Paleoclimate

Geomorphology and ice core proxies

Durban G Keeler

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Overview

- Introduction to paleoclimate
- Glacial geomorphology
- Stable water isotopes
- Ice core reconstructions

Paleoclimate

- Study of the climate (temperature, moisture, wind vectors, etc.) prior to direct, quantitative observations of climatological variables
- Why would we want to know about climate in the past?

Paleoclimate

- How do we measure temperature?

Paleoclimate

- How do we measure temperature?
  - Mercury displacement (traditional thermometers)
  - Changes in electrical properties (digital thermometers)
  - Emission spectrum (satellites, infrared sensors)
- Direct temperature measurements only go back a few hundred years
- How can we estimate temperature before thermometers?
  - Proxies

Paleoclimate proxies

- An indiect measurement of a variable (i.e. the proxy) that is correlated with some other variable of interest (e.g. temperature)
- Percentage of people wearing a coat
- Examples of temperature proxies:
  - Coral distributions
  - Tree ring widths
  - Types and fequency of vegetation/pollen
- Focus on two specific proxies
  - Glacial geomorphology
  - Isotopes in ice cores

Glacial geomorphology

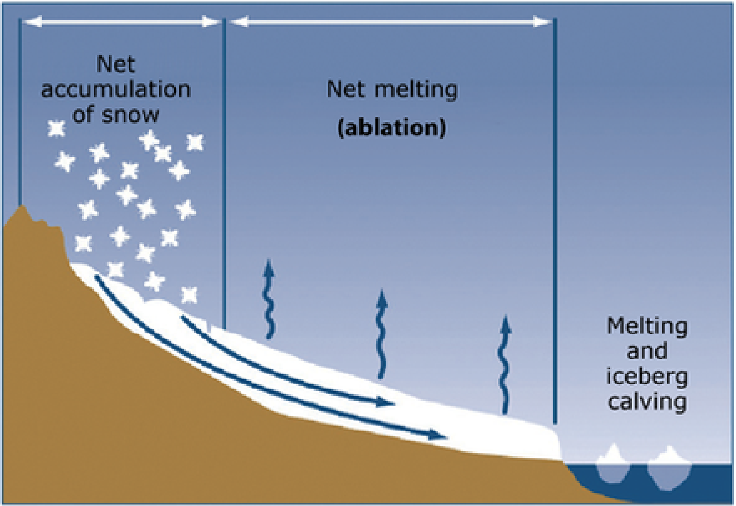
Glacial geomorphology

- Changes in landscape due to presence or changes in nearby glaciers
    - Glacier valleys
    - Moraines
    - Meltwater planes
    - Glacial scouring
    - Glacial erratics

