Climate System II

(Winter 2023/2024)

7th lecture:

Archives of climate change

(marine sediments, corals, speleothems, pollen, tree rings)

Gerrit Lohmann, Martin Werner

Tuesday, 10:15-11:45

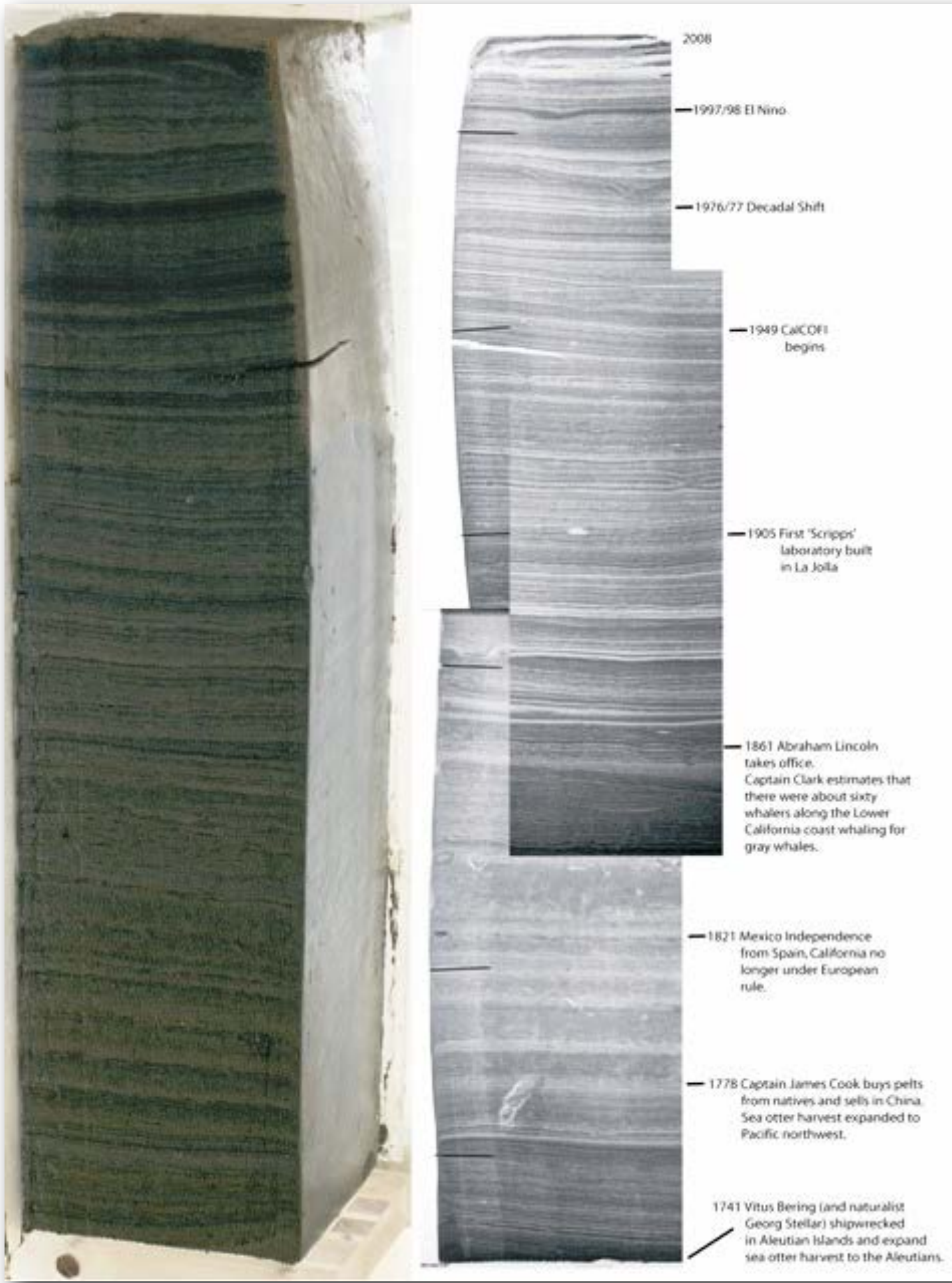
https://paleodyn.uni-bremen.de/study/climate2023_24.html

Key climate archives

Many different climate archives exist on Earth.
Each archive has its strength and weaknesses.
Using them all together enables us to better understand past climate changes in terms of timing, extend, causes and consequences.

- **ice cores** *(lecture #2)*
- **marine sediment cores**
- **corals**
- **speleothems**
- **tree rings**
- **pollen**
- **…**

Marine sediment cores

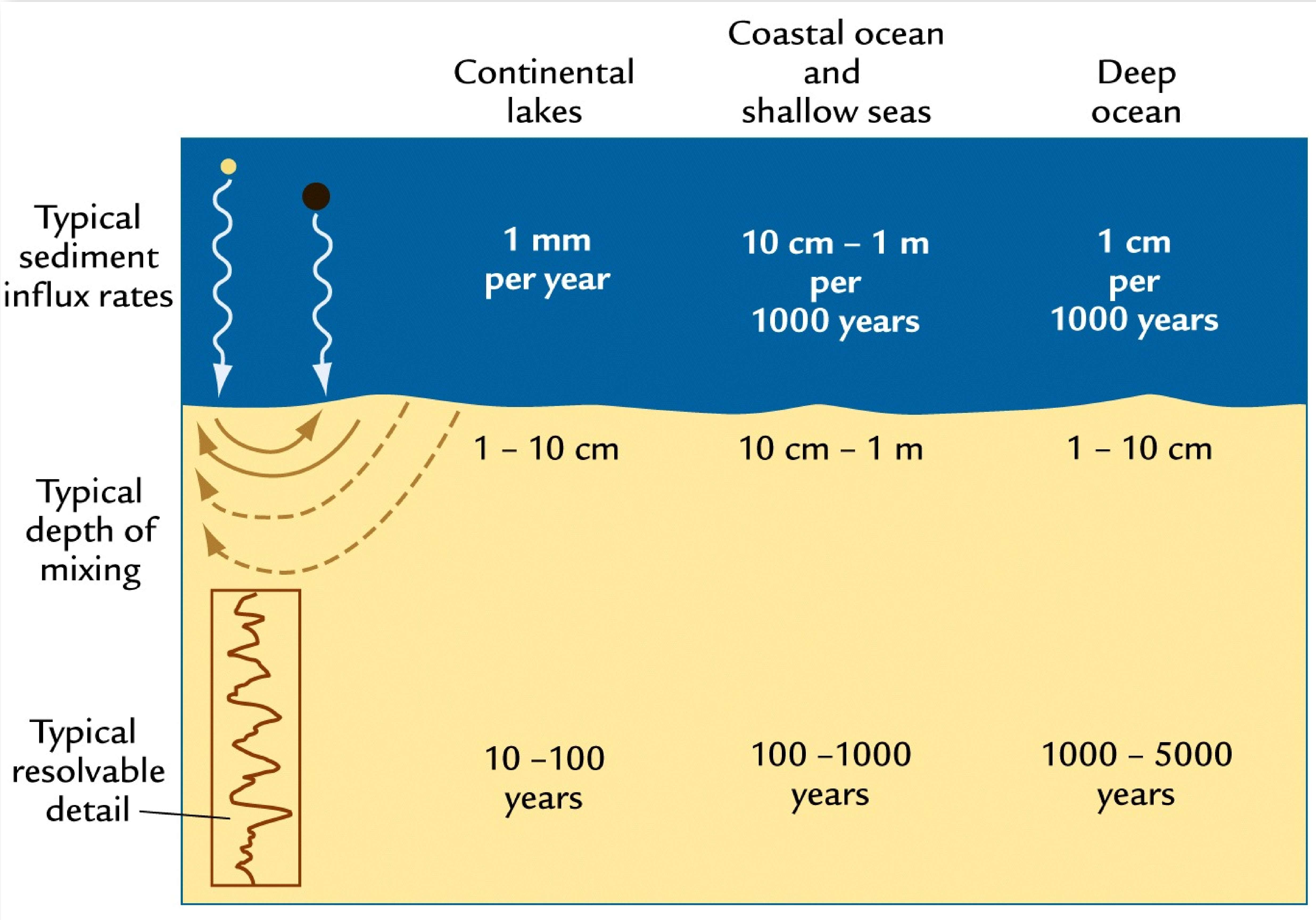


[http://www.hpu.edu/CNCS/Faculty_Staff/CV/DavidFieldCV.html]

1: Japan Sea (color alternation)
2: Japan Sea (laminated sediments)
3: East China Sea (deep sea sediments)
4: Arabian Sea (calcareous ooze)
5: Arabian Sea (calcareous ooze)
6: Sulu Sea (calcareous ooze)
7: Southern Ocean (diatom ooze)

These cores were recovered during cruises by the R/V Hakuho-Maru, Ocean Research Institute, University of Tokyo

Formation of marine sediments



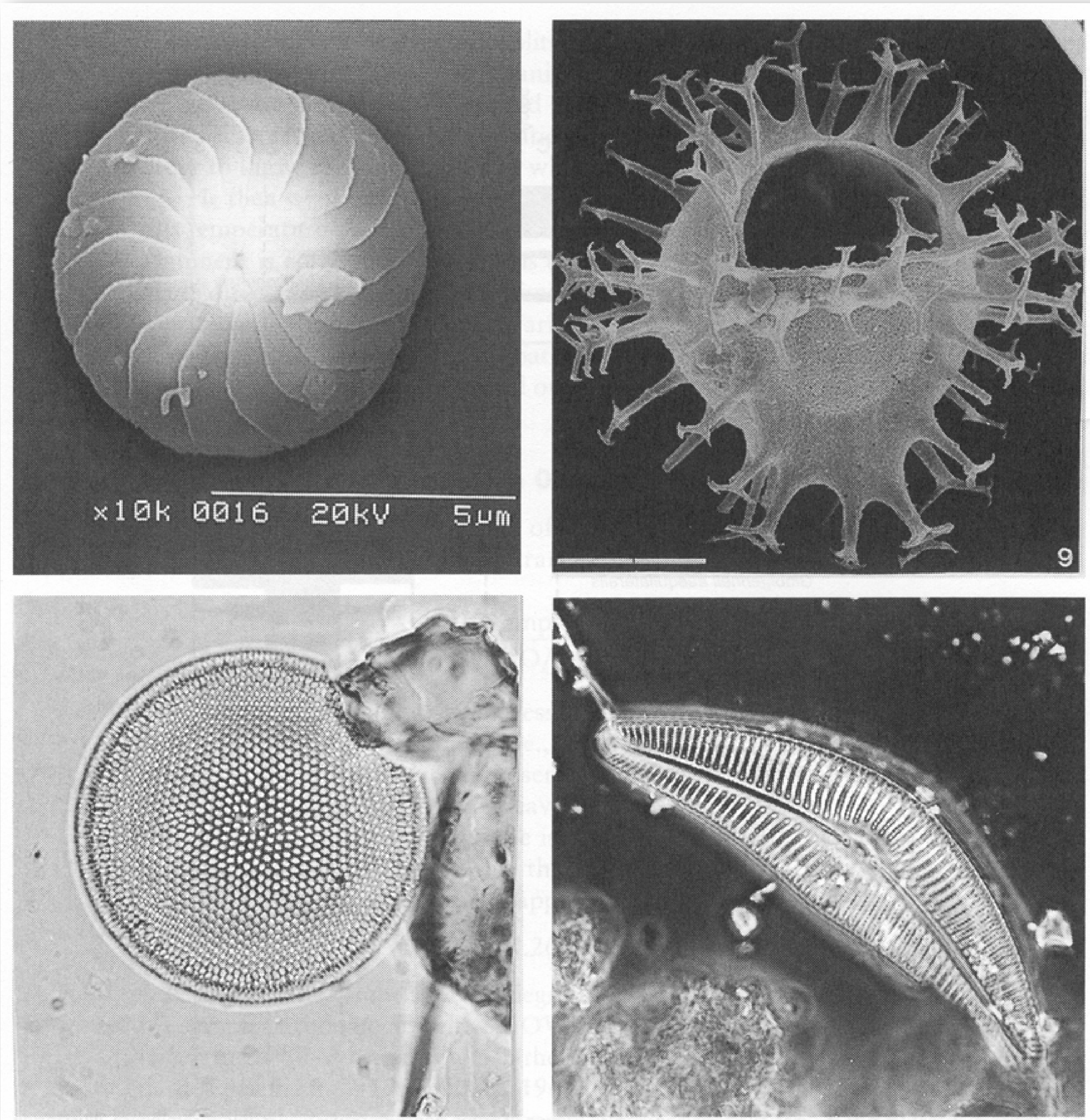
www.atmo.dal.ca/~lohmann/clch/Lecture9.ppt

Formation of marine sediments

- 70% of Earth‘s surface is covered by oceans
- yearly sediment production: approx. 6-11 billion tons (=10^{12}kg)
- sediment contains both biogenic and terrigenous material
- biogenic material:
    - planktic organism = live near the sea surface
    - benthic organism = live near the sea floor
    - biogenic material may be used as a proxy for
        - *water temperatures (surface waters, deep sea waters)*
        - *salinity*
        - *dissolved oxygen, trace substances, etc.*
- terrigenous material
    - is transported from land surfaces to the oceans by the wind
    - can be used as a proxy for aridity and/or changes in wind strength/wind directions

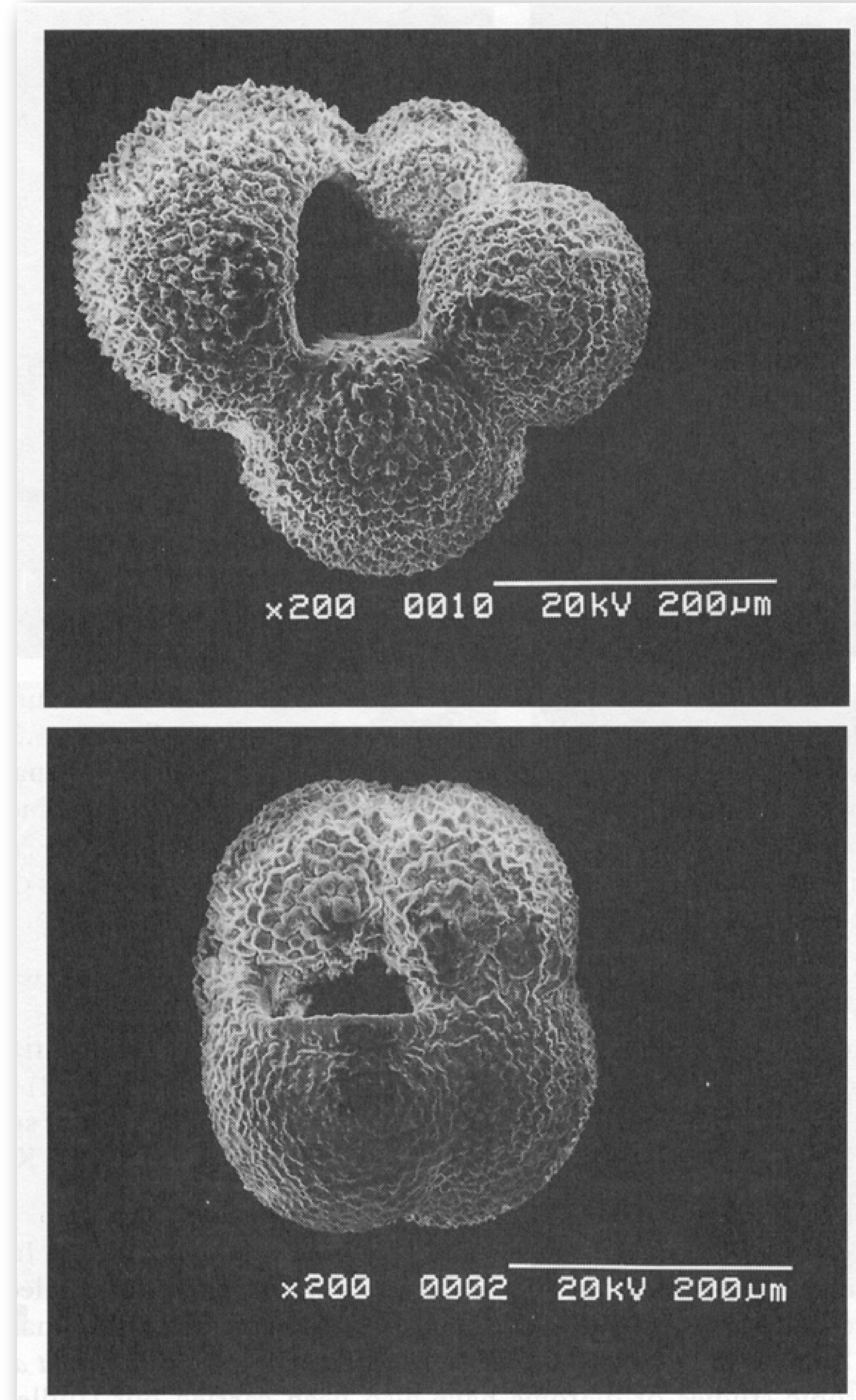
Formation of marine sediments

Coccolithophors
(Phytoplankton)



