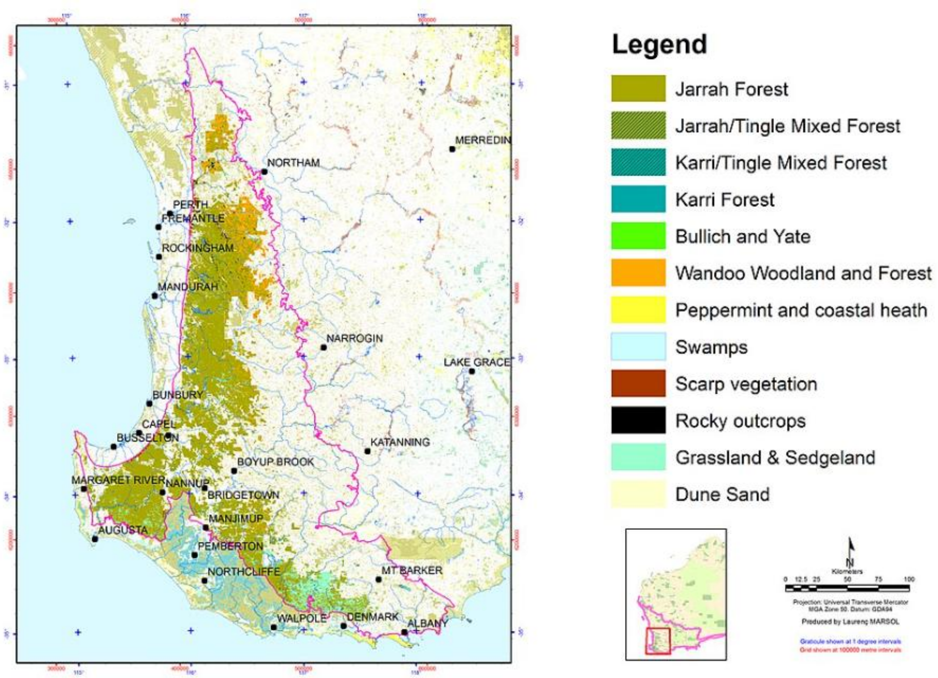
A continent with pollen records limited to specific bioclimatic regions





Problem: archives that do not allow a vegetational reconstruction so far in the past


Arafura
Port Moresby
Mar di Timor
TERRITORIO DEL NORD
QUEENSLAND
Mar dei Corall
Australia
AUSTRALIA OCCIDENTALE
Brisbane
AUSTRALIA MERIDIONALE
NUOVO GALLES DEL SUD
Mammoth Cave
Adelaide
Grande Baia Australiana
TERRITORIO DELLA CAPITALE AUSTRALIANA
VICTORIA


Legend
Jarrah Forest
Jarrah/Tingle Mixed Forest
Karri/Tingle Mixed Forest
Karri Forest
Bullich and Yate
Wandoo Woodland and Forest
Peppermint and coastal heath
Swamps
Scarp vegetation
Rocky outcrops
Grassland & Sedgeland
Dune Sand
MERREDIN
NORTHAM
PERTH
FREMANTLE
ROCKINGHAM
MANDURAH
NARROGIN
LAKE GRACE
BUNBURY
CAPEL
BUSSELTON
KATANNING
BOYUP BROOK
MARGARET RIVER
NANNUP
BRIDGETOWN
MANJIMUP
AUGUSTA
PEMBERTON
NORTHCLIFFE
MT BARKER
WALPOLE
DENMARK
ALBANY
Produced by Laurenç MARSOL

Stalagmite sampling

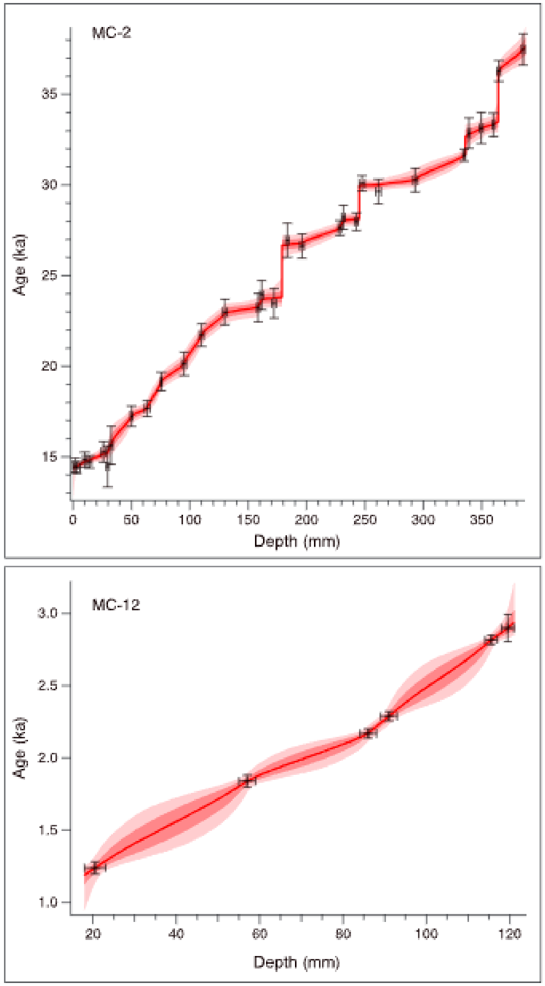


Figure 1. Age-depth models for stalagmites MC-2 and MC-12, from Mammoth Cave, derived from U-Th ages (Table S2) following Hendy et al. (2012). Individual age determinations shown with 2σ uncertainties. Median value of the age model (red line) is shown with one (dark pink) and two (light pink) standard deviations.