Example of glacial erratic

Example of glacial scour

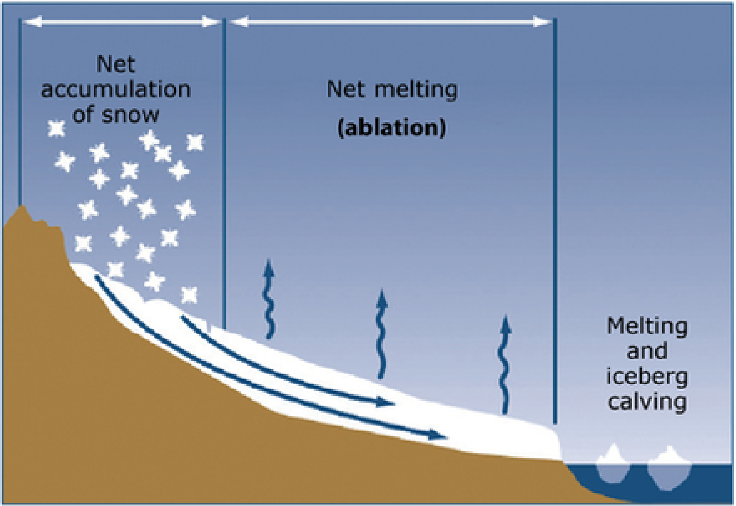
Review of glacier mass balance



$$\dot{b} = accumulation - ablation$$

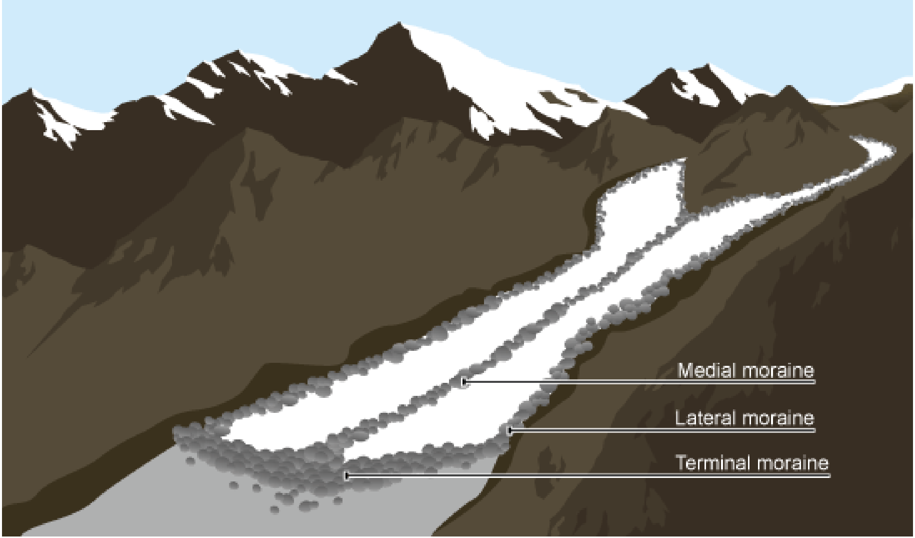
- What happens if temperatures increase?
- What happens if more snow falls?

$\dot{b} = accumulation - ablation$



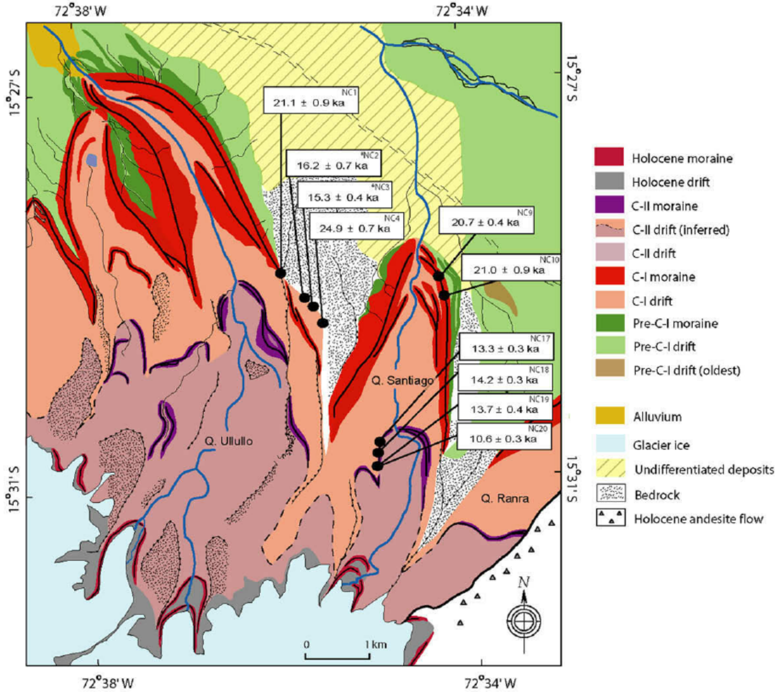
Moraines

- Mass of rock and debris pushed by movement of glacier (best preserved in equilibrium)
- Records the extent of a glacier at a specific point in time
- Three types of moraines:
    - Lateral
    - Medial
    - Terminal


