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12.740 Paleoceanography
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Continental evidence for glacial climate change

- I. 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 lakes sediments and peat bog sections. A few new methods have emerged in the past few years, however.
- II. Studies of moraines, striations, eskers, etc. (sometimes ^{14}C dated) to infer ice sheet movements, coverage at maxima and subsequent retreat pattern.
- 700-1000 m snowline depression in Hawaii, New Guinea, Columbia, and East Africa; Andean and Himalayan ice caps. Models suggest that this would require a 4°C decline in tropical air temperatures during peak glacial times.

Image removed due to copyright considerations.

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

- III. For the last 8,000 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?...)
- IV. Some other bizarre paleoclimate indicators: packrat middens (e.g. what type of seeds were available? What is the $\delta^{13}\text{C}$ of those seeds? Not to mention the $\delta^{13}\text{C}$ of packrat urine..., beetle remains,)
- V. Pollen evidence: Lakes, peat bogs, marine continental margin sediments.

A. (unglaciated) Northern 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 ^{14}C enrichment).

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Source: Woillard (1979), figure 1.

Image removed due to copyright considerations.
Source: Woillard and Mook (1982), figure 1.

- B. 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).
- C. COHMAP program; response functions; patterns of vegetational change in North America since the last glacial maximum
- D. Long Lake records: chronology is a problem beyond the range of ^{14}C

Example: eastern Cascade Range, NW America:

Image removed due to copyright considerations.
Source: Whitlock and Bartlein, 1997, figure 1.

Example: Lake Tulane, Florida

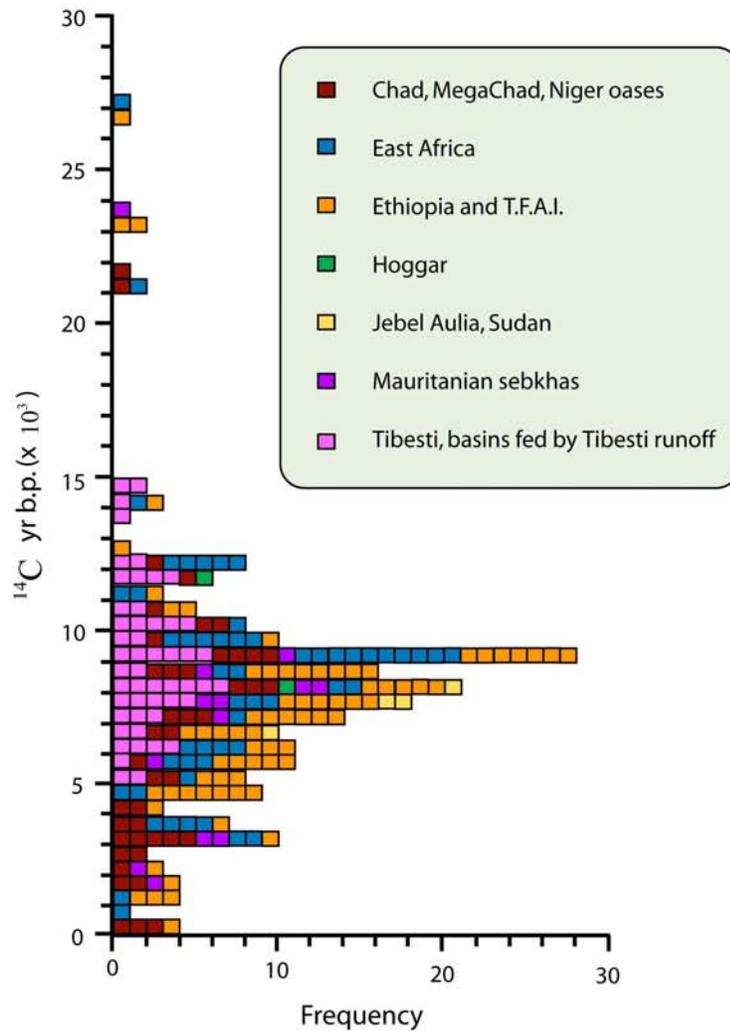
Figures 2 and 4 in Grimm E. C., G. L. Jacobsen, W. A. Watts, B. C. S. Hansen, and K. Maasch. "A 50,000 year record of climate oscillations from Florida and its temporal correlation with the Heinrich Events." *Science* 261 (1993): 198-200.

E. Varved lake records

Image removed due to copyright considerations.
 Source: von Grafenstein et al., 1999, figure 1.