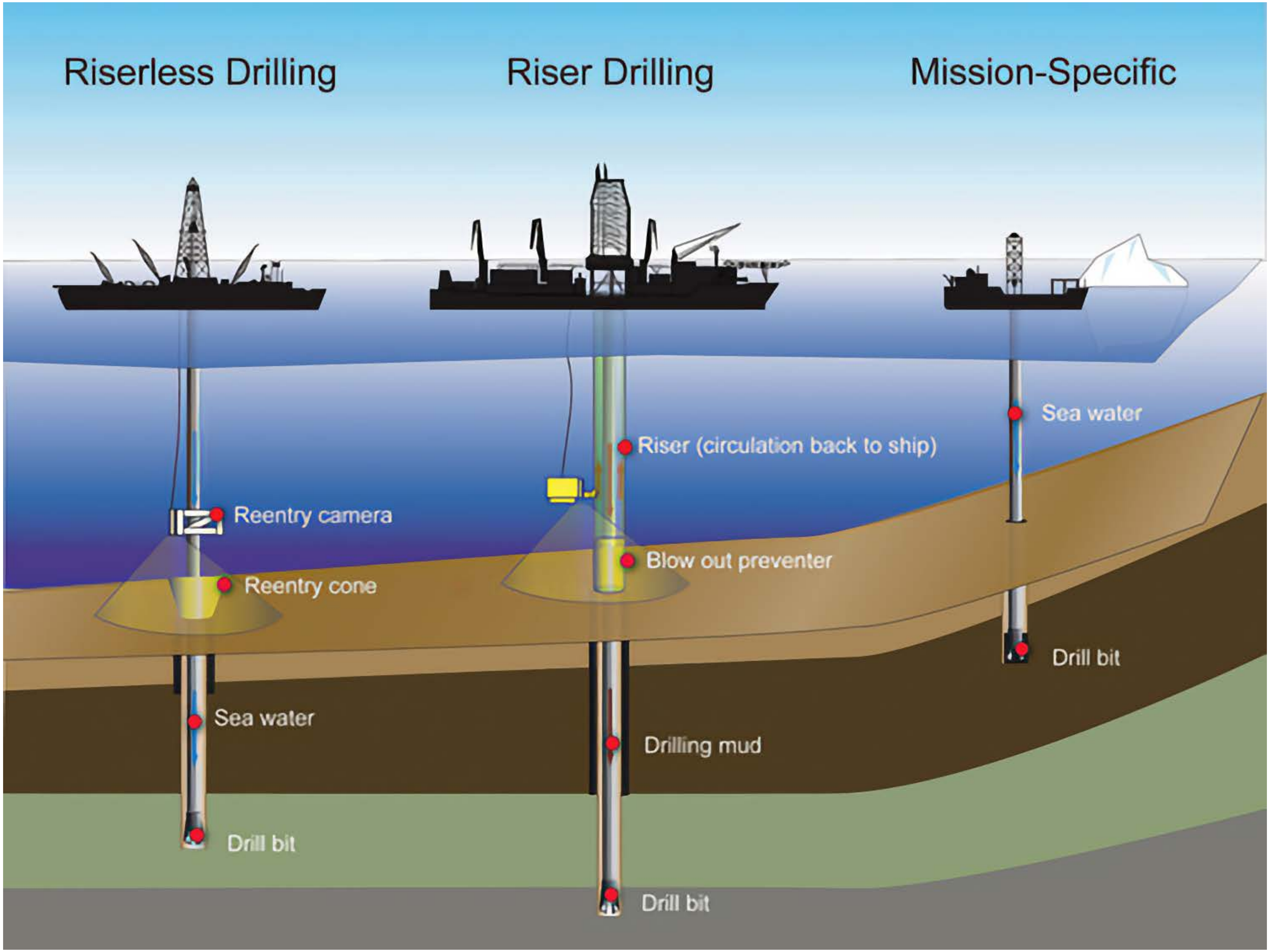
Bradley, Abb. 6.5

Foraminifers
(Zooplankton)



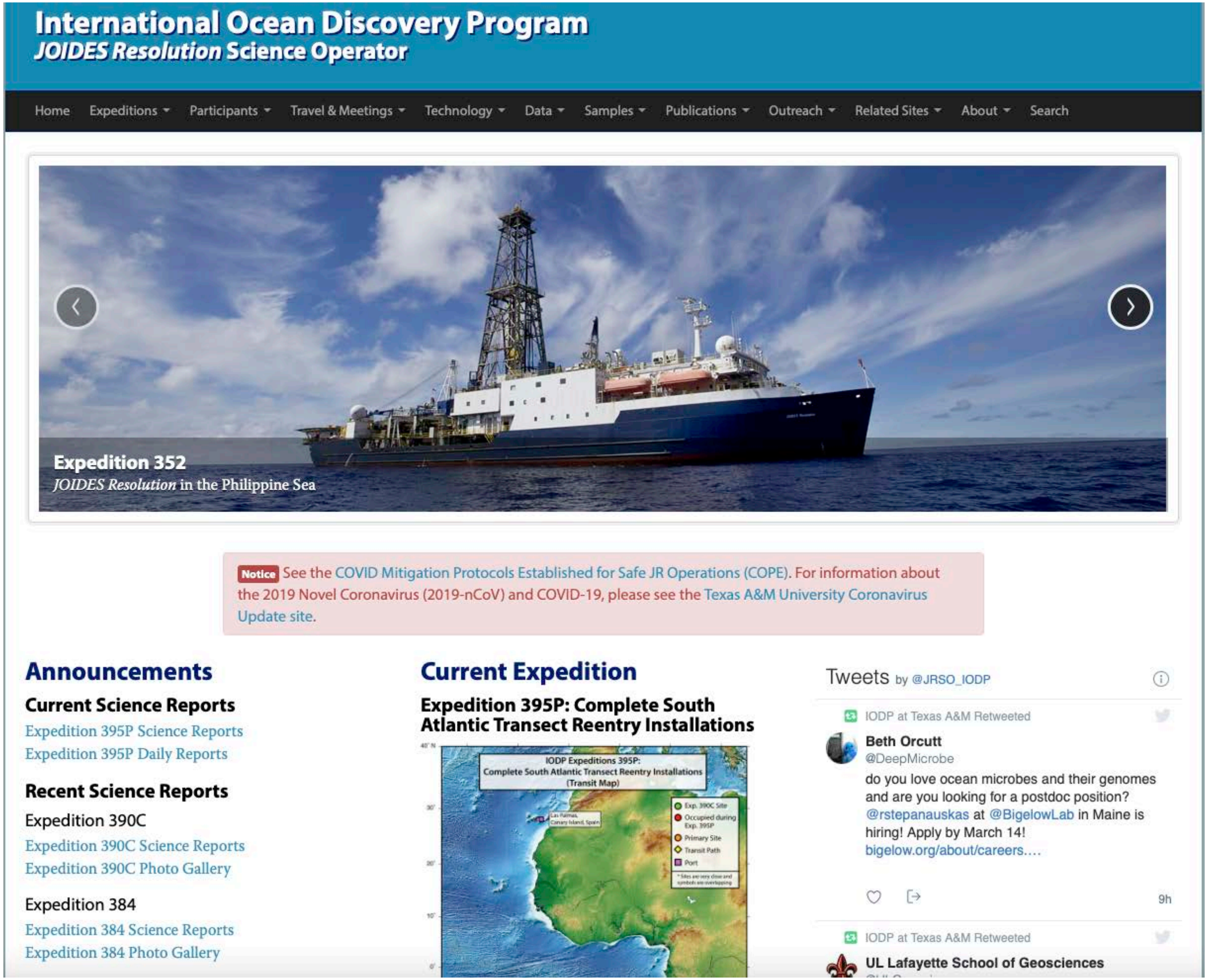
Bradley, Abb. 6.3

Drilling of marine sediment cores



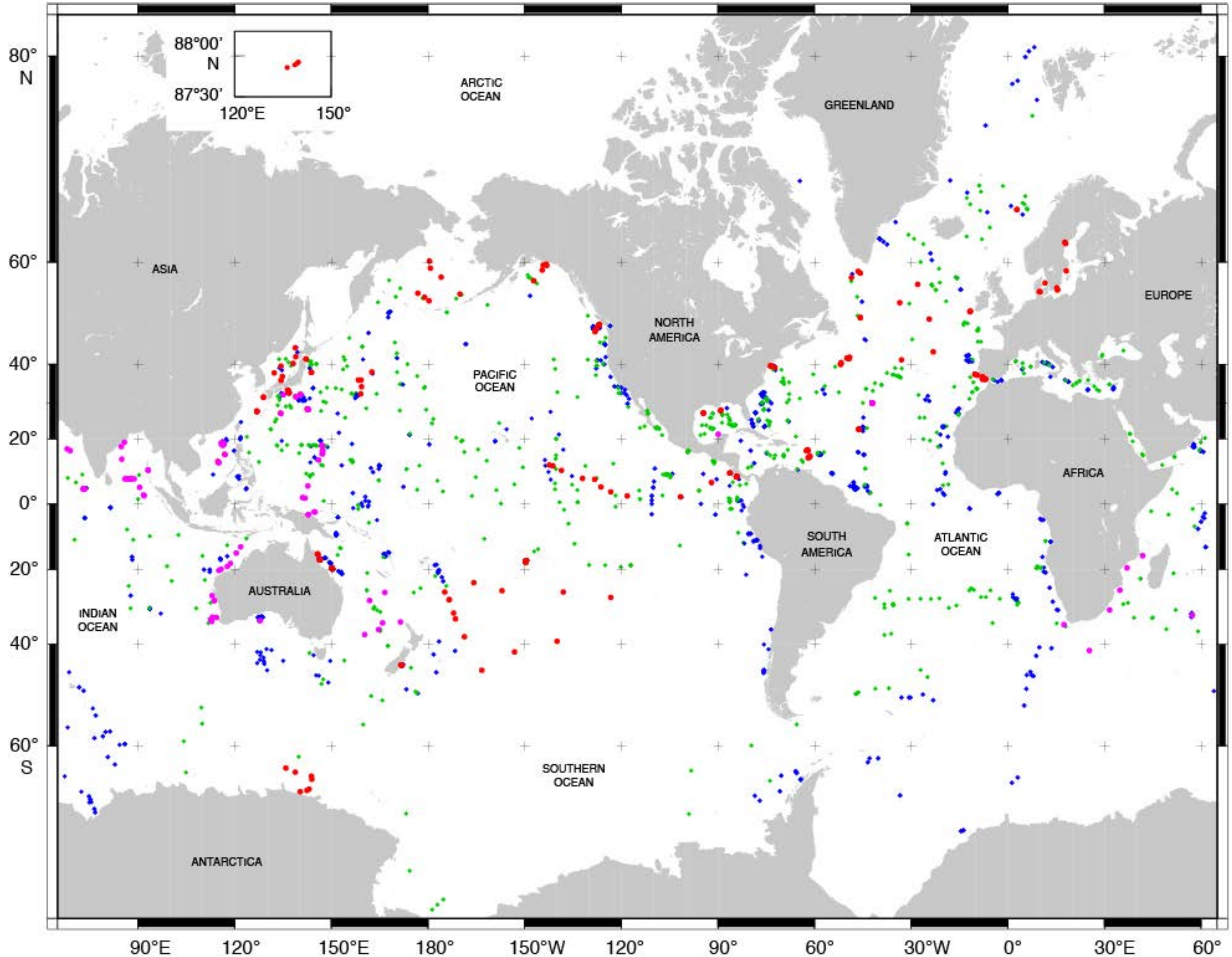
https://www.iodp.org/iodp/expeditions/page-2

The International Ocean Discovery Programme (IOPD)



http://iodp.tamu.edu/index.html

Drill sites of international drilling programs



DSDP Legs 1–96 (●), ODP Legs 100–210 (●), IODP Expeditions 301–348 (●), IODP Expeditions 349–371 (●)

Storage of marine sediment cores

IODP
INTERNATIONAL OCEAN DISCOVERY PROGRAM

IODP at MARUM ▪ IODP Bremen Core Repository

IODP Bremen Core Repository

MARUM - University of Bremen
Leobener Strasse 8
28359 Bremen

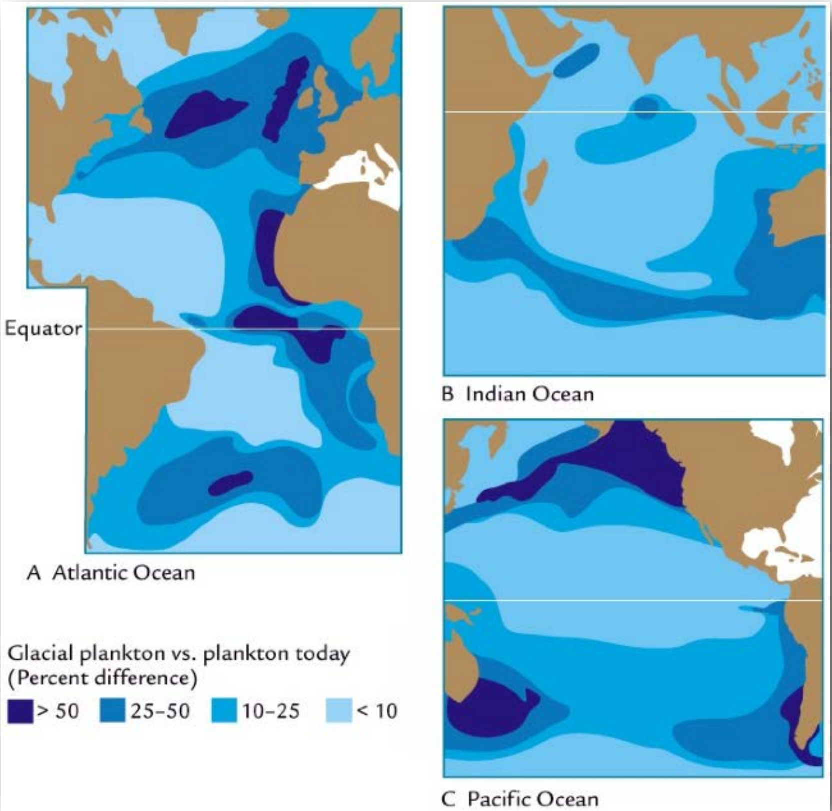
Phone: +49 421 218-65567
Mobile: +49 421 218-65566
bcr@marum.de

IODP BCR Reefer in MARUM I building

- University of Bremen hosts one of tree international IODP repositories
  - *the other two are in College Station, Texas, and Kochi Core Center (KCC), Japan*
- BCR presently contains more than 158 km of deep-sea cores from 90 expeditions in around 250,000 boxes
- around 200 scientists visit the repository annually, working on the cores in sampling meetings
- as many as 50,000 samples per year are removed from the cores by guests and by the repository staff

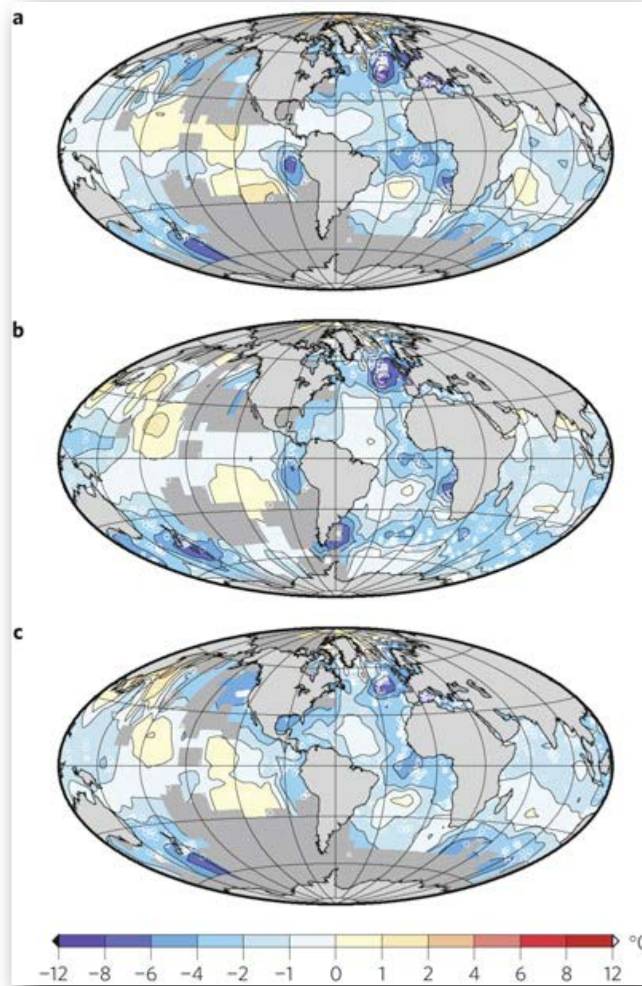
https://www.marum.de/en/Research/IODP-Bremen-Core-Repository.html#section1019