Medial moraine
Lateral moraine
Terminal moraine

Moraines

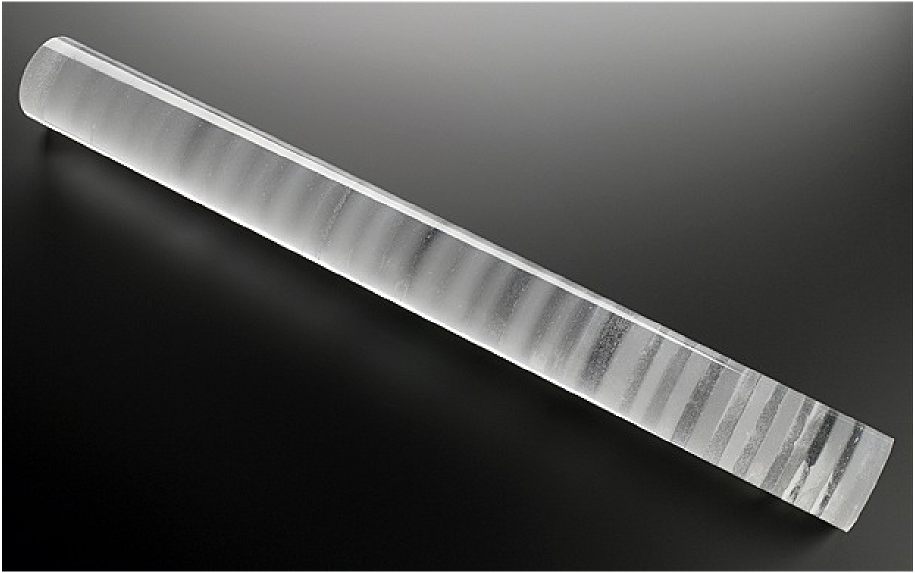
- We can use moraine positions to reconstruct glacier growth/retreat over time
- We can then make inferences about the changes in climate driving those glacial changes


72°38' W
72°34' W
15°27' S
15°31' S
21.1 ± 0.9 ka
NC1
16.2 ± 0.7 ka
*NC2
15.3 ± 0.4 ka
*NC3
24.9 ± 0.7 ka
NC4
20.7 ± 0.4 ka
NC9
21.0 ± 0.9 ka
NC10
13.3 ± 0.3 ka
NC17
14.2 ± 0.3 ka
NC18
13.7 ± 0.4 ka
NC19
10.6 ± 0.3 ka
NC20
Q. Santiago
Q. Ullullo
Q. Ranra
N
0
1 km
Holocene moraine
Holocene drift
C-II moraine
C-II drift (inferred)
C-II drift
C-I moraine
C-I drift
Pre-C-I moraine
Pre-C-I drift
Pre-C-I drift (oldest)
Alluvium
Glacier ice
Undifferentiated deposits
Bedrock
Holocene andesite flow

Complications

- Different glaciers respond to climate differently
- Features can erode naturallly, or overridden by later glacial events
- Difficult to seperate effects of different climatic variables
  (e.g. temperature or preciptation?)
- Can be difficult to place a specific moraine set to an absolute point in time