VI. Lake level evidence: ^{14}C dates of shoreline deposits. Paleo-monsoons

A. African lake level histories



Histogram of 238 ^{14}C dates from intertropical Africa which record high or intermediate lake levels. Lacustral phases before 21,000 yr b.p. are under-represented because of erosion and burial of their deposits.

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

Images removed due to copyright considerations.
Source: Street and Grove, 1976, figure 2, 3, 4, and 5.

VII. Loess deposits in caves and in China; paleomagnetic 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).

Image removed due to copyright considerations.
Source: George Kukla (Lamont annual report).

VIII. Lake carbonates, speleothems and vein calcites

- A. 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 $\delta^{18}\text{O}$ is influenced by changes in both T and groundwater $\delta^{18}\text{O}$.

Images removed due to copyright considerations.
Source: Wang et al. (2001), figure 1 and 2.

- B. Some hard water lakes precipitate CaCO_3 that accumulates in sediments. Isotopic composition is a function of changes in the water (mean temperature of precipitation) and local temperature.
- C. Devil's Hole vein calcite controversy. Winograd et al. (1985) and Ludwig et al. (1992) analyzed calcite deposited in a narrow groundwater vein in Nevada for $\delta^{18}\text{O}$ and Th/U age. They reported that the deposit grew from ~566 to ~60 kyrBP, and that the $\delta^{18}\text{O}$ of this record indicated less depleted values at 140 kyrBP. They suggested that this record contradicted the SPECMAP chronology.
1. Several 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 $^{231}\text{Pa}/^{235}\text{U}$ 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 $\delta^{18}\text{O}$ 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 $\delta^{18}\text{O}$ 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.

Image removed due to copyright considerations.

Source: Herbert et al. (2002).

IX. Continental chronology is a problem once we are past the useful ^{14}C time span. Other dating techniques: thermoluminescence; speleothems can be ^{230}Th dated (although the assumption that initial ^{230}Th is zero is at least somewhat questionable)

X. Low-latitude mountain glaciers

A.

B. Some low-latitude mountain glaciers are suitable for ice coring: e.g., Guliya Ice Core, Tibet

Figure 3 in Thompson L. G., T. Yao, M. E. Davis, K. A. Henderson, Thompson E. Mosely, P.-N.Lin, J. Beer, H.-A. Synal, Dai J. Cole, and J. F. Bolzan. "Tropical climate instability: the last glacial cycle from a Quinhai-Tibetan ice core." *Science* 276 (1997): 1821-1825.

XI. Noble gas solubilities in relic groundwaters

A. Basic idea is exquisitely simple: the different noble gases have different temperature dependence for their aqueous solubilities:

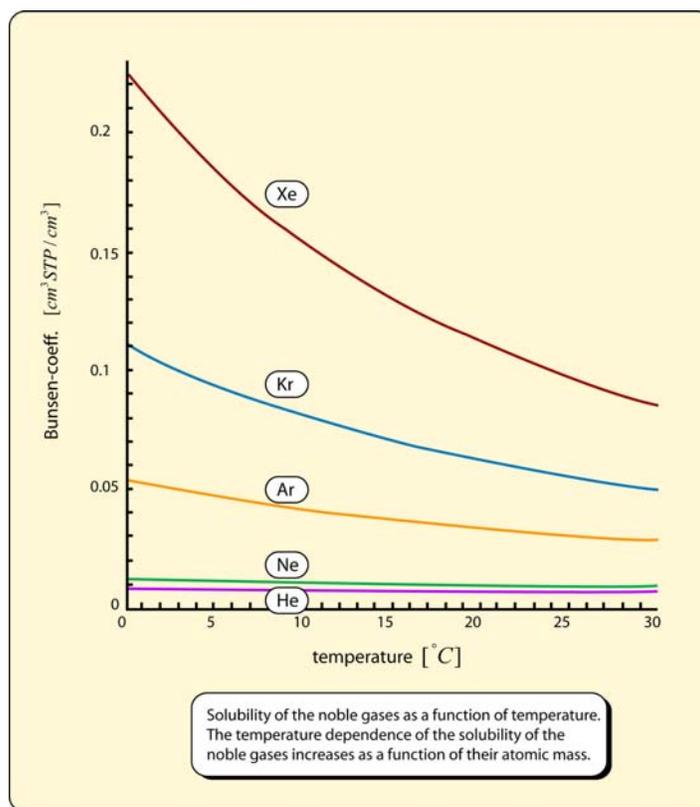
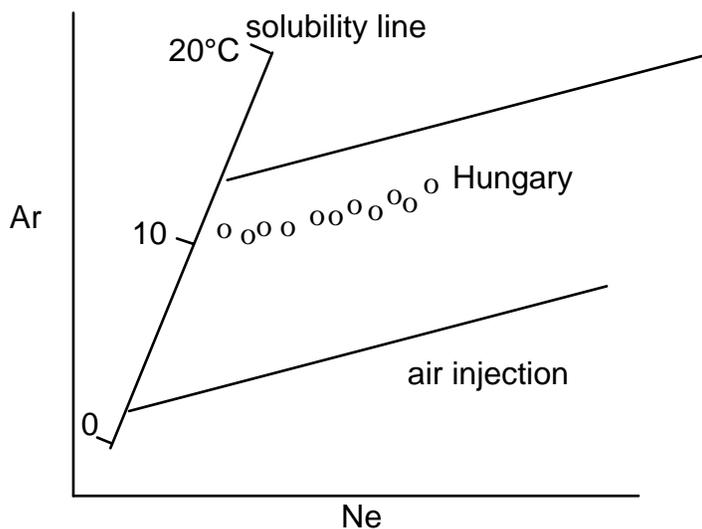