Examples of marine sediment analyses



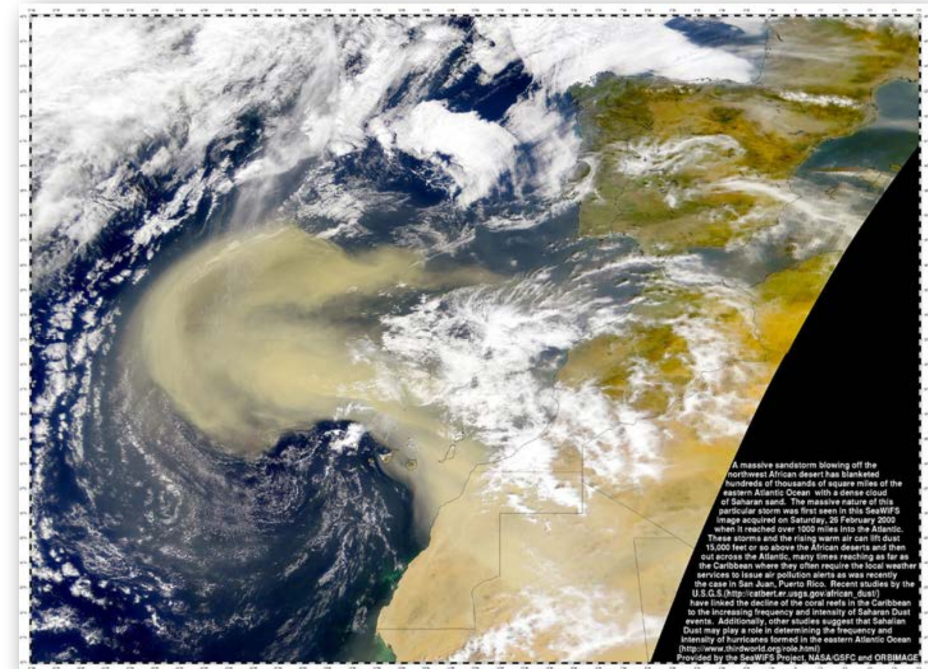
[from: Ruddiman, 2008]

plankton assemblages



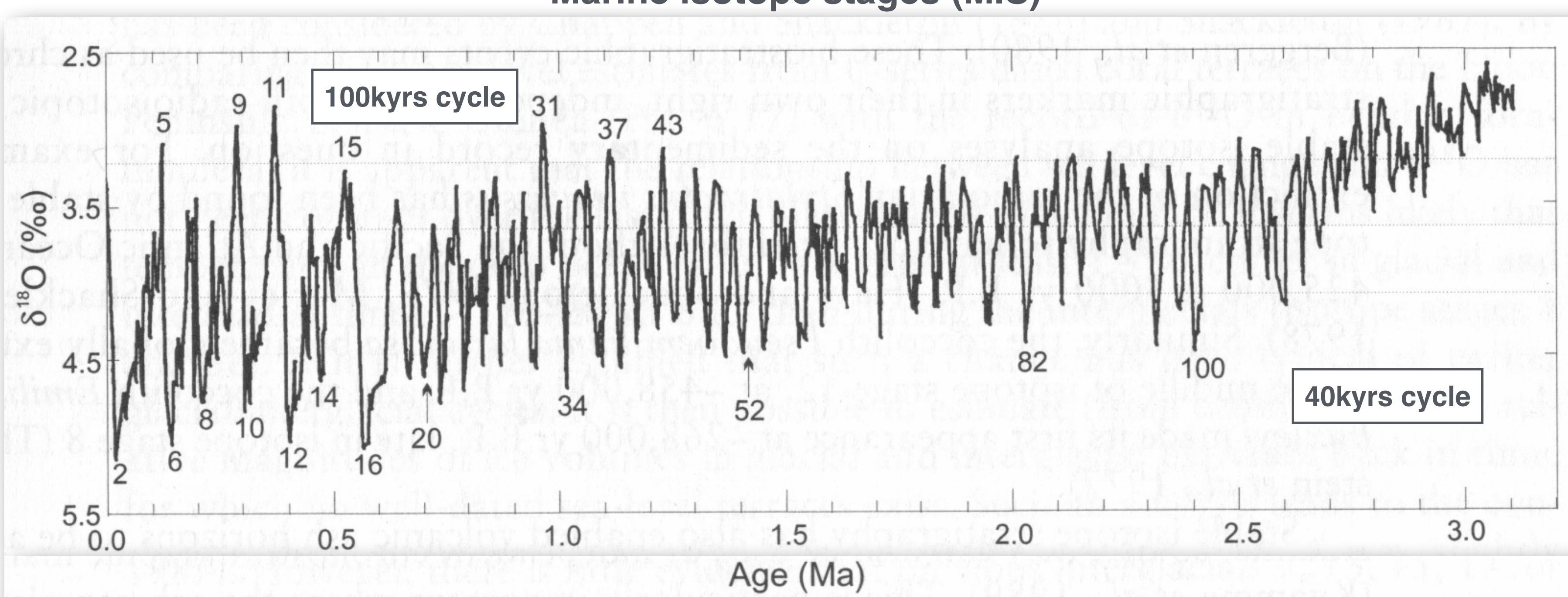
[MARGO Project Members, Nature Geoscience, 2009]

LGM SST reconstructions



dust & other inorganic material

Marine isotope stages (MIS)



Example: The Lisiecki & Raymo benthic $\delta^{18}O$ stack

PALEOCEANOGRAPHY, VOL. 20, PA1003, doi:10.1029/2004PA001071, 2005

A Pliocene-Pleistocene stack of 57 globally distributed benthic $\delta^{18}O$ records

Lorraine E. Lisiecki
Department of Geological Sciences, Brown University, Providence, Rhode Island, USA

Maureen E. Raymo
Department of Earth Sciences, Boston University, Boston, Massachusetts, USA

[1] We present a 5.3-Myr stack (the "LR04" stack) of benthic $\delta^{18}O$ records from 57 globally distributed sites aligned by an automated graphic correlation algorithm. This is the first benthic $\delta^{18}O$ stack composed of more than three records to extend beyond 850 ka, and we use its improved signal quality to identify 24 new marine isotope stages in the early Pliocene. We also present a new LR04 age model for the Pliocene-Pleistocene derived from tuning the $\delta^{18}O$ stack to a simple ice model based on 21 June insolation at 65°N. Stacked sedimentation rates provide additional age model constraints to prevent overtuning. Despite a conservative tuning strategy, the LR04 benthic stack exhibits significant coherency with insolation in the obliquity band throughout the entire 5.3 Myr and in the precession band for more than half of the record. The LR04 stack contains significantly more variance in benthic $\delta^{18}O$ than previously published stacks of the late Pleistocene as the result of higher-resolution records, a better alignment technique, and a greater percentage of records from the Atlantic. Finally, the relative phases of the stack's 41- and 23-kyr components suggest that the precession component of $\delta^{18}O$ from 2.7–1.6 Ma is primarily a deep-water temperature signal and that the phase of $\delta^{18}O$ precession response changed suddenly at 1.6 Ma.

Example: The Lisiecki & Raymo benthic $\delta^{18}O$ stack

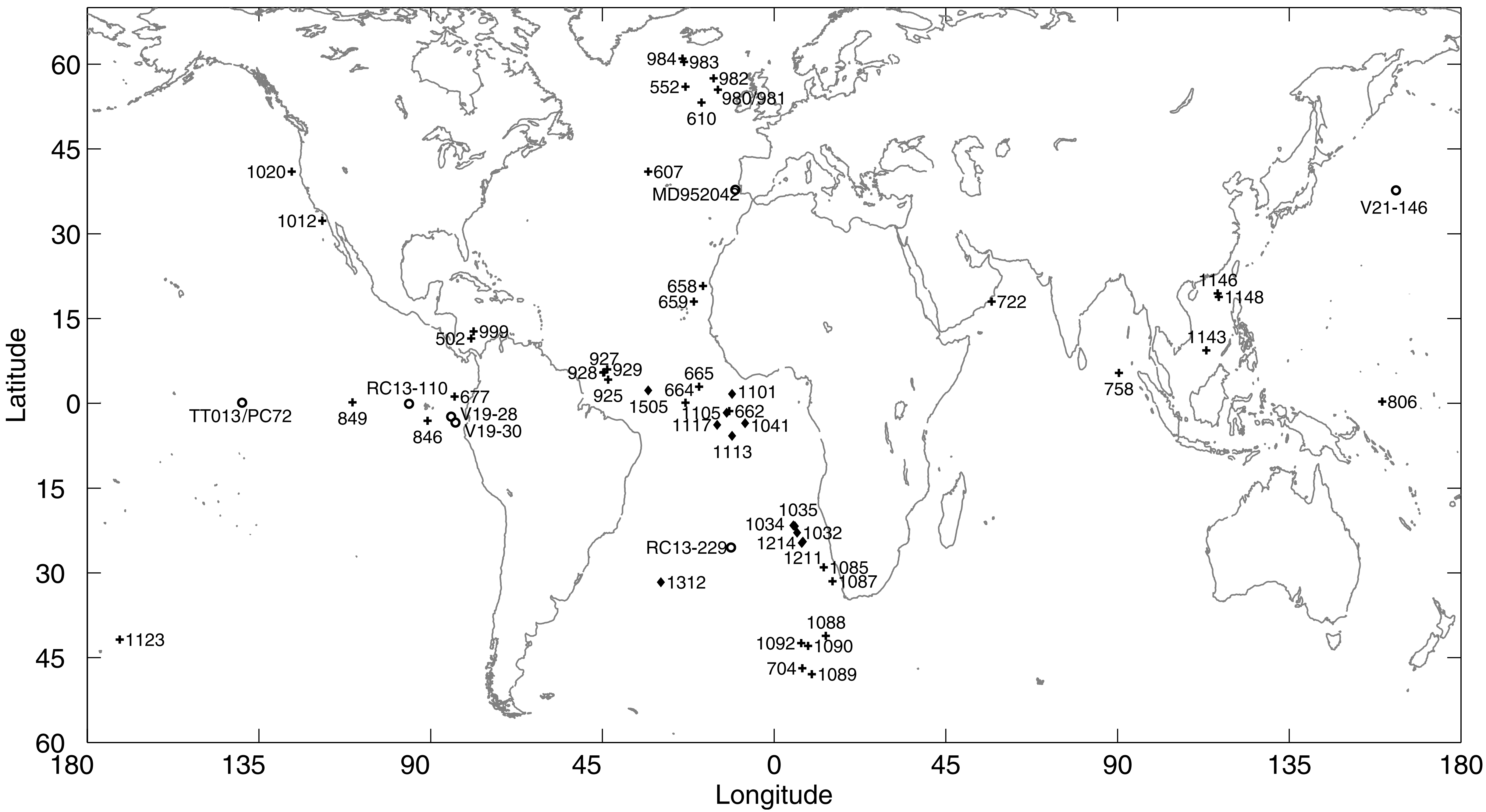
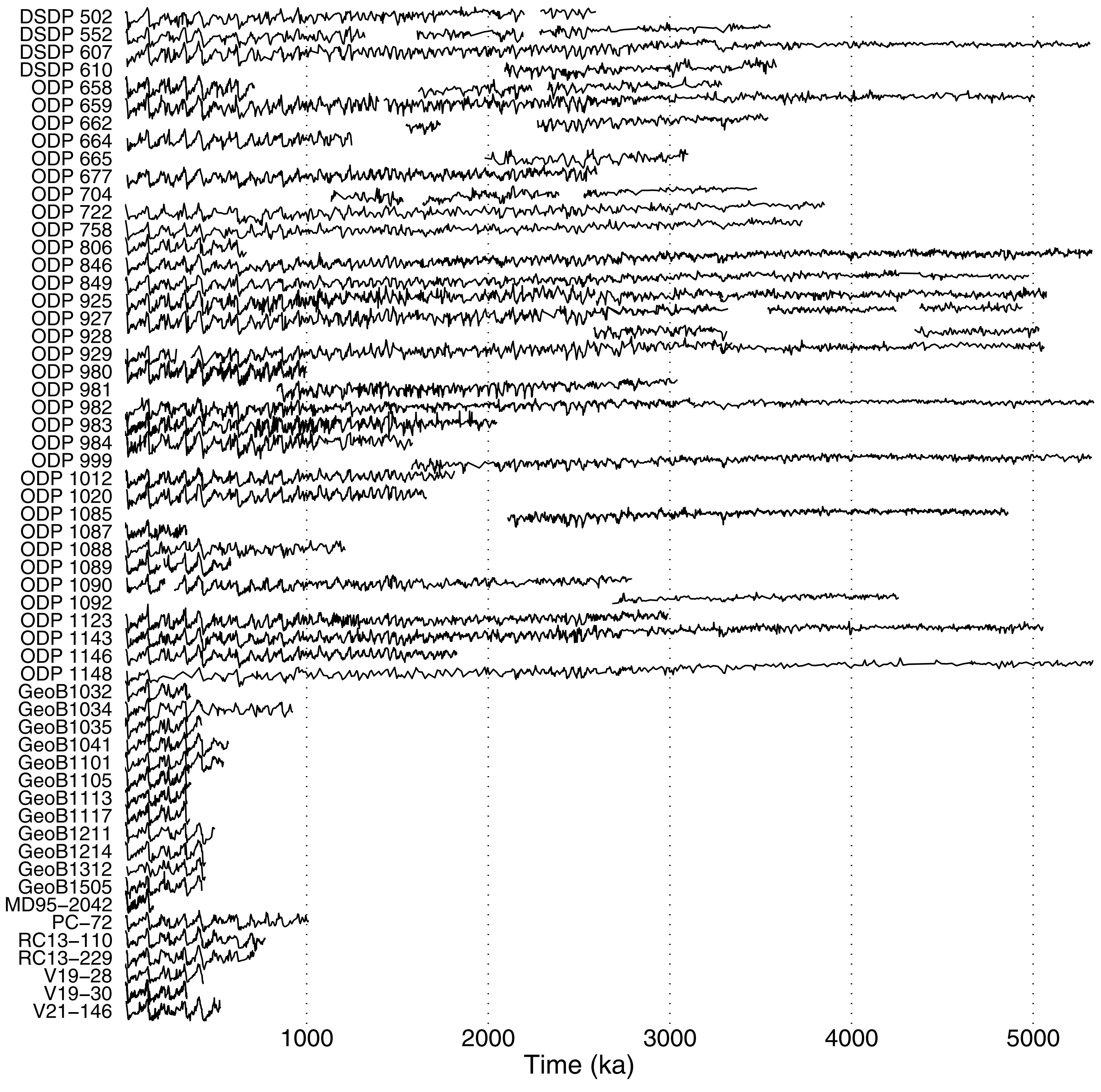


Figure 1. Location of the cores used in this study. Benthic $\delta^{18}O$ data are taken from Deep-Sea Drilling Project (DSDP) and Ocean Drilling Program (ODP) sites (crosses), GeoB sites (diamonds), and others (circles).

[Lisiecki & Raymo, 2005]

Example: The Lisiecki & Raymo benthic $\delta^{18}O$ stack



[Lisiecki & Raymo, 2005]

Figure 2. Graphically aligned benthic $\delta^{18}O$ data, plotted with their original variance but offset vertically. Data are from Sites 502 [*deMenocal et al.*, 1992], 552 [*Shackleton and Hall*, 1984], 607 [*Ruddiman et al.*, 1989; *Raymo et al.*, 1989; *Raymo et al.*, 1992; this study], 610 [*Raymo et al.*, 1992], 658 [*Tiedemann*, 1991], 659 [*Tiedemann et al.*, 1994], 662 (this study), 664 [*Raymo et al.*, 1997], 665 [*Curry and Miller*, 1989], 677 [*Shackleton et al.*, 1990], 704 [*Hodell and Venz*, 1992], 722 [*Clemens et al.*, 1996], 758 [*Chen et al.*, 1995], 806 [*Berger et al.*, 1993], 846 [*Mix et al.*, 1995a; *Shackleton et al.*, 1995a], 849 [*Mix et al.*, 1995b], 925 [*Bickert et al.*, 1997; *Billups et al.*, 1998; *Franz*, 1999], 927 [*Bickert et al.*, 1997; *Franz*, 1999], 928 [*Franz*, 1999], 929 [*Bickert et al.*, 1997; *Billups et al.*, 1998; *Franz*, 1999], 980 [*Oppo et al.*, 1998; *McManus et al.*, 1999; *Flower et al.*, 2000], 981 [*Mc Intyre et al.*, 1999; *Raymo et al.*, 2004], 982 [*Venz et al.*, 1999; *Venz and Hodell*, 2002; this study], 983 [*Mc Intyre et al.*, 1999; *Raymo et al.*, 2004], 984 [*Raymo et al.*, 2004], 999 [*Haug and Tiedemann*, 1998], 1012 and 1020 [*Herbert et al.*, 2001; Z. Liu, personal communication, 2002], 1085 (D. Andreasen, personal communication, 2002), 1087 [*Pierre et al.*, 2001], 1088 [*Hodell et al.*, 2003], 1089 [*Hodell et al.*, 2001], 1090 [*Venz and Hodell*, 2002], 1092 [*Andersson et al.*, 2002], 1123 [*Hall et al.*, 2001; *Harris*, 2002], 1143 [*Tian et al.*, 2002], 1146 (S. Clemens, personal communication, 2002), 1148 [*Jian et al.*, 2003], GeoB 1032, 1041, 1101 [*Bickert and Wefer*, 1996], GeoB 1113 [*Sarnthein et al.*, 1994], GeoB 1117, 1211, 1214 [*Bickert and Wefer*, 1996], GeoB 1312 [*Hale and Pflaumann*, 1999], GeoB 1505 [*Zabel et al.*, 1999], MD95-2042 [*Shackleton et al.*, 2000], PC72 [*Murray et al.*, 2000], RC13-110 [*Mix et al.*, 1991; *Imbrie et al.*, 1992], RC13-229 [*Oppo et al.*, 1990], V19-28 [*Ninkovitch and Shackleton*, 1975], V19-30 [*Shackleton and Pisias*, 1985], V21-146 [*Hovan et al.*, 1991].

Example: The Lisiecki & Raymo benthic δ18O stack

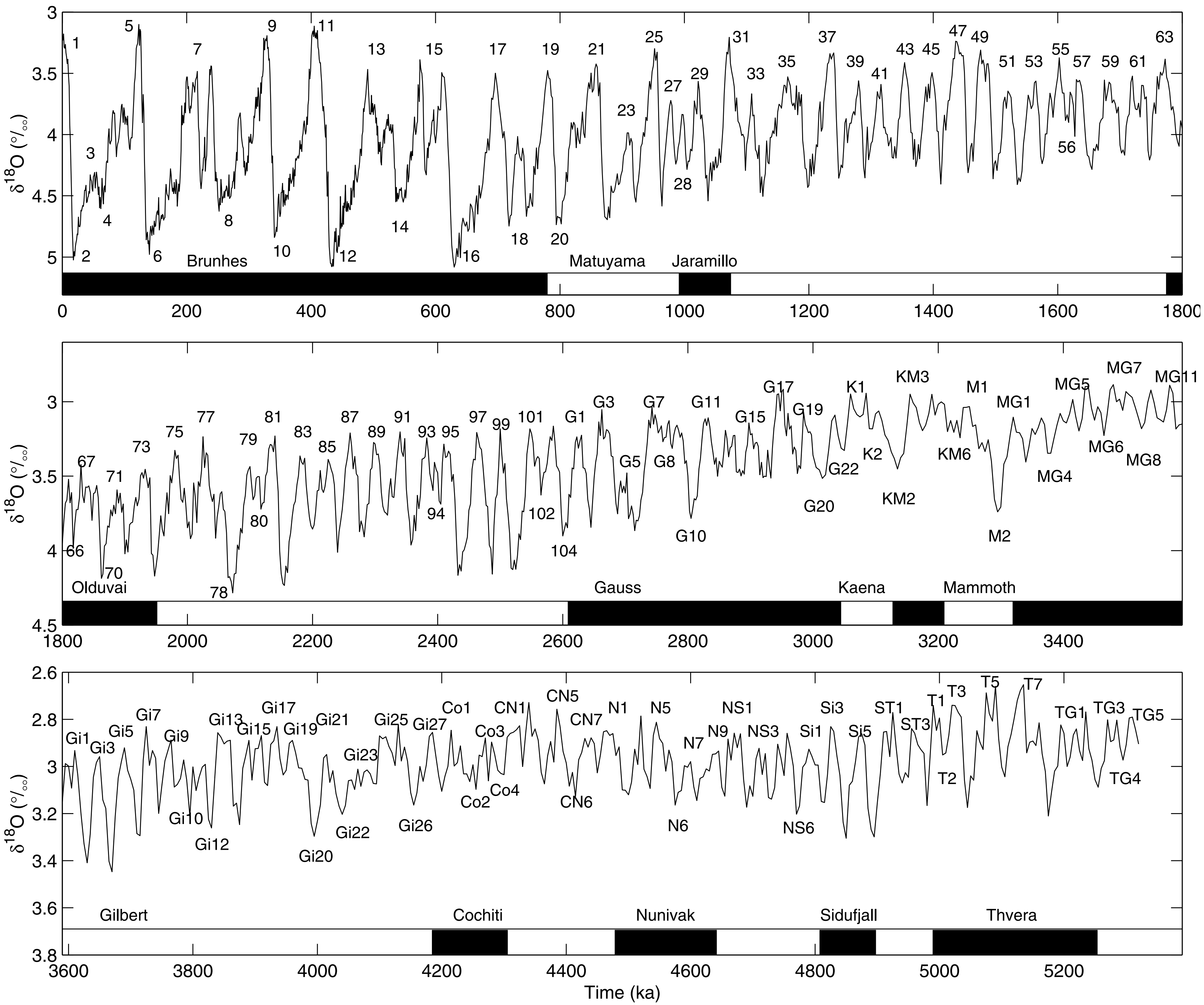


Figure 4. The LR04 benthic $\delta^{18}O$ stack constructed by the graphic correlation of 57 globally distributed benthic $\delta^{18}O$ records. The stack is plotted using the LR04 age model described in section 5 and with new MIS labels for the early Pliocene (section 6.2). Note that the scale of the vertical axis changes across panels.