Ice cores

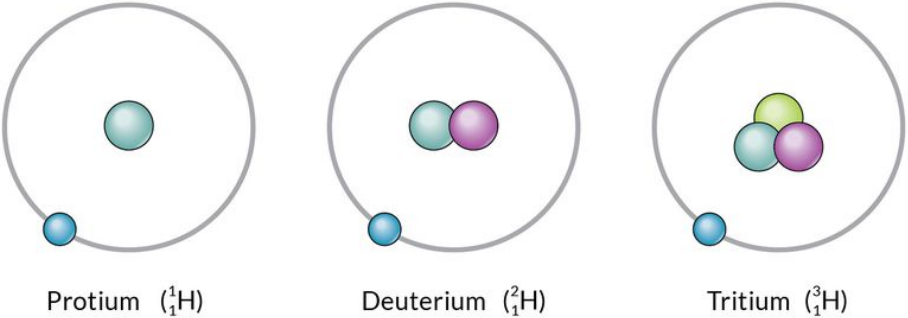


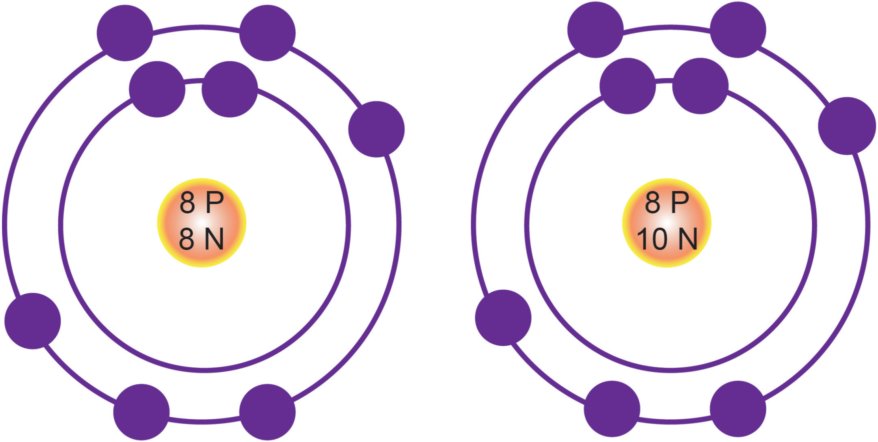
Stable water isotopes

- Focus specifically on two isotope species
  - Deuterium (^2H) and oxygen-18 (^{18}O)
- Stable isotopes (i.e. they do not decay over time)
- Naturally occurring, but in much lower abundance
- Isotopes behave chemically similar to more abundant variety
  - Forms water molecules (e.g. $H_2^{18}O$ and $^1H^2H^{18}O$)

Isotope review

- Same element with differing number of neutrons in the nucleus

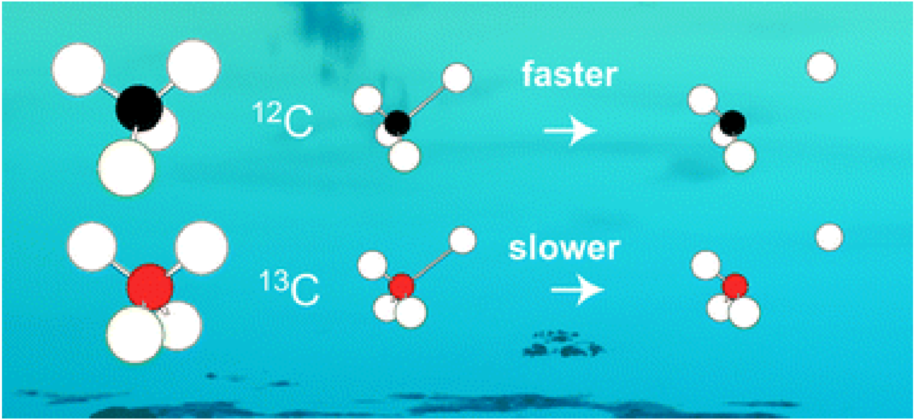




^{16}O Isotope ^{18}O Isotope

Fractionation physics

- Although chemically similar, isotopes respond slightly differently due to differences in bond strength and diffusion velocity
- Heavier isotopes (e.g. ^{2}H and ^{18}O) vibrate at a lower frequency and diffuse more slowly (conservation of momentum)
  - Energetically more favorable in lower energy states
- This leads to a fractionation effect i.e. a preference of heavier isotopes go into/remain in lower energy phases
  - Isotopic ratio changes during a phase change



faster
slower
^{12}C
^{13}C

Table 2.1: Natural abundances of oxygen and hydrogen isotopes. After Mook (2001).

