12.740 Paleoceanography
Spring 2008

Continental Evidence for Glacial Climate

12.740 Topic 12 Spring 2008

Introduction

In general, paleoclimatology is tougher on the continents than in the ocean. It is hard to find continuous accumulation sequences; in particular, near and under the northern ice sheets, the climate record is self-erasing. Also, the paleo-ecology is more problematical; does land vegetation respond simply to temperature and rainfall (or both or extremes of both)? There are fewer good geochemical indicators as well. The most successful techniques have involved lake sediments and peat bog sections. A few new methods have emerged in the recent years..

Studies of moraines, eskers, striations, etc.

Used to infer ice sheet presence, extent (from maximum through deglaciation), flow directions.

Note 700-1000 m depression of snow line (Hawaii, New Guinea, Columbia, and East Africa; Andean and Himalayan ice caps, others). Models suggest that this would require a 4°C decline in tropical air temperatures during peak glacial times.

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source: Broecker and Denton (1990) from data compiled by S. Porter

Tree rings

For the past ~8000 years, tree rings can help infer climate, either from width variations and O,C,H isotopes in the cellulose. ^{14}C variations also provide useful information. However, there are significant methodological questions about the meaning of stable isotopes in tree rings (are they affected by age of tree? do they record surface water or ground water? What is the effect of evapotranspiration on D and O in trees?...)

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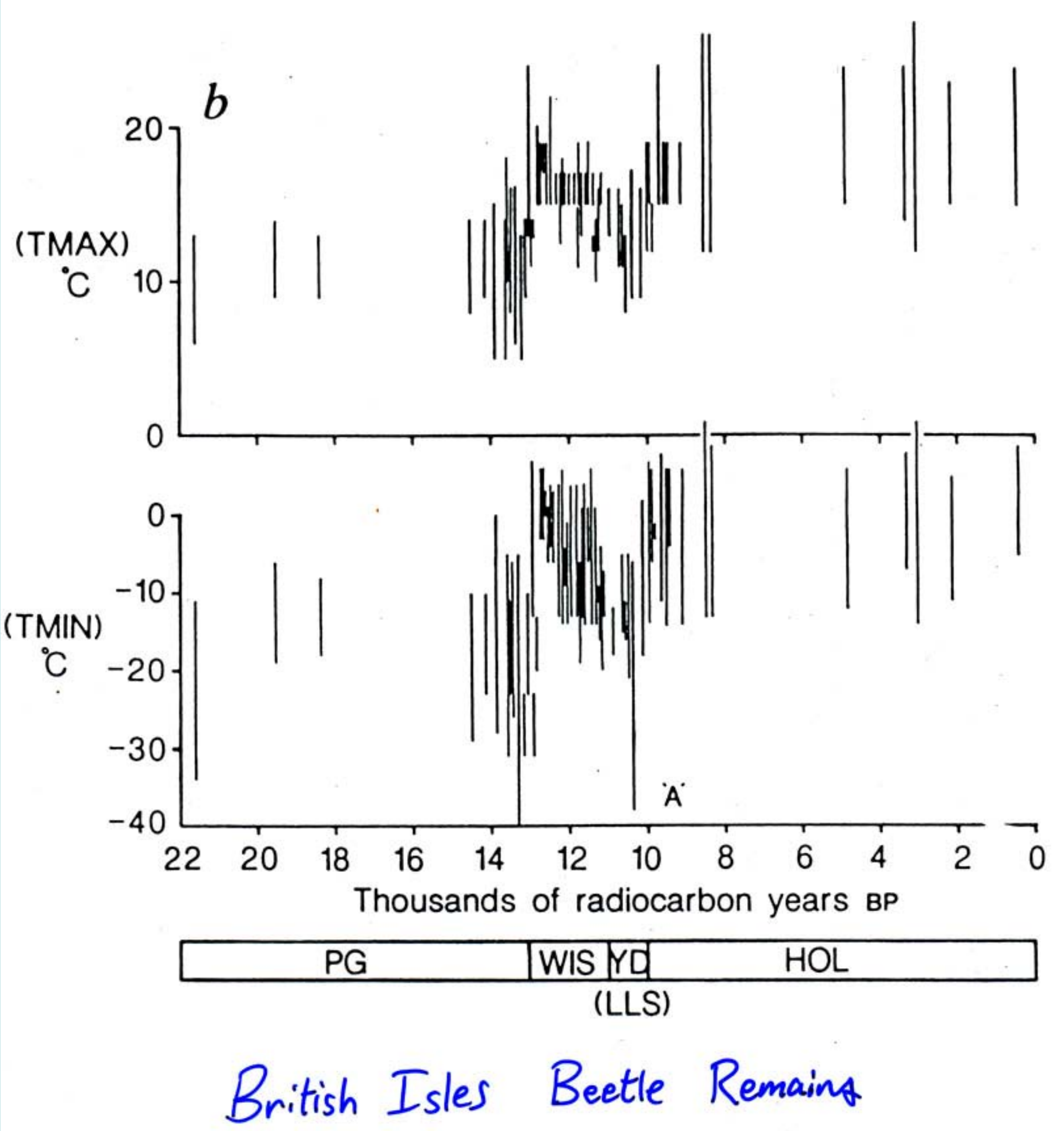
Yapp and Epstein