[Lisiecki & Raymo, 2005]

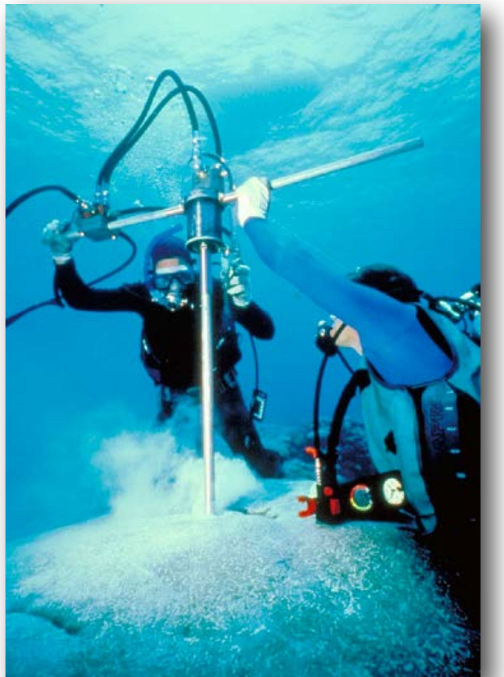
Corals

http://www.ncdc.noaa.gov/paleo/slides/

Corals

- main interest for paleoclimatological studies: Hermatypic corals (reef-building corals)
  - *exist mainly between 30°N - 30°S, with an average SST of 20°C*
  - *if SST are below 18°C, the coral reefs grow only very slowly or even die (at colder temperatures)*
- typical coral analyses:
  growth rates, isotopes, trace elements, …
- coral records may cover the last 100,000 years (or even older periods)
  - *often, corals just grow during warm climates*
- corals are a very promising climate archive for the reconstruction of tropical SST

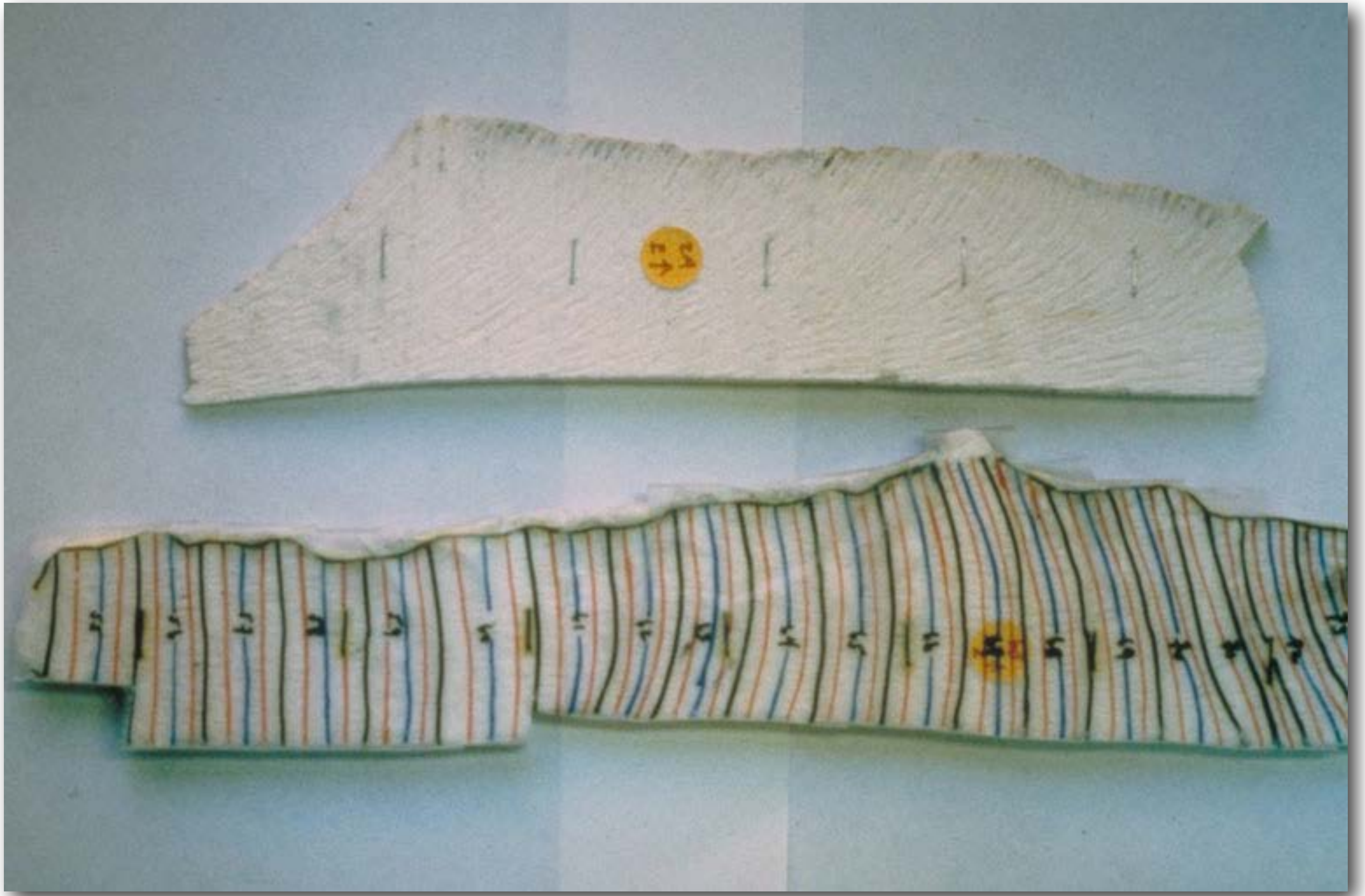
Corals



http://www.ncdc.noaa.gov/paleo/slides/

Growth of corals

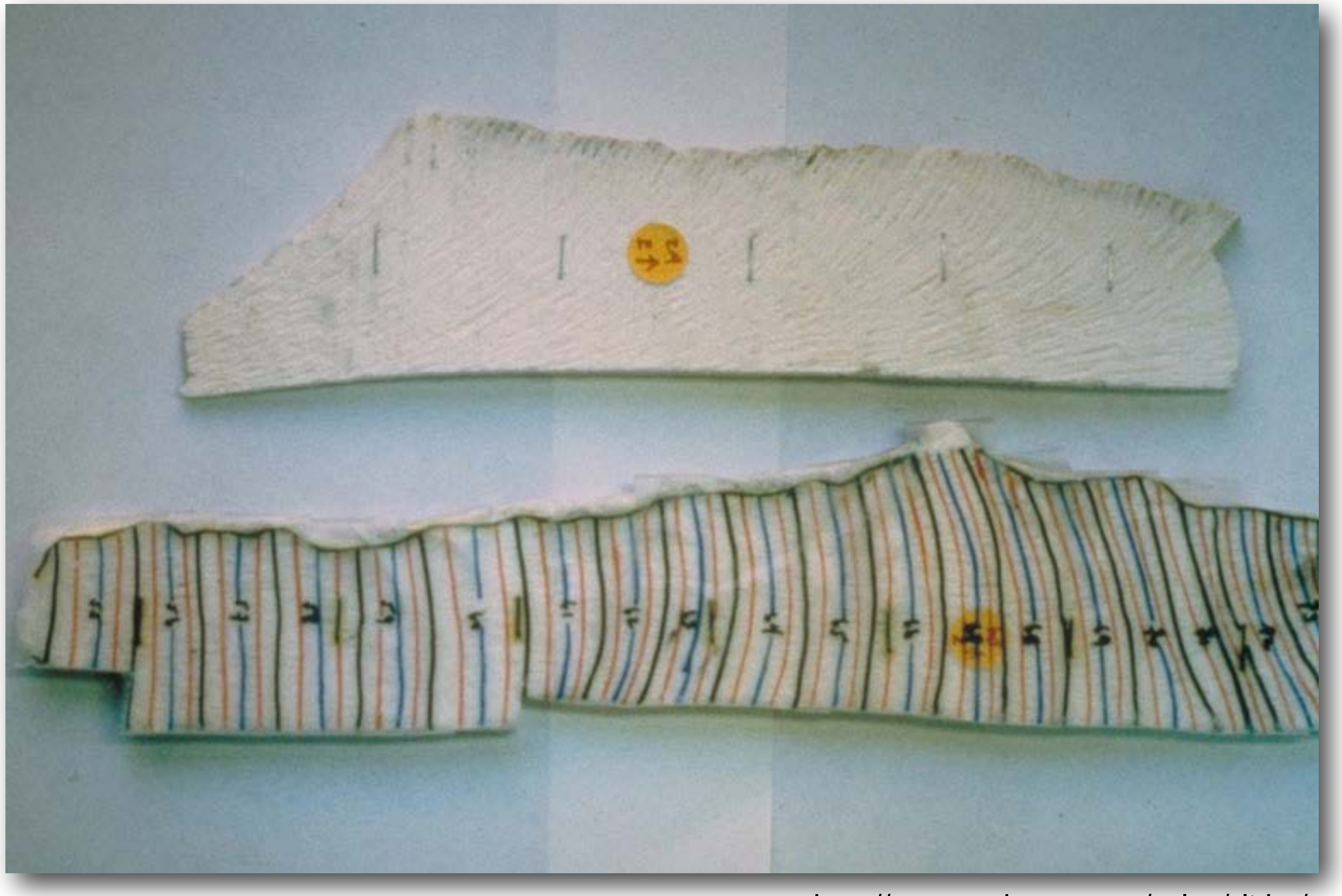
- coral growth varies with the season of the year
  - *growth rate depends on SST and available nutrients*
- higher (lower) density for warmer (colder) SST
  - *density variations allow the identification of annual layers*



http://www.ncdc.noaa.gov/paleo/slides/

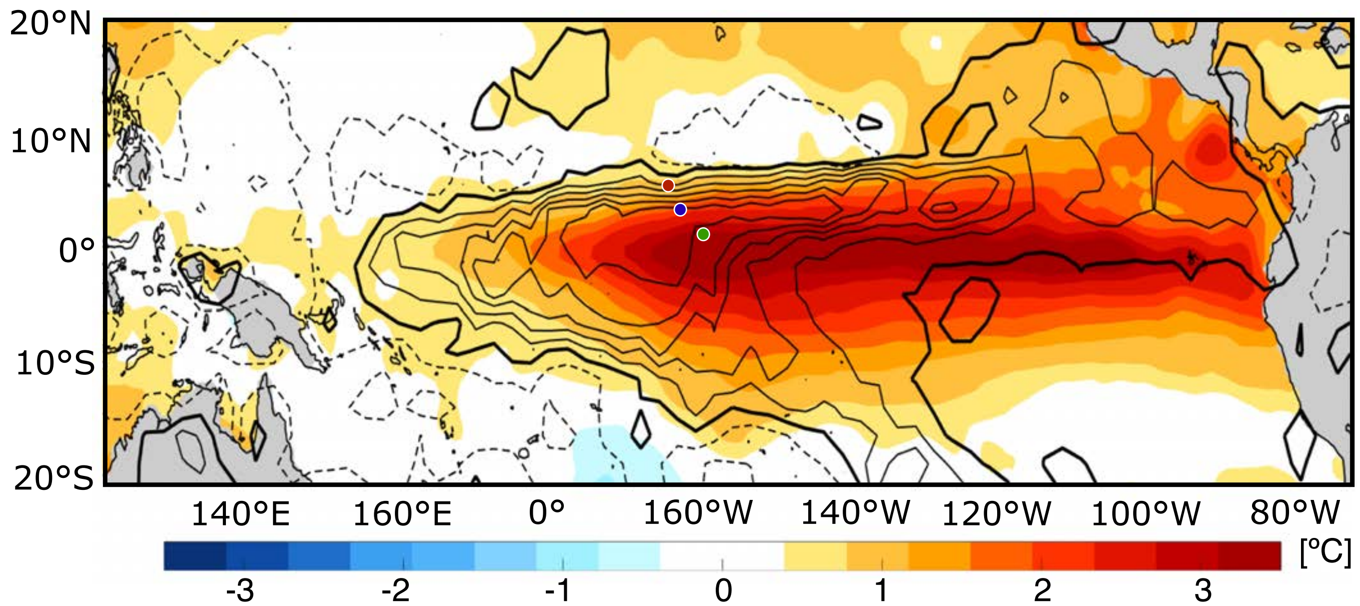
Analyses example: $\delta^{18}O$ measurements on corals

- Depletion/enrichment of ^{18}O in calcium-carbonate ($CaCO_3$) can be measured on corals, too
- two different effects can influence ^{18}O in $CaCO_3$
  - *temperature-related fractionation (determined by SST changes)*
  - *changes of the ^{18}O content of the ocean water (e.g., by large amounts of tropical rainfall in shallow, coastal waters)*
- as corals mainly exist in tropical regions, the El Niño/Southern Oscillation phenomenon is often dominating the coral ^{18}O records
  - *$\delta^{18}O$ analyses on corals enable a reconstruction of past El Niño events*