Dating: U/Th geochemical analysis -> 1 mm of Stalagmite depth = c. 60 years

Pollen recovery and treatment: pieces of stalagmite were taken along trough the depth of the stalagmite and dissolved in pure HCl

Vegetational reconstruction

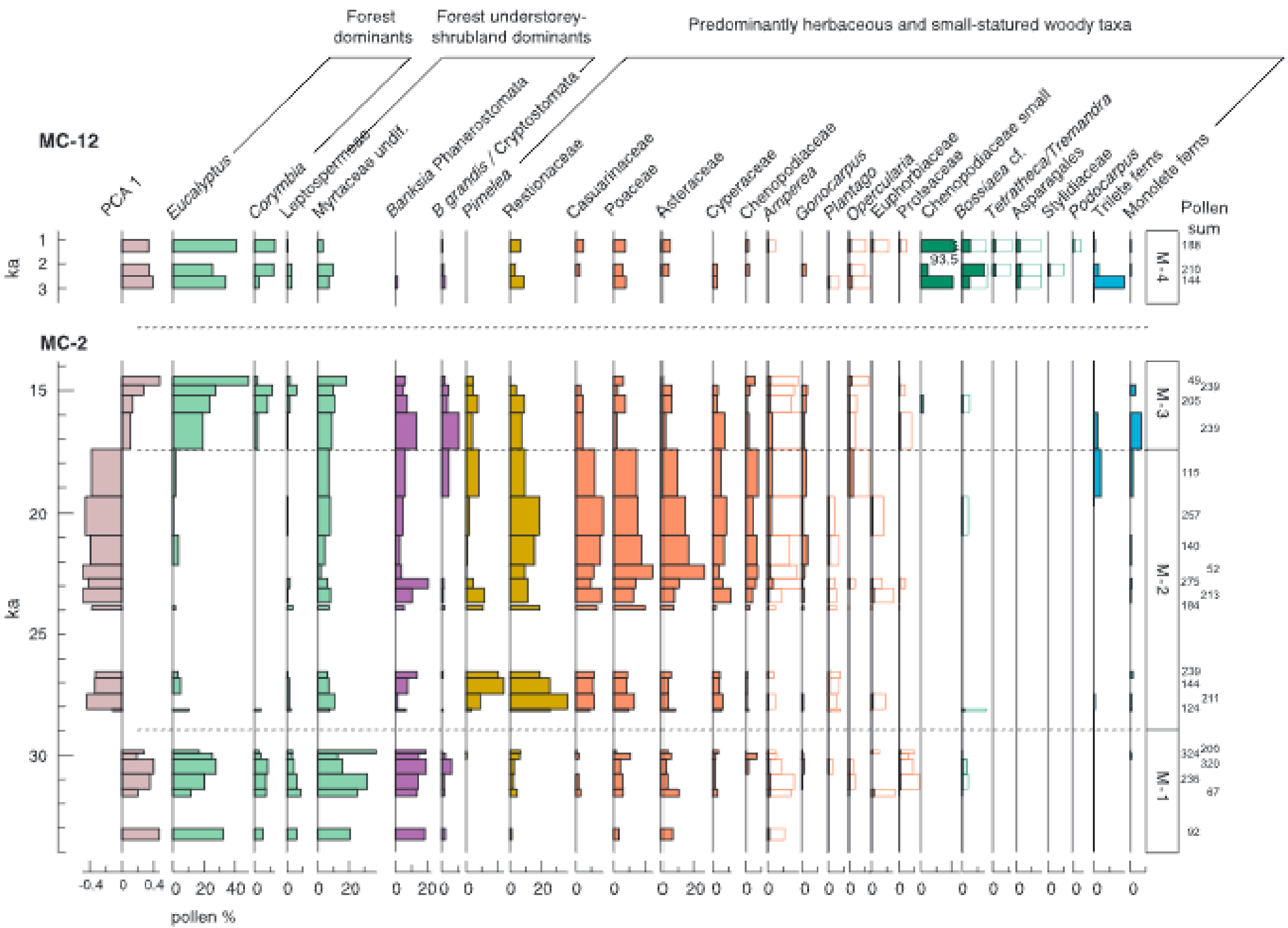


Figure 2. Mammoth cave pollen percentage record derived from MC-2 and MC-12. *Banksia* is separated into two morphologically distinct groups (Sniderman et al., 2016), small sized grains with affinity to subgenus Phanerostomata, and large grains with affinity to *B. grandis* (Phanerostomata) or subgenus Cryptostomata (Mast & Givnish, 2002).

Main conclusions

«Our pollen record, **supported by 30 U-Th dates**, reveals the vegetation response to Late Pleistocene climatesbetween ~34 and 14 ka, through the body of the LGM. Before ~28 ka, sclerophyll forests were more open than today, but **at ~28 ka forest cover was essentially eliminated, and treeless conditions were maintained until progressive reforestation at ~17.5 ka**. This ~10-ka-long full glacial episode correlates with other mid-high latitude Southern Hemisphere records, suggesting that LGM environmental changes were closely coordinated across the hemisphere»