Some other bizarre climate indicators

- Packrat middens (e.g. what type of seeds were available? What is the $\delta^{13}C$ of those seeds? Not to mention the $\delta^{13}C$ of packrat urine…)
- beetle remains:



Pollen in lakes, peat bogs, and marine continental margin sediments

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(unglaciated) Europe was dominated by grasslands rather than arboreal landscapes.

Timing is comparable to oceanic record for the period covered by ^{14}C (extended to 70,000 years by enrichment)

Note: conventional ^{14}C years (not calibrated)

Woillard (1979)

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Woillard and Mook (1982)

COHMAP 2

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Science 241:1048.

Hi-elevation (2580 m) lake in Columbia (Laguna de Fuquene) provides a 20 kyr record that suggests that open vegetation dominated in place of forest (implying perhaps a 1500m lowering of vegetational zones)

Carp Lake, eastern Cascade Range, northwest America

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Lake Tulane, Florida

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Grimm. Science (1993) 261:199. Figures 2 and 4.

Varved lake record: Amersee, southern Gemany

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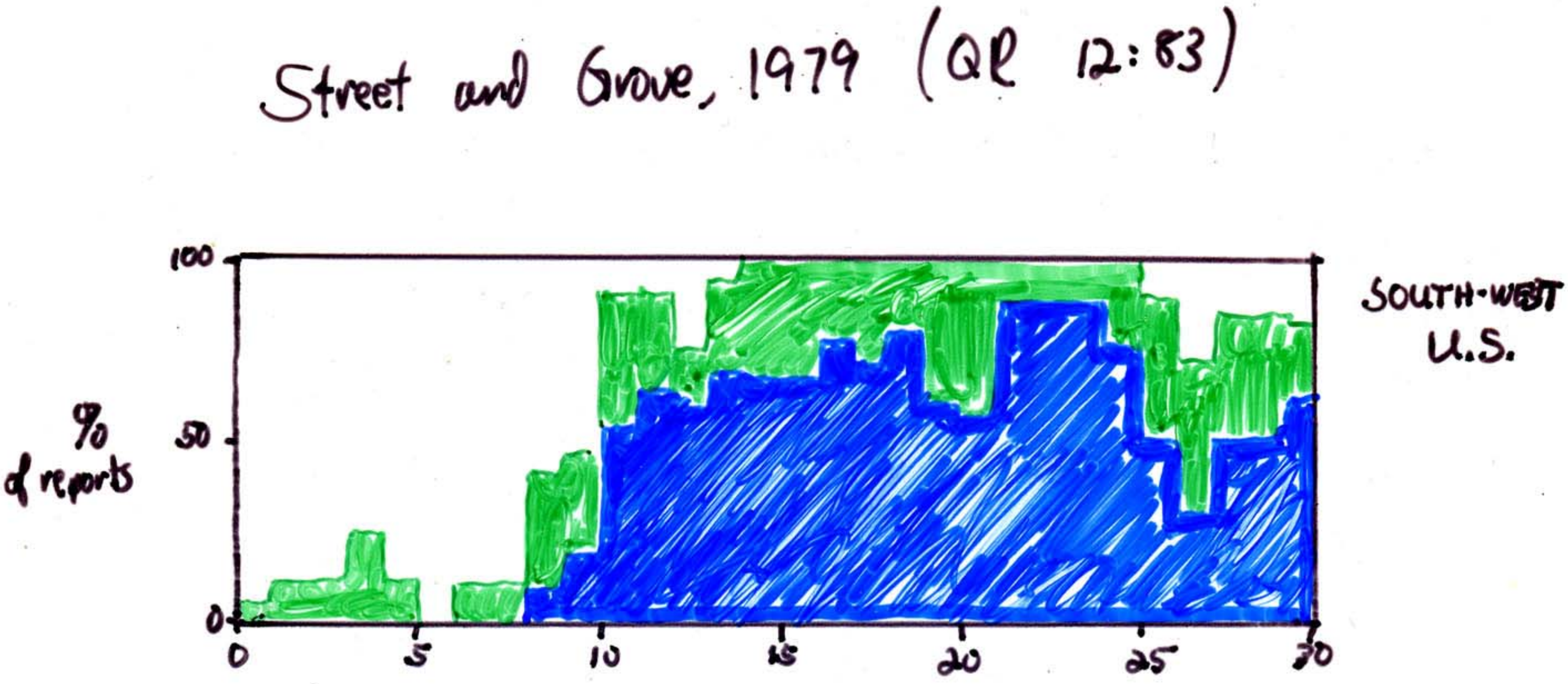
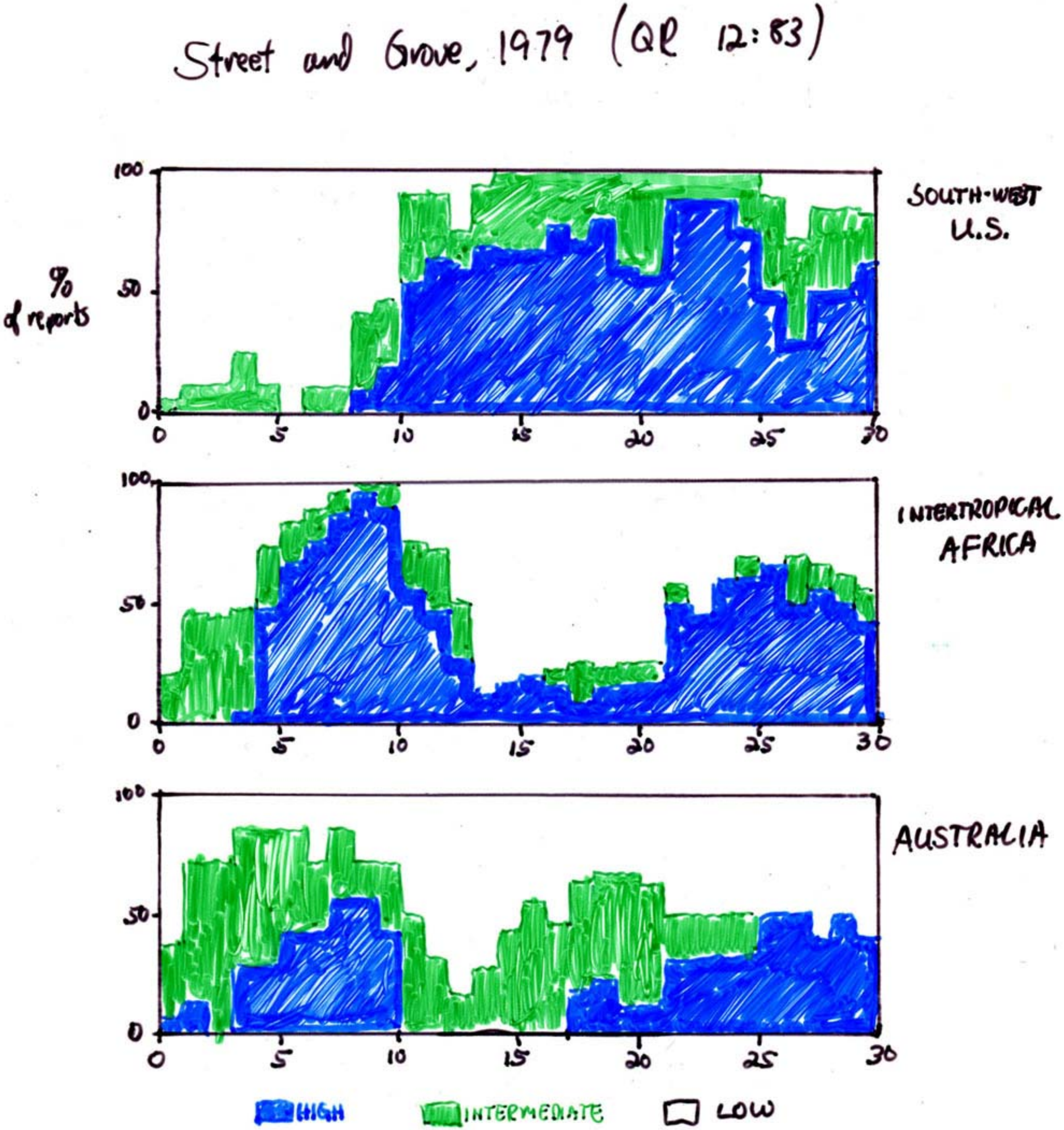
Science (1999) Vol. 284. Figure 1.