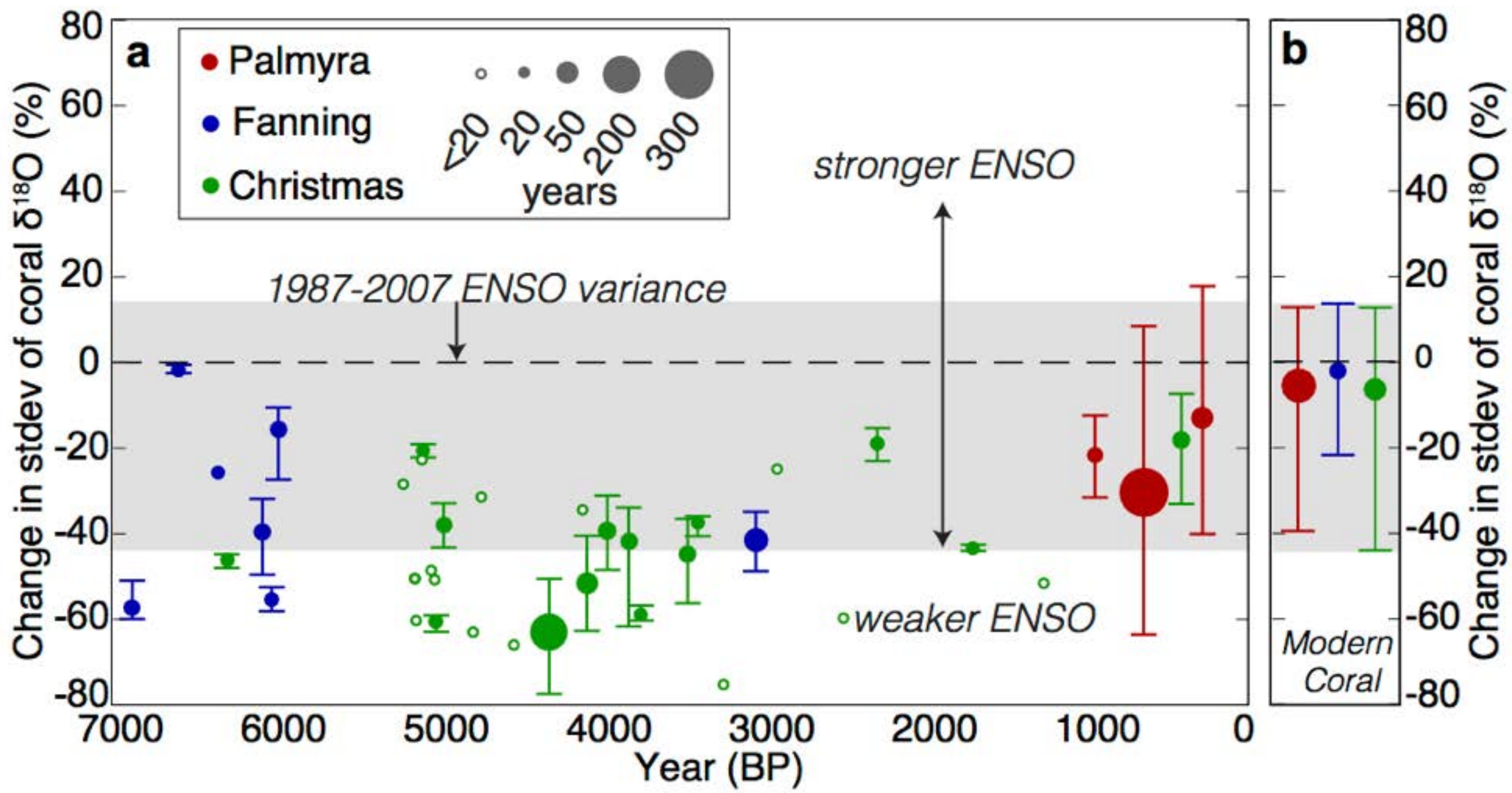


http://www.ncdc.noaa.gov/paleo/slides/

δ¹⁸O measurements on corals: El Niño reconstructions

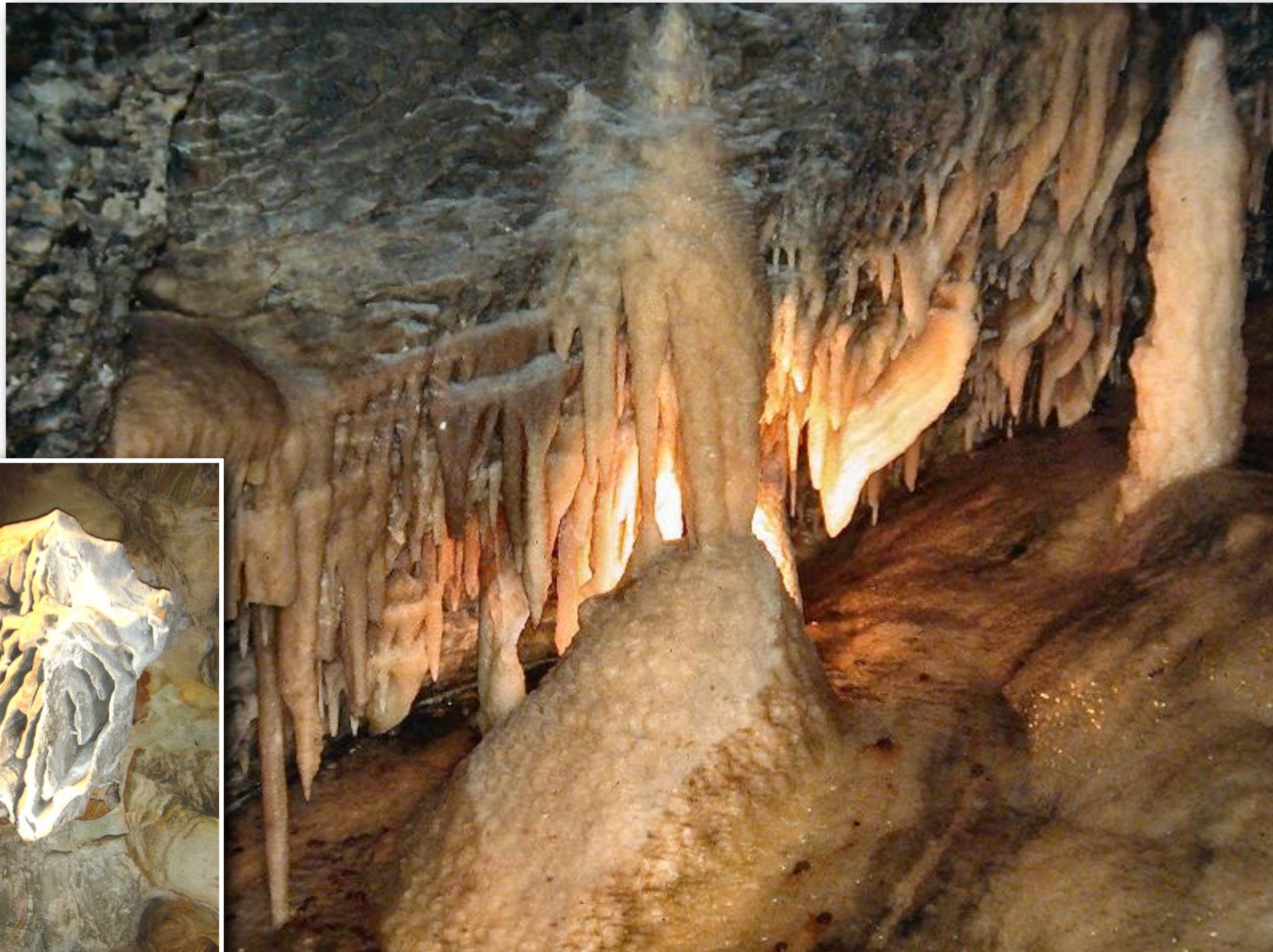


[Grothe et al., 2020]



https://usclivar.org/research-highlights/coral-reconstructions-central-tropical-pacific-climate-suggest-25-increase

Speleothems

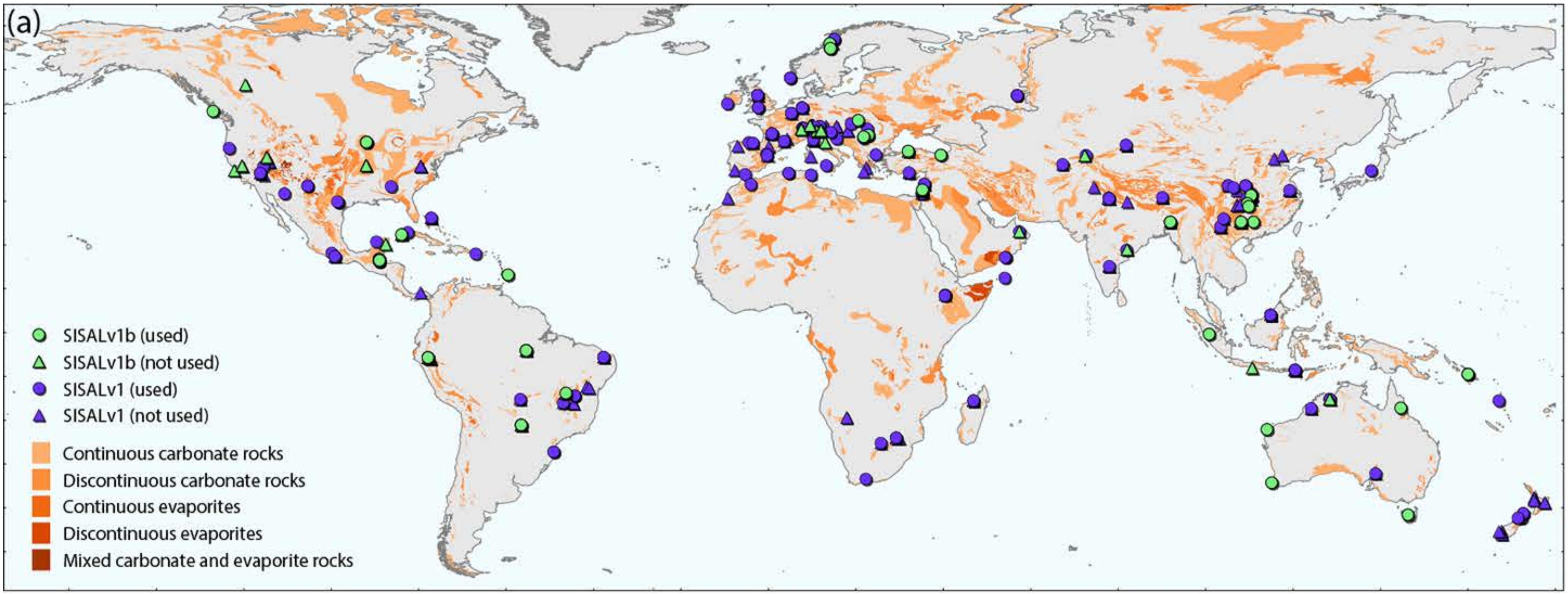


Speleothem formation

- The following conditions must exit for the formation of speleothems:
  - *The water entering the cave must contain CO_2 to dissolve $CaCO_3$*
  - *The soil above the cave should contain $CaCO_3$ which can be dissolved by water*
  - *The ceiling of the cave needs some fissures for water flowing into the cave*

- The growth rate of the speleothems is determined by several factors
  - *amount and rate of dripping water*
  - *CO_2 concentration of the drip water and within the cave*
  - *$CaCO_3$ concentration of the drip water*
  - *cave temperature*

Speleothem locations



[Comas-Bru et al., ClimPast, 2019]

Cave sites included in the SISAL database

Speleothem coverage

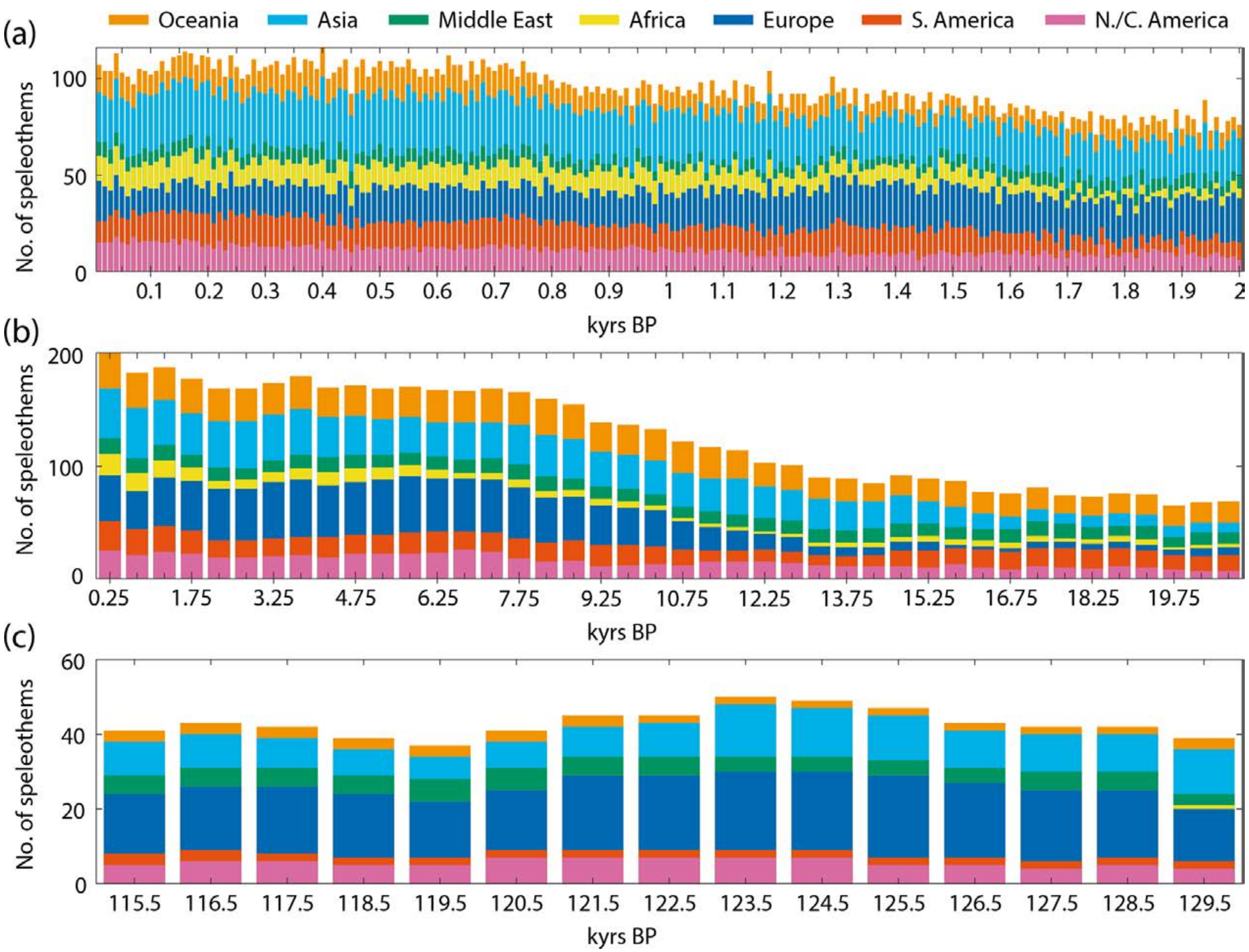


Figure 7. Global and regional temporal coverage of entities in the SISALv2. **(a)** Last 2000 years, with a bin size of 10 years; **(b)** last 21 000 years, with a bin size of 500 years; **(c)** the period between 115 000 and 130 000 years BP, with a bin size of 1000 years. BP refers to "before present", where present is 1950 CE. Regions defined as in Table 7.

Temporal coverage of speleothems in the SISAL database

[Comas-Bru et al., ESSD, 2020]

Speleothems

Dating:

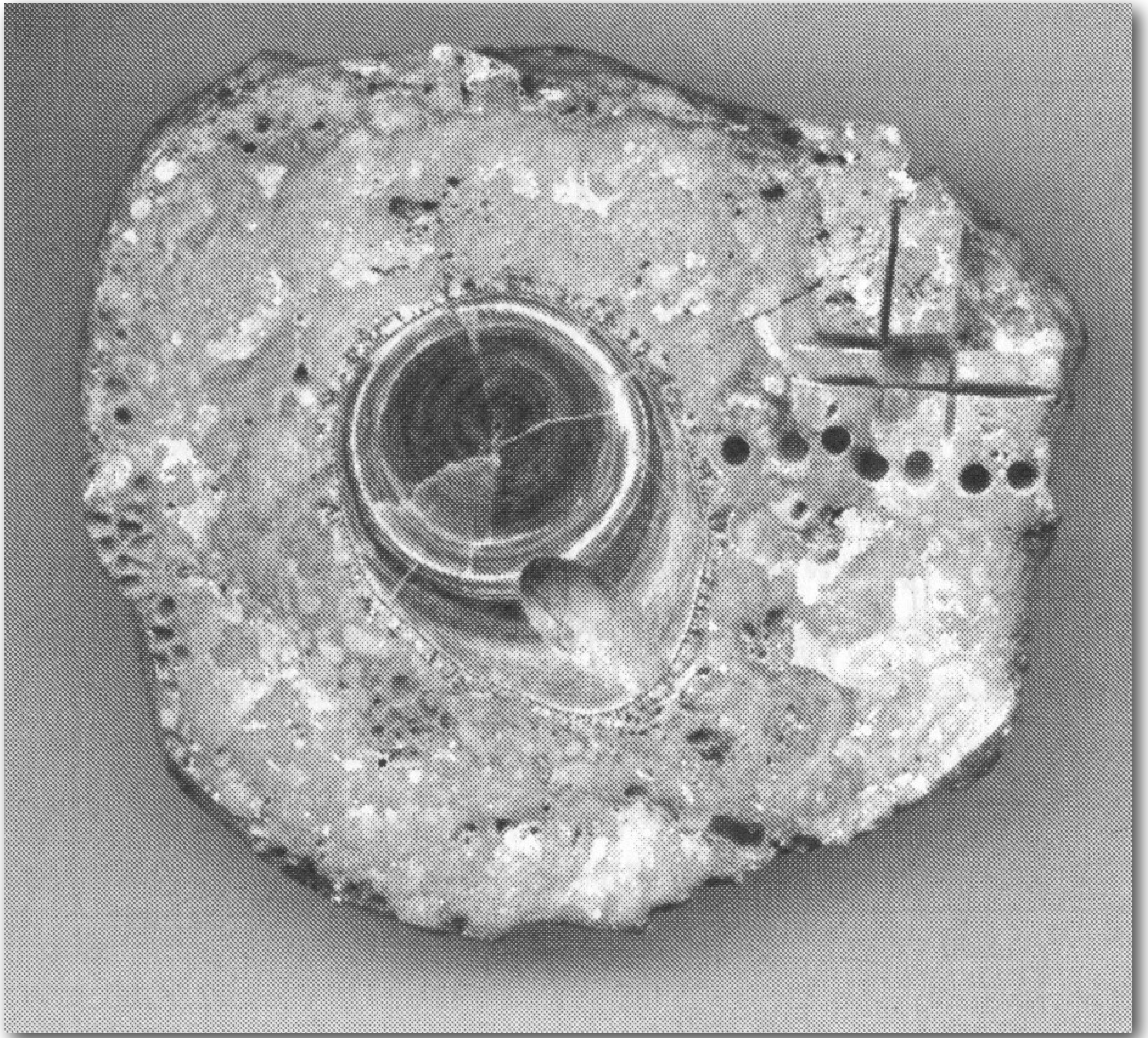
- thorium analyses ($^{230}Th/^{234}U$)
- alternative dating via thermal ionization mass spectroscopy (TIMS)

Age:

- up to 400,000-500,000 years

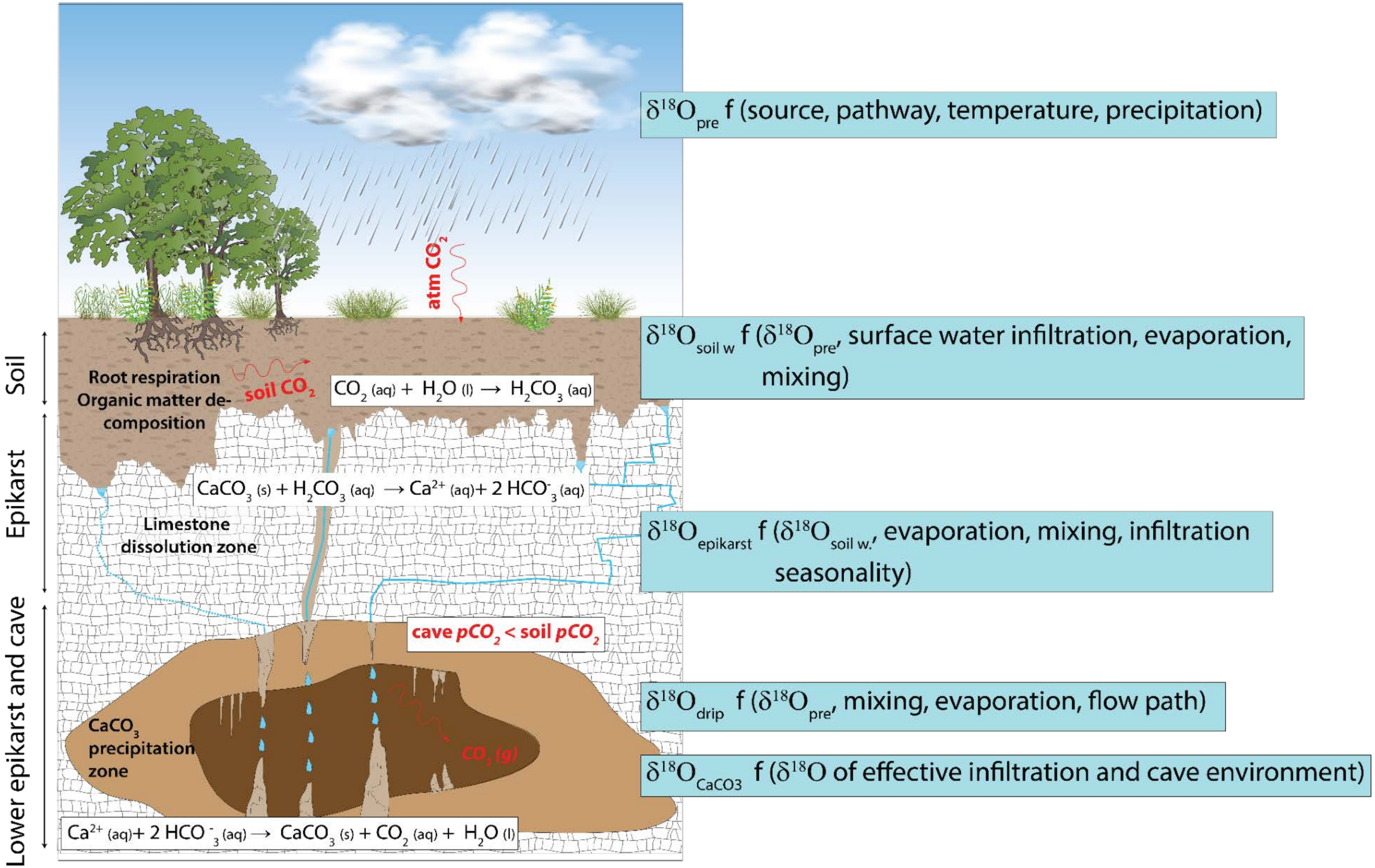
Analyses:

- *Growth rate, $\delta^{18}O$, $\delta^{13}C$, …*



Bradley, Fig. 7.33

Speleothems: Factors impacting the $\delta^{18}O$ record



[figure by: Laia Comas-Bru, Reading University, UK]

Speleothems: The Asian monsoon record

ARTICLE

doi:10.1038/nature18591

The Asian monsoon over the past 640,000 years and ice age terminations

Hai Cheng[1,2], R. Lawrence Edwards[2], Ashish Sinha[3], Christoph Spötl[4], Liang Yi[5], Shitao Chen[6], Megan Kelly[2], Gayatri Kathayat[1], Xianfeng Wang[7], Xianglei Li[1], Xinggong Kong[6], Yongjin Wang[6], Youfeng Ning[1] & Haiwei Zhang[1]

Oxygen isotope records from Chinese caves characterize changes in both the Asian monsoon and global climate. Here, using our new speleothem data, we extend the Chinese record to cover the full uranium/thorium dating range, that is, the past 640,000 years. The record's length and temporal precision allow us to test the idea that insolation changes caused by the Earth's precession drove the terminations of each of the last seven ice ages as well as the millennia-long intervals of reduced monsoon rainfall associated with each of the terminations. On the basis of our record's timing, the terminations are separated by four or five precession cycles, supporting the idea that the '100,000-year' ice age cycle is an average of discrete numbers of precession cycles. Furthermore, the suborbital component of monsoon rainfall variability exhibits power in both the precession and obliquity bands, and is nearly in anti-phase with summer boreal insolation. These observations indicate that insolation, in part, sets the pace of the occurrence of millennial-scale events, including those associated with terminations and 'unfinished terminations'.

Speleothems: The Asian monsoon record

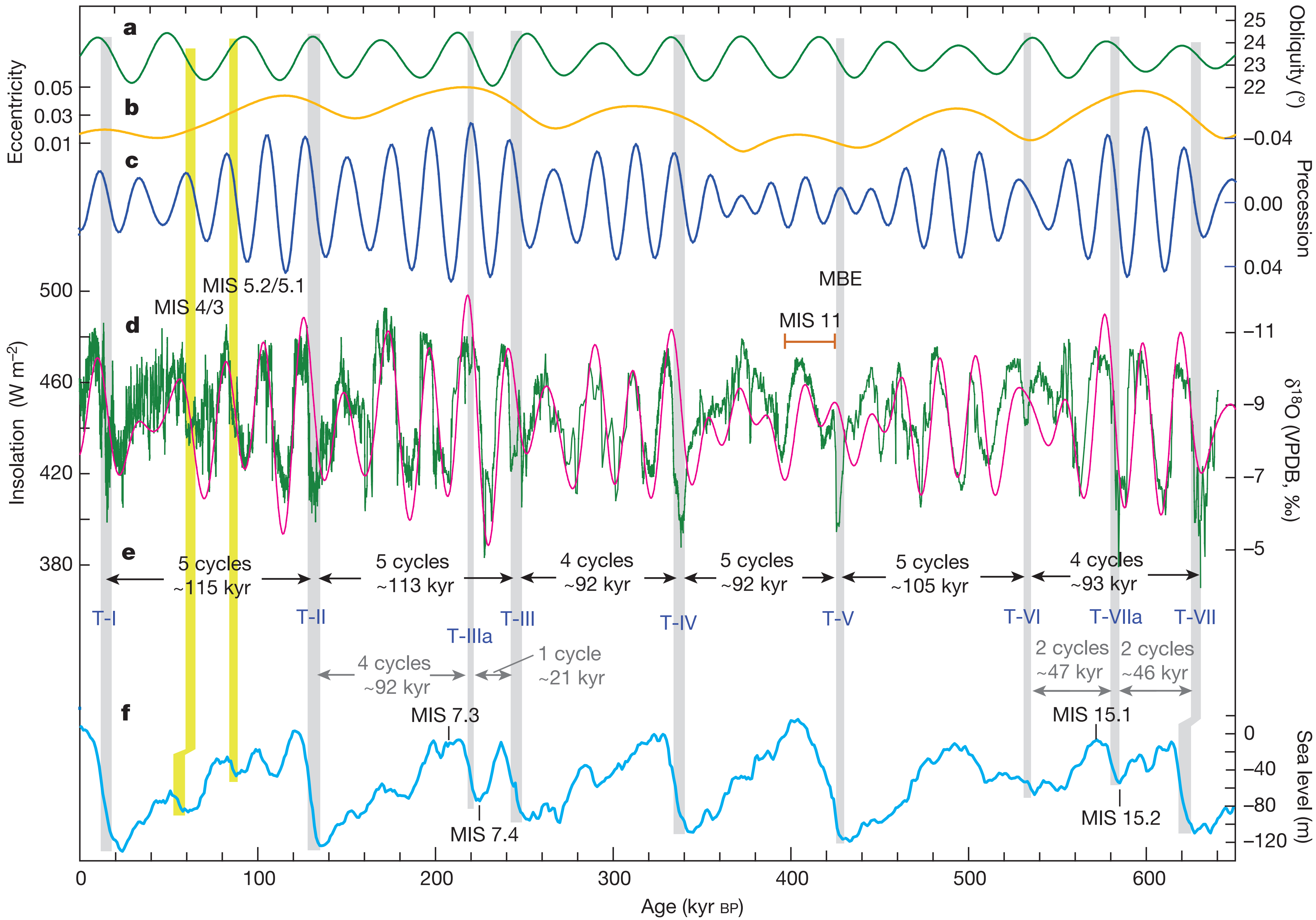
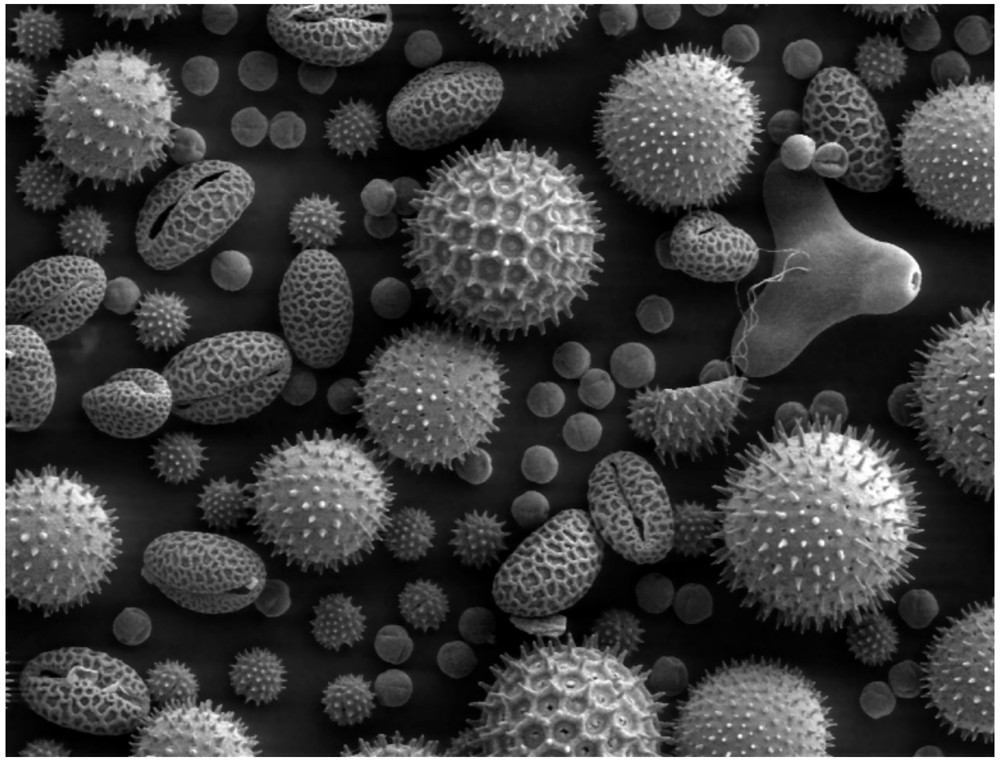


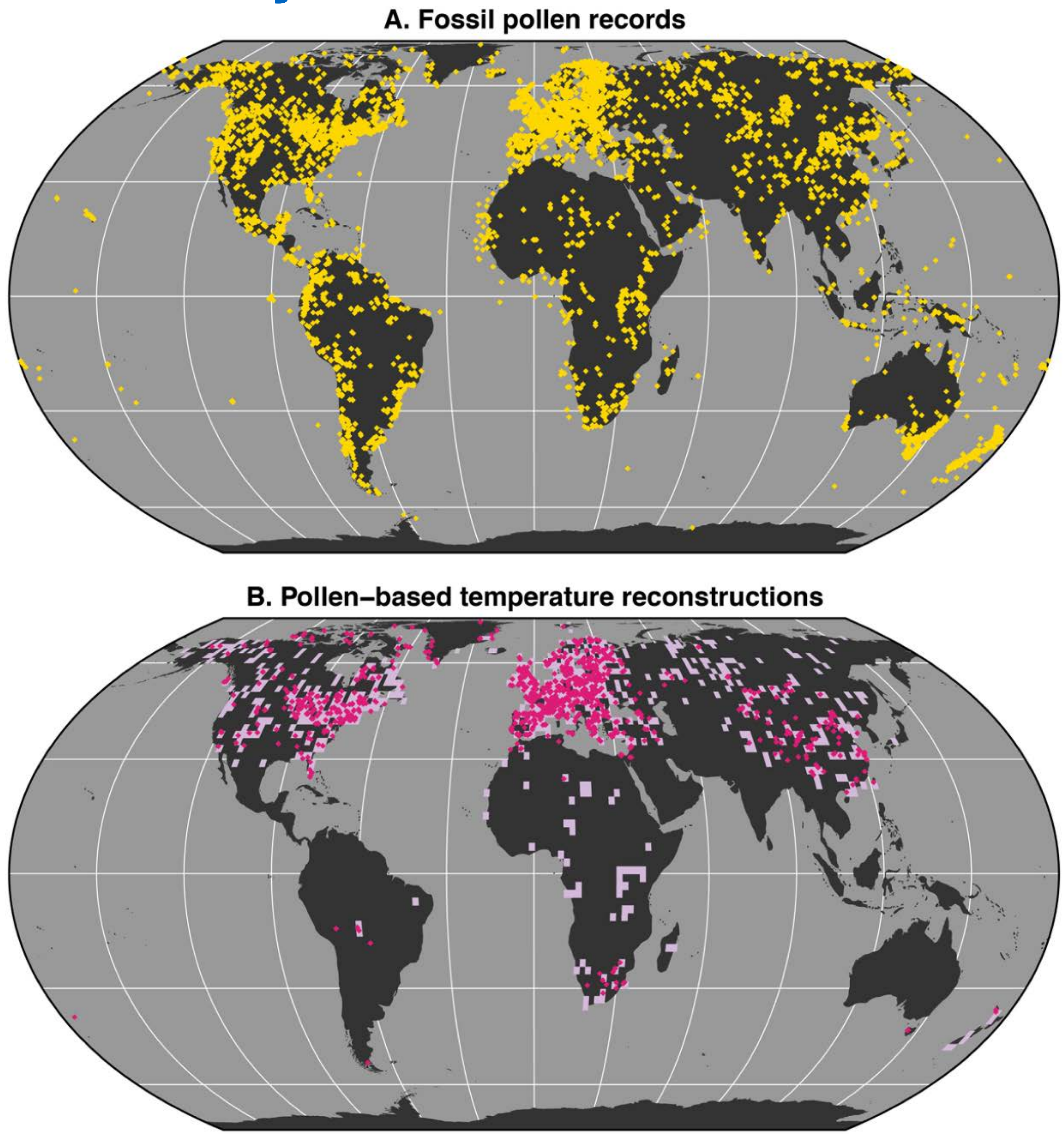
Figure 1 | Asian monsoon variations in the context of the Earth's orbital parameters. a–c, Changes in obliquity (**a**), eccentricity (**b**) and precession[45] (**c**). **d**, The composite AM $\delta^{18}O$ record (green; this study) and 21 July insolation at 65° N (ref. 45; pink). **e**, Termination pacing and duration. Vertical bars mark the timing of WMIs correlated to glacial terminations (grey) and two similar events (MIS 4/3 and 5.2/5.1 transitions) (yellow). The timing of T-IIIa-WMI in this study differs from the one described in ref. 4, although we consider the latter a plausible alternative (see main text and Extended Data Fig. 9). **f**, The composite sea level[17]. The timings of MBE, MIS 11, 7.3, 7.4, 15.1 and 15.2 are also depicted.

[Cheng et al., Nature, 2016]

Pollen analyses



https://paleonerdish.wordpress.com/2013/08/19/pollen-analysis-and-the-science-of-climate-change/

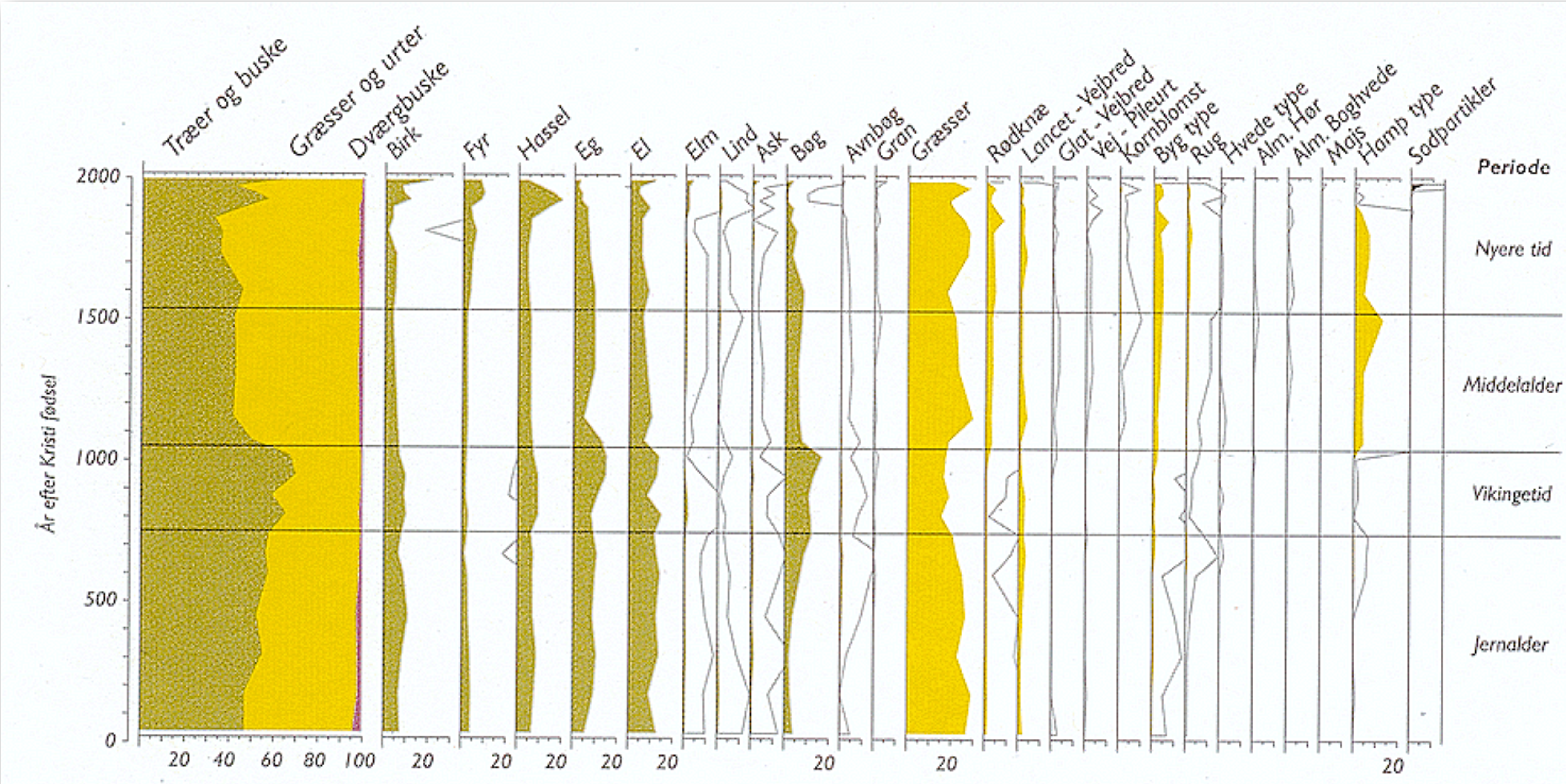


M. Chevalier et al.: Pollen-based climate reconstruction techniques for late Quaternary studies
Earth Science Reviews, 2020