Figure by MIT OpenCourseWare.
Adapted from source: M. Stute.

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.

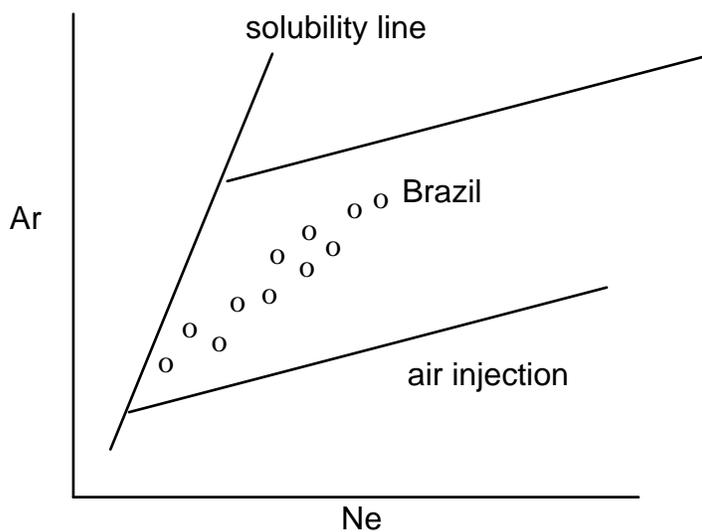
B. Complications: (1) ^4He is added from radioactive decay - and this addition can't be inferred from first principles; (2) in addition to equilibrium solubility, some atmospheric bubbles are trapped and dissolved at higher pressures. The gas content of this component reflects the inter-gas ratio of 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.

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:



(schematic, not actual data)

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

C. Groundwater aquifers - typical flow velocities of the order of 1 meter per year - sometimes contain very old water - but how do you estimate the age?

1. ^{14}C dating of groundwater. Problem of "hard water" artifacts (dissolution of old calcium carbonate) requires avoidance of aquifers moving through carbonates.

Image removed due to copyright considerations.
Source: Stute, 1989.

Image removed due to copyright considerations.
Source: Stute et al. (1992).

D. Dispersion will cause some smoothing of the climate signal in the aquifer - can't expect to see short events.

E. Some results:

1. Great Hungarian Plain
2. Texas
3. New Mexico
4. Brazil coastal site - also 5 degC (involves double correction -air plus heavy)
5. South Africa - 5.5
6. South Australia - 4
7. Two sites in Europe (nearer to the ice sheet) show larger temperature drops.

F. 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.

XII. In summary, continental evidence from low-latitude sites (mostly from higher elevations, however) favors a cooler, dryer climate during the last glacial maximum. But is this consistent with the CLIMAP sea surface temperature reconstructions and the oxygen isotope evidence?

A. 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.

B. Broecker (1986) argues that the oxygen isotope evidence favors CLIMAP, with some possible uncertainties.

C. 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. However, Bard (1999) points out that in computer GCM climate models, the continents are cooler than the ocean - partly because of the 130 m sea level drop (hence continents are 130 m higher relative to sea level than today) and also because continental interiors are colder than marine-influenced boundaries.

XIII. Marine-continental correlations

- A. "eolian diatoms"
- B. pollen blown (or river or slump transported) into oceanic sediments;
- C. wind-blown detrital sediments

Reading:

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