Lake Level Evidence: southwestern North America



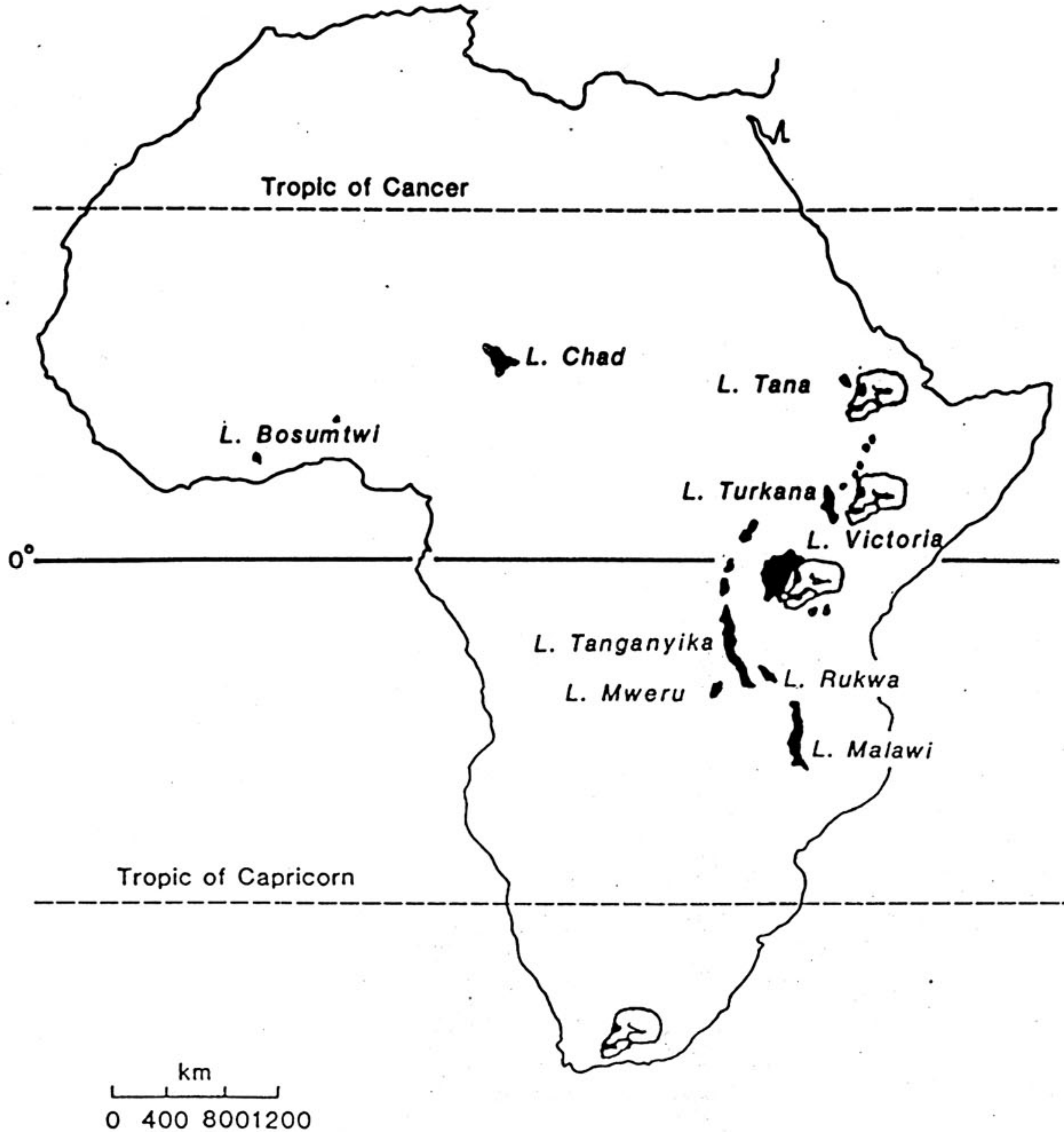
Lake Level Evidence: Africa and Australia, the distraction of “the pluvial”