Pollen analyses

- every year, about ~10^9 kg pollen and spores are emitted to the atmosphere
- a pollen compilation often represents the existing vegetation very well
- pollen can be classified very well due to their characteristic shape and colour
- pollen are stable on long time scales(!)
  - *pollen samples can be found both in lake sediments as well as in other terrestrial archives*
  - *the majority of pollen samples stems from the Holocene and/or the last glacial*
- The vegetation composition at one location often relies on a very few number of climate parameters (hours of sunshine, temperature, precipitation)
  - *key issues for paleoclimate pollen analyses:*
    - *How fast does a vegetation pattern adapt to local climate changes?*
    - *Does it always adapt in the same manner?*

Pollen diagrams



http://www.geus.dk/departments/quaternary-marine-geol/research-themes/env-cli-pollen-uk.htm

Calibration of Pollen Studies

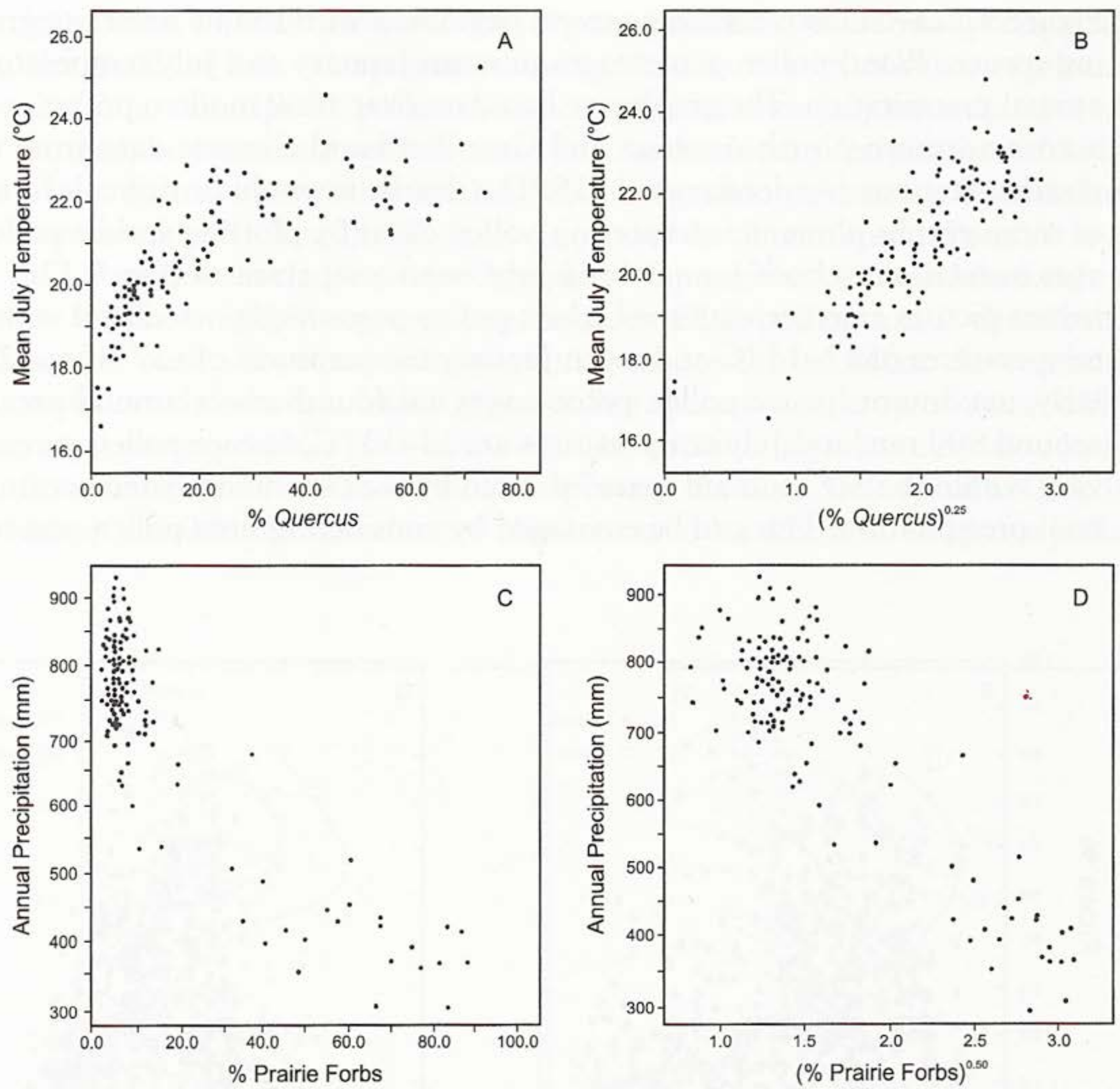


FIGURE 9.11 Scatter diagrams for **(A)** July mean temperature vs the percentages of *Quercus* (oak) pollen; **(B)** July mean temperature vs the percentages of *Quercus* pollen raised to the 0.25 power; **(C)** annual precipitation vs the percent of prairie-forb pollen (excluding *Ambrosia*) and **(D)** annual precipitation vs the percent of prairie-forb pollen raised to the 0.5 power (Bartlein *et al.*, 1984).

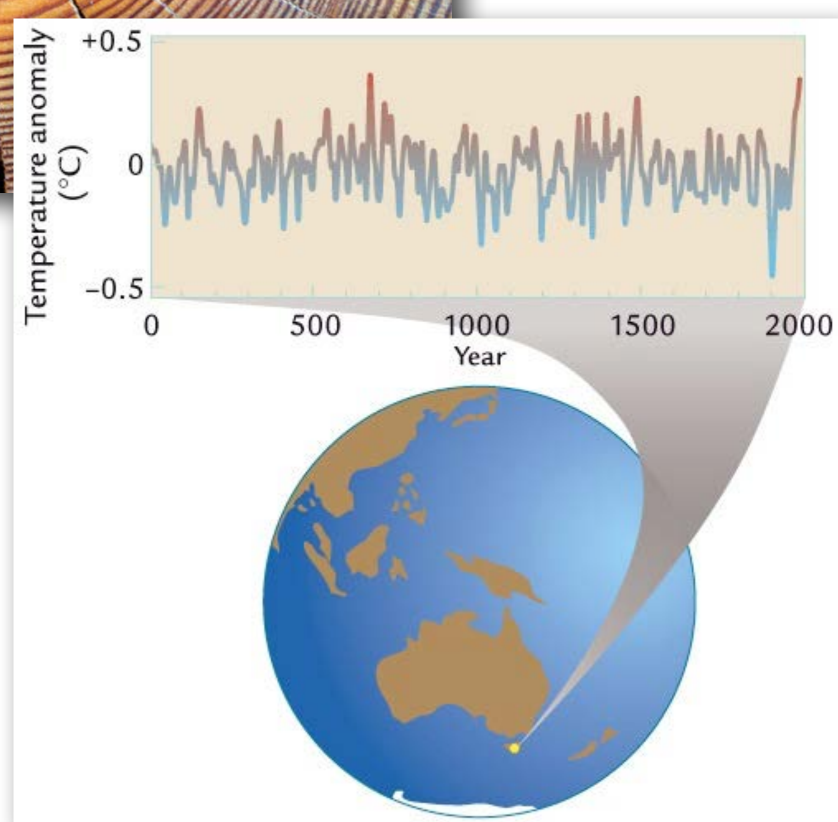
Bradley, Fig. 9.11

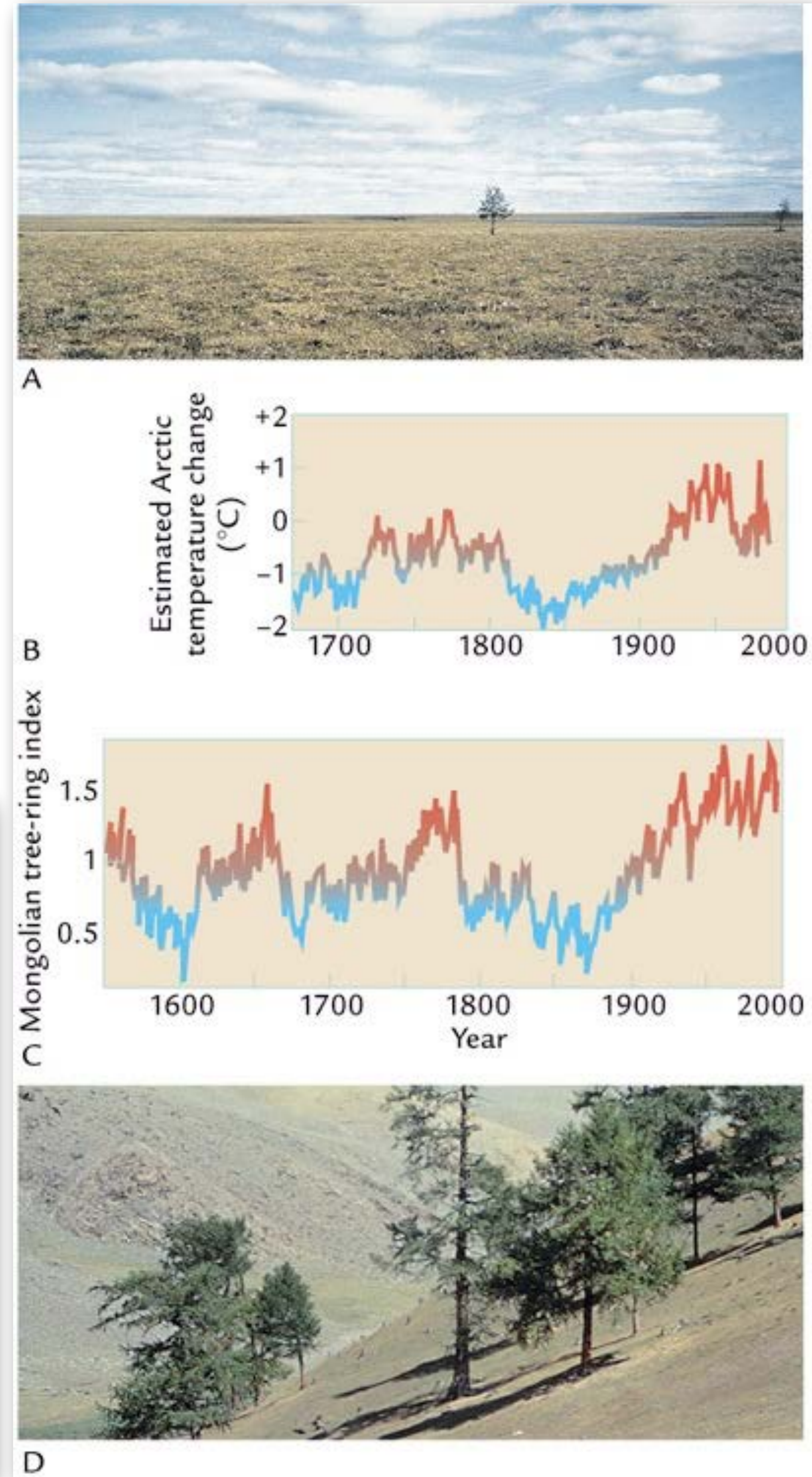
Tree Rings

https://www.sciencenews.org/article/tree-story-book-explores-what-tree-rings-can-tell-us-about-past

Tree Rings

- Variations of tree ring width and density are an indicator of (local) climate change
- the use of tree rings to reconstruct climate change is called dendroclimatology



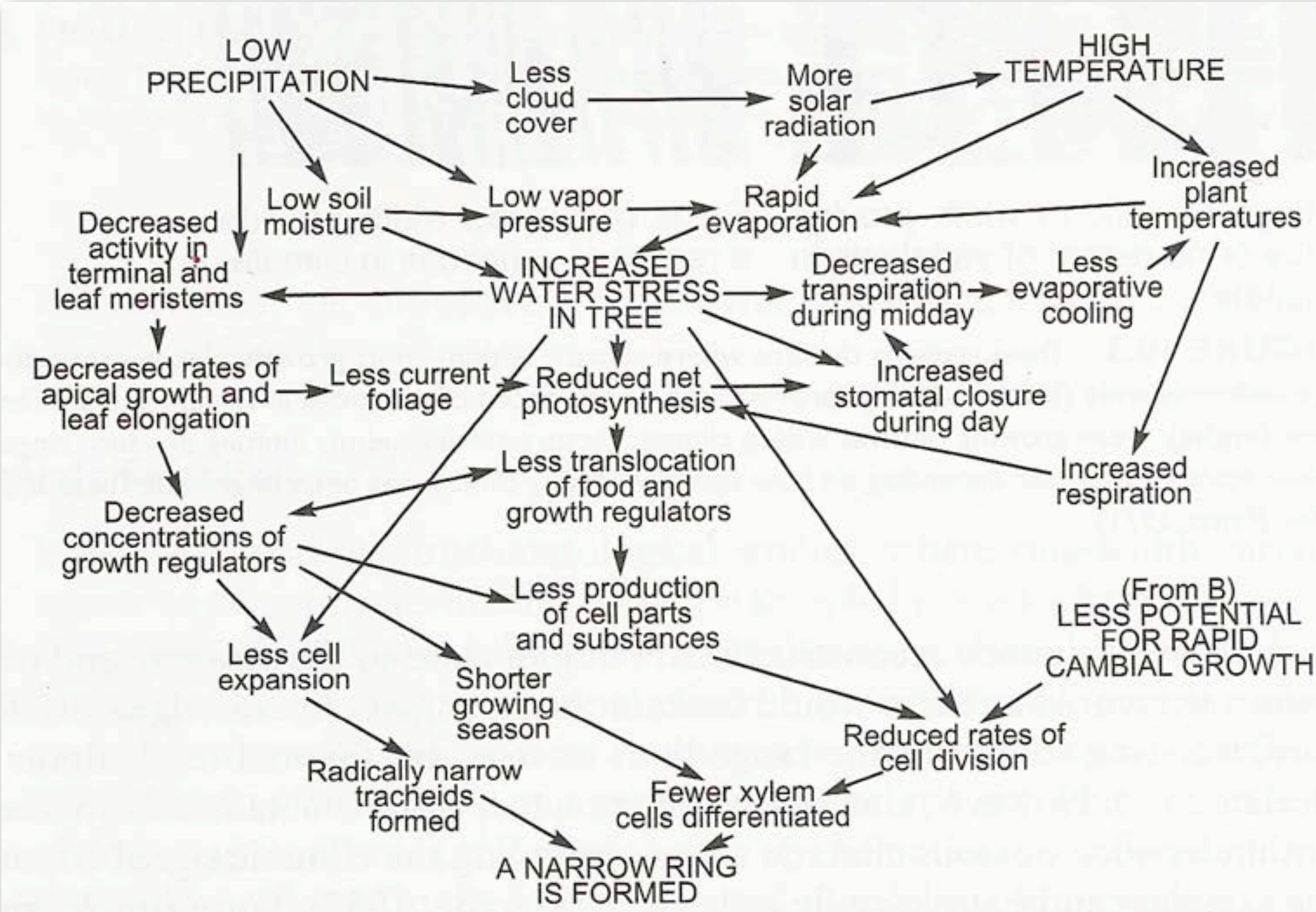


[from: Ruddiman, 2008]

Dendroclimatology

- The width of the annual tree rings is in general a complex function that depends on the tree species, tree age, available nutrients (in the soil and in the tree), sun shine hours, amount of precipitation, temperature, wind conditions, relative humidity, etc.)