African Lakes

Lakes of Africa

All the major archeological sites (denoted by skulls) are located in East and southern Africa. The lakes of interest to geologists, for tectonic information, are in East Africa. And yet the most convenient and reliable lake for an initial core, Lake Bosumtwi, is in West Africa.



Inter-tropical Africa lake level records, critical re-evaluation

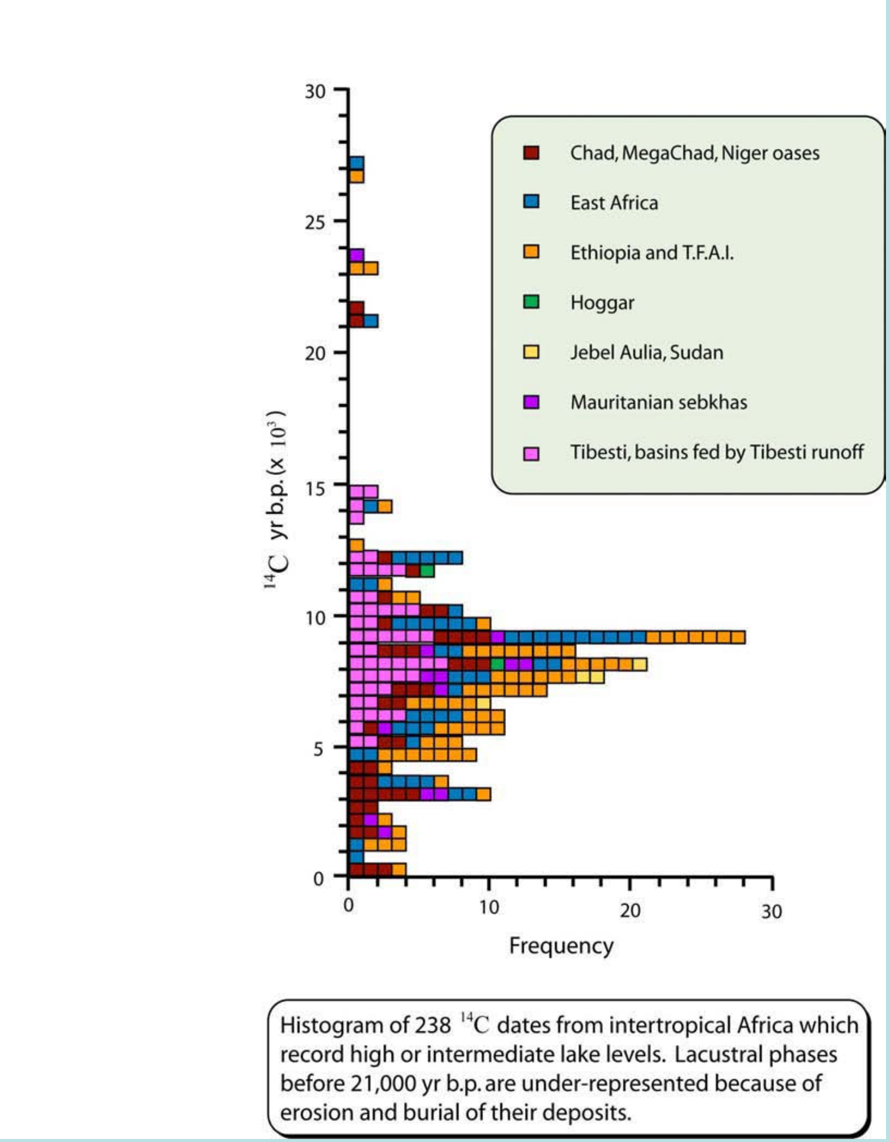


Figure by MIT OpenCourseWare. Adapted from source: Street and Grove (1979).

African lake levels, 0-18 kyr BP

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The monsoon effect: a well-understood influence of insolation changes on climate

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J. Kutzbach and others

Mediterranean sapropels and $\delta^{18}O$

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Modern dune deserts

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M. Sarnthein, Nature

LGM dune deserts

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M. Sarnthein, Nature

6000 ka BP

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M. Sarnthein, Nature

Deserts and humid conditions 0-18 ka BP

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0

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6

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18

Loess deposits in caves and in China; magnetic susceptibility

Wind-blown dust deposits in some areas leave a semi-continuous record. In some regions of China, the basic stratigraphy of these deposits can be readily established by measurements of magnetic susceptibility (how strongly a sediment sample retains a superimposed magnetic field).

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George Kukla (Lamont annual report)

? Amazon glacial aridity ? ("refugia" hypothesis)

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Also: interpretation of changes in mineralogy of sediments in Amazon fan - reduction of kaolinite during LGM interpreted as due to aridity of Amazon - but in fact most of the sediment yield from the Amazon comes from upstream ancient Andean sediments, not the moist tropical lowlands. What really changed is that when sea level dropped, Amazon sediments that today are swept northwards along the coast were deposited at shelf edge. Kaolinite comes from somewhere else…

Speleothems and Vein Calcites

Speleothems (stalactites and stalagmites) are carbonate deposits produced when groundwater drips from the roofs of caves and release CO_2 - thereby supersaturating in calcium carbonate and precipitating successive solid layers. Because groundwater is high in U, these deposits can be dated by U/Th methods (although one has to be careful about initial ^{230}Th). Carbon and oxygen isotope measurements are straightforward, although $\delta^{18}O$ is influenced by changes in both T and groundwater $\delta^{18}O$.

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Hulu Cave, China [1]

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Wang et al. (2001) Figure 1.

Hulu Cave, China [2]

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Wang et al. (2001) Figure 2.

Devil's Hole vein calcite controversy [1]

Winograd et al. (1985) and Ludwig et al. (1992) analyzed calcite deposited in a narrow groundwater vein in Nevada for δ18O and Th/U age. They reported that the deposit grew from ~566 to ~60 kyrBP, and that the $\delta^{18}O$ of this record indicated less depleted values at 140 kyrBP. They suggested that this record contradicted the SPECMAP chronology.

1. Many people questioned the reliability of their chronology (e.g., how could they be sure that the initial ^{230}Th was negligible when the youngest sample had significant ^{230}Th?). More recently, Edwards et al. (1997) used $^{231}Pa/^{235}U$ dating to check the ages of two Devil's Hole samples and found that the age was concordant with the ^{230}Th age - making it likely that the chronology is accurate. On the other hand, the meaning of the $\delta^{18}O$ record (knowing that groundwater can often be 20-40 kyr old) is not entirely straightforward. But recently Herbert et al. (2002) have used alkenone temperature estimates to show that there appears to be a significant phase offset for the temperatures of the southwestern US relative to the marine $\delta^{18}O$ record, with warming occurring well before deglaciation. This evidence suggests that the two records are showing a regional response to climate change that differs from the global mean.

Devil's Hole vein calcite controversy 2

Image removed due to copyright restrictions.

Winograd et al. Science (1992) Vol. 258. Figure 3.