The Imprint of Climate Changes in Tree Rings

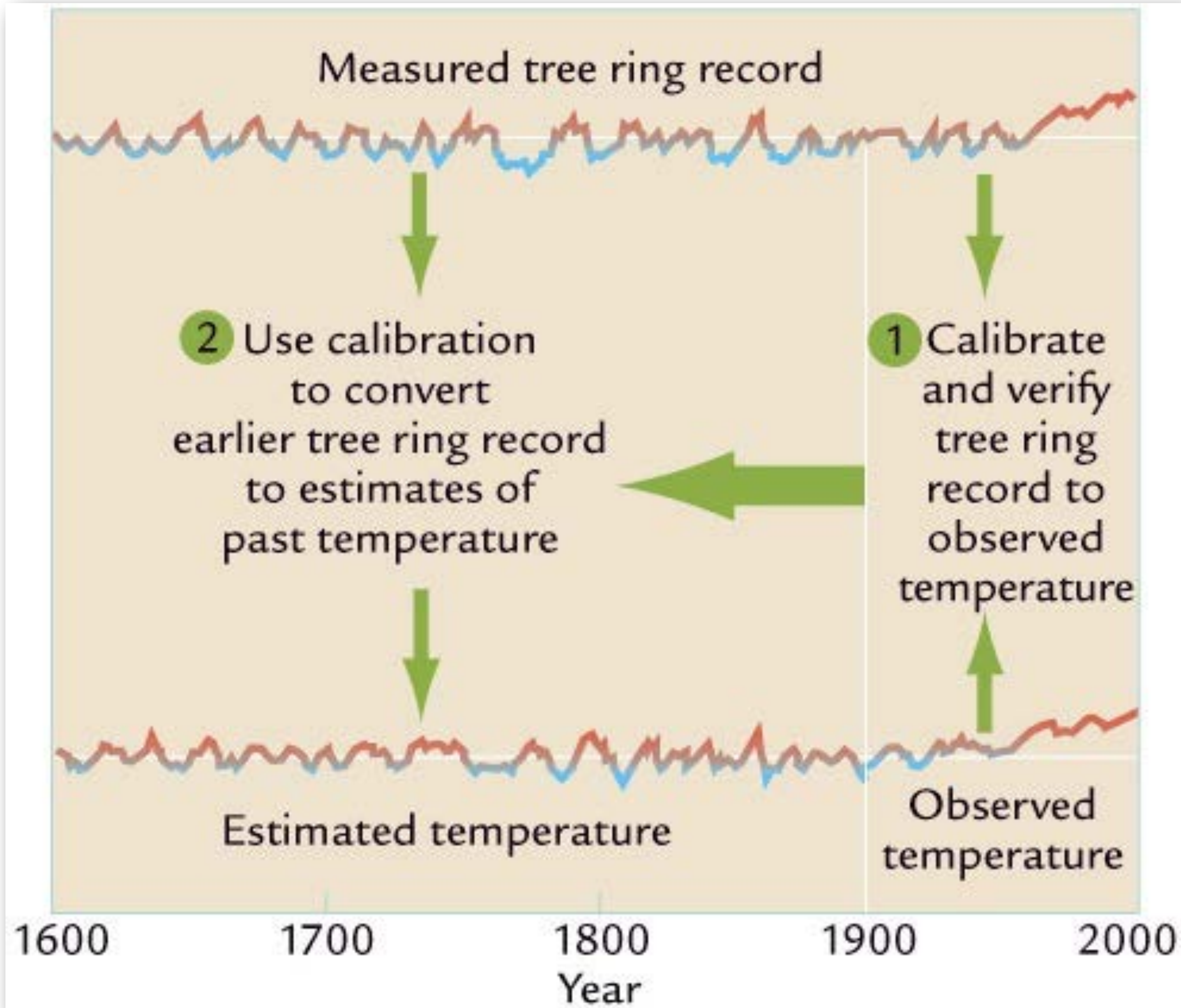


Bradley, Fig. 10.4

Dendroclimatology

- The width of the annual tree rings is in general a complex function that depends on the tree species, tree age, available nutrients (in the soil and in the tree), sun shine hours, amount of precipitation, temperature, wind conditions, relative humidity, etc.)
  - *at suitable sites (and for suitable tree species) the function can be reduced to 1-2 influencing parameters, only*
- Dating methods: ^{14}C, cross dating using several different trees
- Analyses: Density variations, ^{18}O

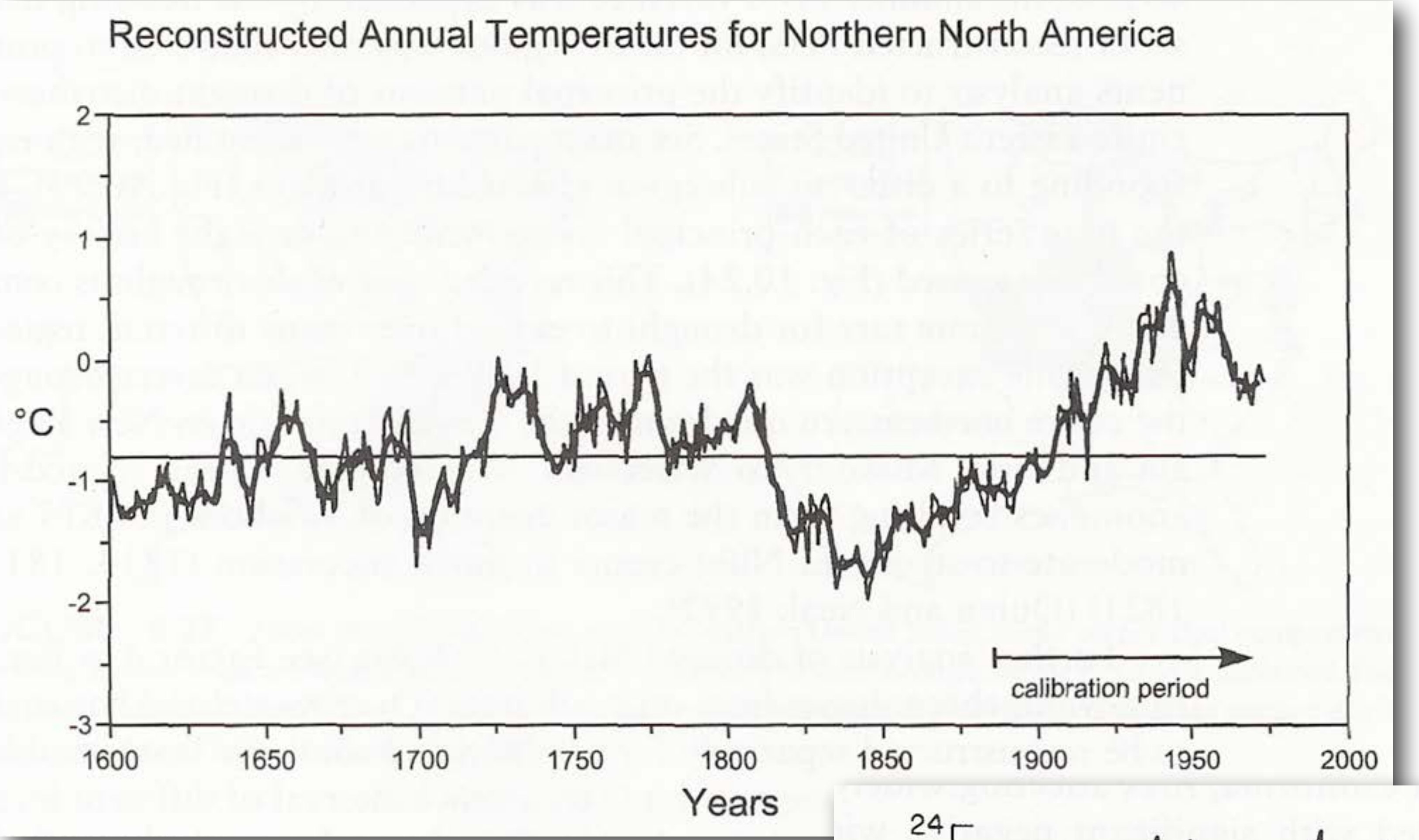
Climate reconstructions using tree ring records



[from: Ruddiman, 2008]

- a modern calibration (=relation between tree ring record and climate variable, e.g. temperature) is used to convert past tree ring variations into climate changes
  - *similar to other methods, one has to assume a priori that the the modern calibration curve can be applied for past times*

Climate reconstructions using tree ring records



- tree ring records can be a good proxy for regional climate changes during the last centuries

- many records show substantial warming in the 20th century
  - *however, the latest warming is missing in some of the tree records*

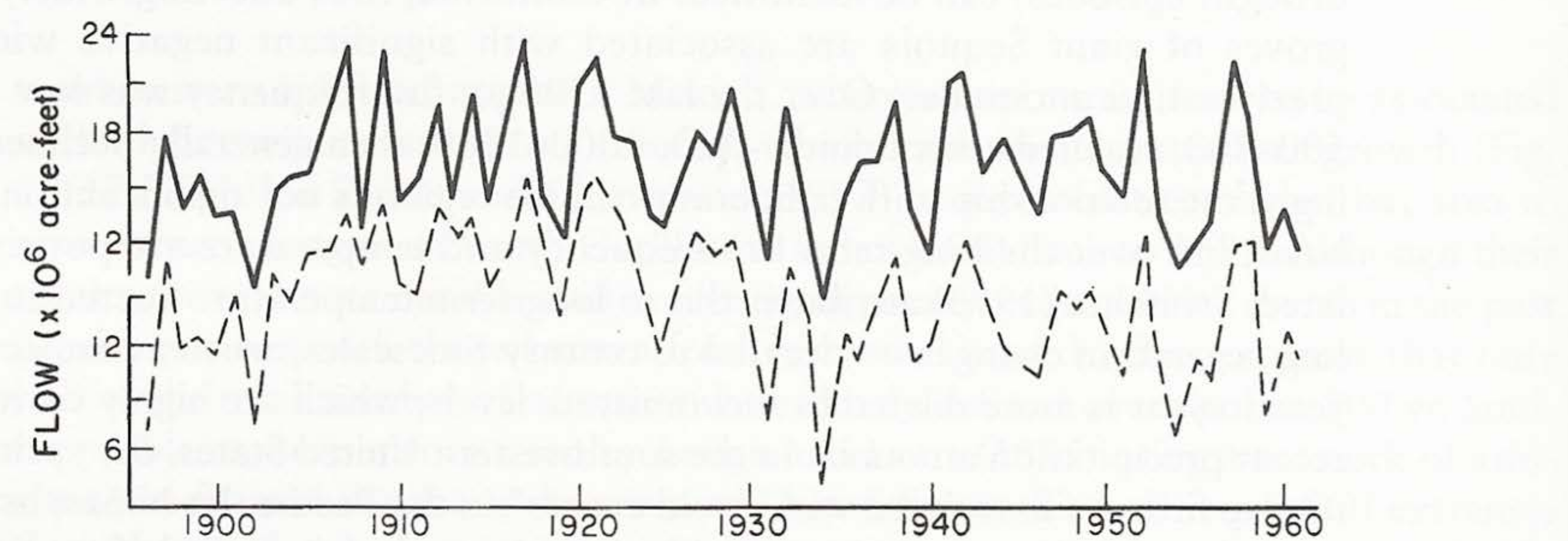
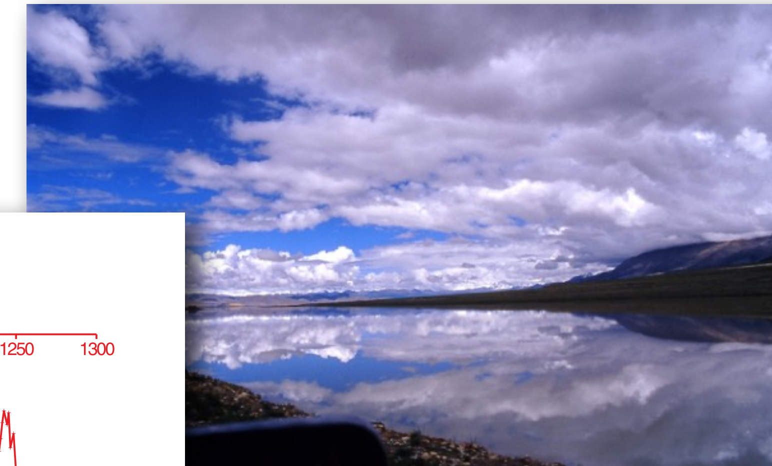


FIGURE 10.28 Runoff in the Upper Colorado River Basin. Reconstructed values (-----) are based on tree-ring width variations in trees on 17 sites in the basin. Actual data, measured at Lee Ferry, Arizona, are shown for comparison (——). Based on this calibration period, an equation relating the two days sets was developed and used to reconstruct the flow of the river back to 1564 (Fig. 10.29) (Stockton, 1975).

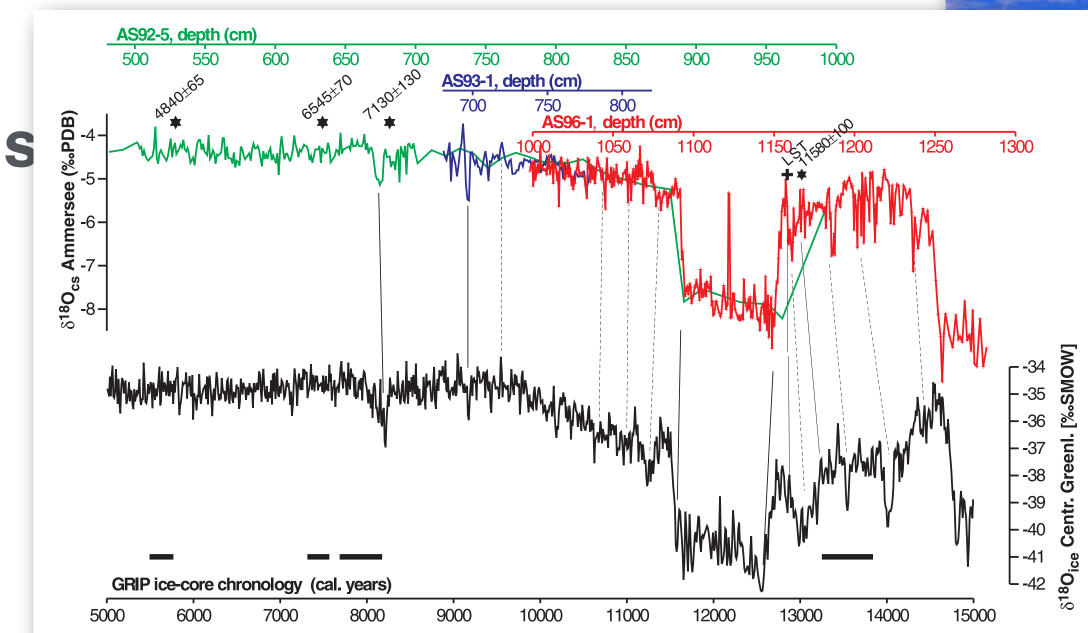
Bradley, Fig. 10.22, 10.28

Further climate archives

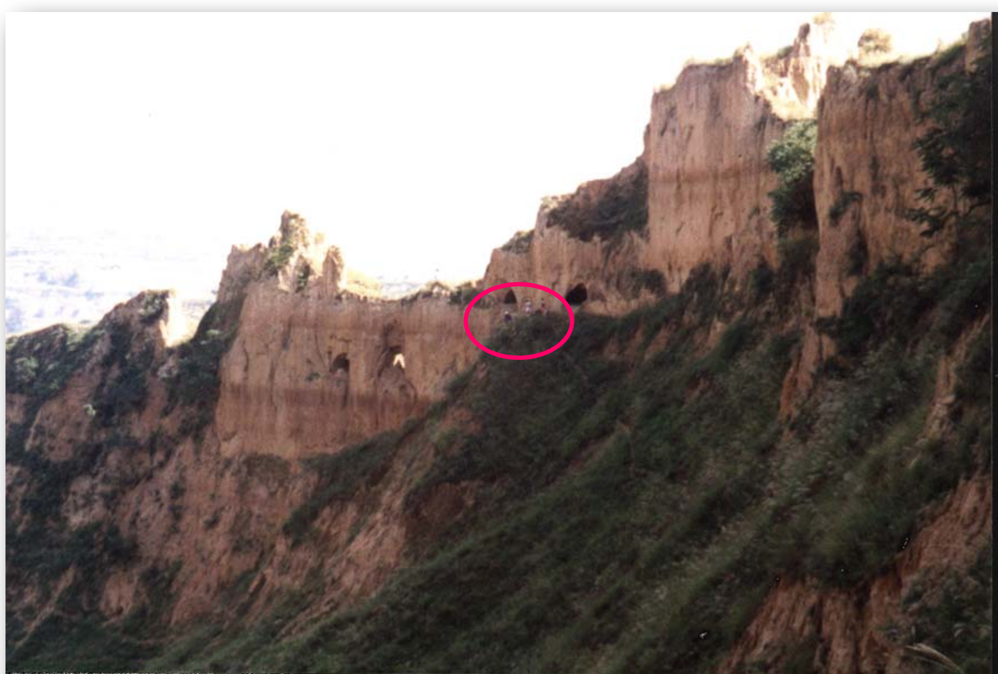
- lake sediment cores
- loess archives
- snow-line reconstructions and glacier movements
- lake level changes
- ....



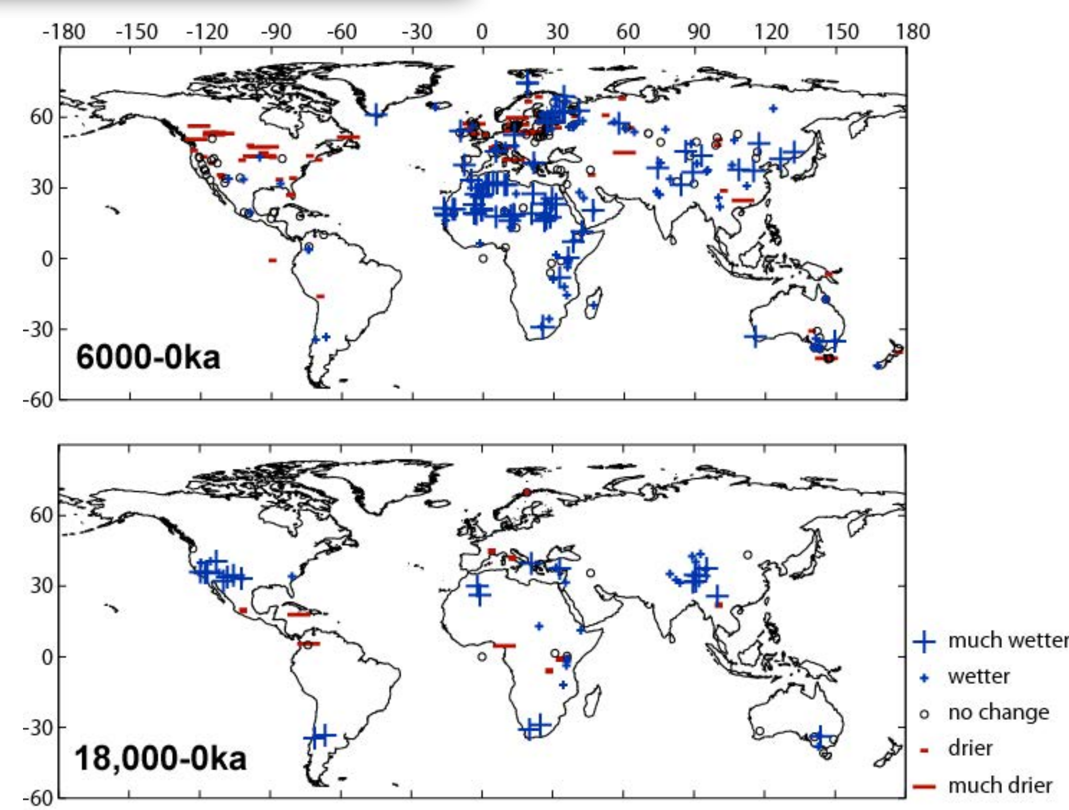
Nam Co lake, Tibetan Plateau



v. Grafenstein et al., Science, 1999



The loess/palaeosol sequence at Potou, Central Loess Plateau, China. The darkest of the bands seen in the sequence is the palaeosol complex S5. Search for the intrepid field-workers just above S4 for scale! http://www.aber.ac.uk/~qecwww/loessprog.html



PMIP Global Lake Status For The Mid-Holocene And Last Glacial Maximum
[https://pmip2.lsce.ipsl.fr/synth/lakestatus.shtml]

Climate System II

(Winter 2023/2024)

7th lecture:

Archives of climate change

(marine sediments, corals, speleothems, pollen, tree rings)

End of lecture.

Slides available at:

https://paleodyn.uni-bremen.de/study/climate2023_24.html