Ocean temperatures off the southwest U.S.

Images removed due to copyright restrictions.

Herbert et al.

Noble gas groundwater paleotemperatures

- Basic idea is exquisitely simple: the different noble gases have different temperature dependence for their aqueous solubilities:
- If we have data on the equilibrium content of any two noble gases, the temperature is defined. Having multiple noble gases, the system is over-determined.
- Complications:
  - ^4He is added from radioactive decay; this addition can't be inferred from first principles
  - in addition to equilibrium solubility, some atmospheric bubbles are trapped and dissolved at higher pressures. The gas content of this component reflects the gas ratios of the atmosphere, not the solubility. This problem is significant, but it can be corrected for given data on several noble gases: e.g., by finding out which mixture of solubility equilibrium and air dissolution matches the data the best for Ne-Xe. The residual anomaly for He is taken as a measure of the radioactive decay contribution.
  - A recent multivariate approach to the data (Ballentine and Hall, 1999) suggests that the errors in the noble gas paleotemperature may be larger than stated by Stute et al., and that the Brazilian data in particular should be regarded with caution

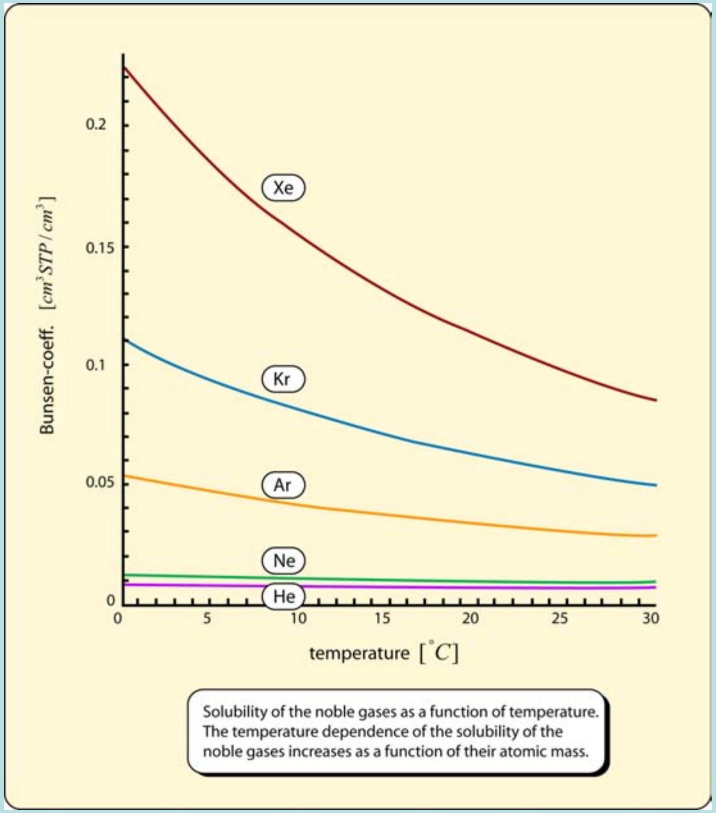
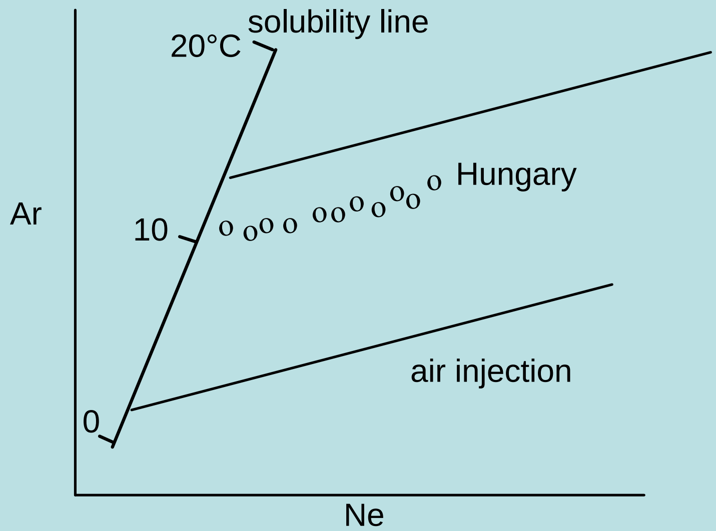


Figure by MIT OpenCourseWare.
Adapted from source: M. Stute.

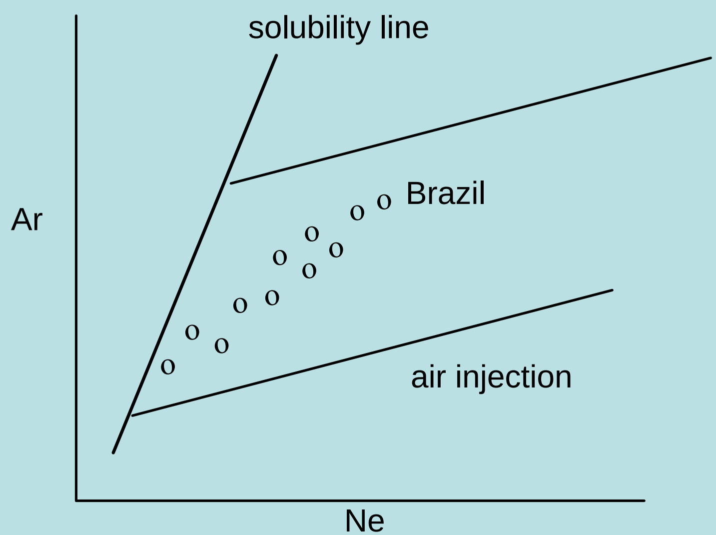
If there are numerous samples with different extents of bubble entrapment, the situation is easily identified:



(schematic, not actual data)

Unfortunately, it appears that in some cases the situation can be even more complicated:

"excess heavies" in Brazil aquifer - due to something other than solubility and air injection



(schematic, not actual data)

Groundwater aquifers - dating

- Typical flow velocities of the order of 1 meter per year - sometimes aquifers contain very old water. How do you estimate the age?

- ^{14}C dating of groundwater. Problem of "hard water" artifacts (dissolution of ancient calcium carbonate) requires avoidance of aquifers moving through carbonates. Any ^{14}C date has to be considered “less than or equal to…”

Noble gas temperature records

Image removed due to copyright restrictions.

Southwest U.S.

Stute et al., 1992

Great Hungarian Plain

Stute, 1989

Image removed due to copyright restrictions.

- Brazil coastal site -5°C (involves double correction -air plus heavy)
- South Africa - 5.5°C
- South Australia – 4°C

In summary, continental evidence from low-latitude sites (mostly from higher elevations) favors a cooler, dryer tropical climate during the last glacial maximum

- Is this consistent with the CLIMAP sea surface temperature reconstructions and the oxygen isotope evidence?
- Rind and Peteet (1985) showed that a particular GCM (Global Circulation Model) for the atmosphere could not reconcile CLIMAP with the continental evidence. In order to produce a cooler, dryer low-latitude continental climate, they had to cool tropical surface temperatures by 4°C in order to match the model climate with the continental observations.
- Broecker (1986) argued that the oxygen isotope evidence favors CLIMAP, with some possible uncertainties.
- Is this discrepancy due to problems with one or both data sets, or is it a problem with the climate model? More recent evaluations, using alternative marine paleotemperature methods (alkenones, Mg/Ca) and revised foraminiferal transfer functions suggest that the tropics cooled a bit, but by not as much as the continents.
- lapse rate ~5°C/km – so 130 m drop in sealevel would decrease continental temperature relative to sea surface temperature by about 0.7°C
- Bard (1999) points out that in computer GCM climate models, the continents are cooler than the ocean - partly because continents are 130 m higher relative to sea level than today and also because continental interiors are colder than marine-influenced boundaries.

Marine-continental correlations

- "eolian diatoms"
- Wind-blown pollen (or river- or slump-transported) into oceanic sediments;
- wind-blown detrital sediments

Low-latitude ice cores

- Mountain glaciers
- Most mountain glaciers are receding - may not be there much longer
- Logistical issues (how to get there and back; how to transport (frozen) samples
- Chronology

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