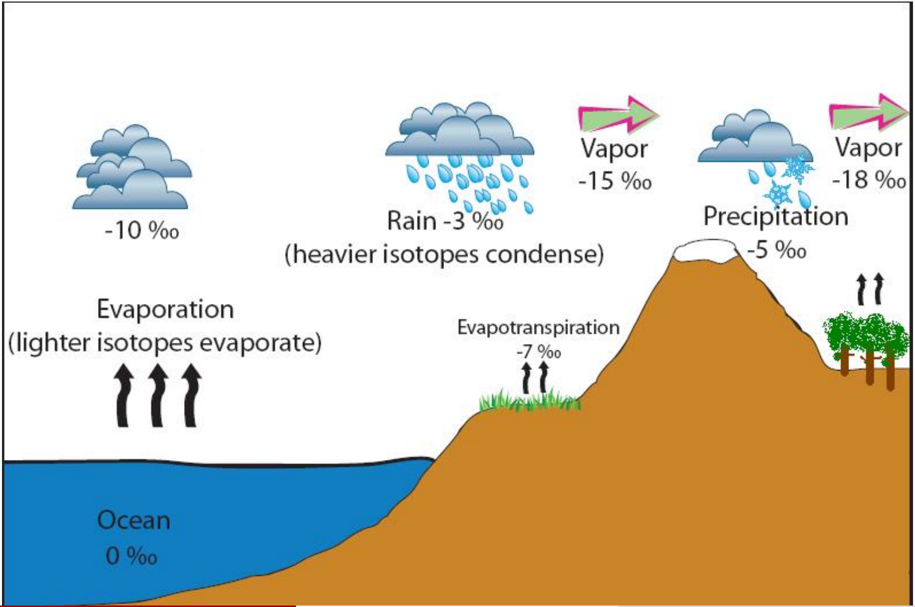
Oxygen		Hydrogen	
Isotope	Abundance (%)	Isotope	Abundance (%)
^{16}O	99.76	^{1}H	99.985
^{17}O	0.038	$^{2}H(D)$	0.015
^{18}O	0.200	$^{3}H(T)^{*}$	$< 10^{-15}$

*radioactive isotope

Figure 1: Stable water isotope abundances

- Measure isotopic values as a ratio between the rare isotope and the more common form
  - E.g. ${}^{18}R = \frac{[H_2^{18}O]}{[H_2^{16}O]}$
- More informative when we express these ratios relative to a standard (V-SMOW)
  - $\delta^{18}O = \frac{{}^{18}R_{sample} - {}^{18}R_{std}}{{}^{18}R_{std}} x1000$

- Evaporation leads to a water vapor depleted in heavier isotopes, and remnant liquid water enriched



Equilibrium fractionation

- Equilibrium and kinetic fractionation influence final δ values
- In regards to precipitation cycles, most of the isotopic fractionation is governed by equilibrium effects
- Vapor transport gives sufficient time for liquid/vapor constituents to remain in equilibrium
- The amount of equilibrium fractionation is governed by a reaction constant (the 'fractionation factor' α)

$$\alpha^{18}O_{water-vapor} = \frac{(^{18}O/^{16}O)_{water}}{(^{18}O/^{16}O)_{vapor}}$$

- At lower temperatures, this fractionation constant is highly temperature-dependent

$$10^3 \cdot ln(\alpha_b^a) = \frac{A \cdot 10^6}{T^2} + B$$

- (A and B are constants unique to the substances in exchange)

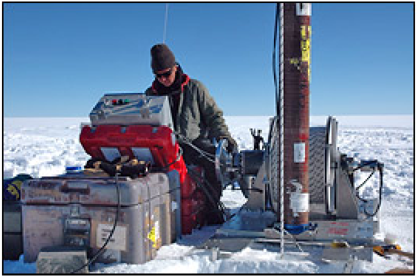
$$10^3 ln(\alpha_b^a) \approx \delta_a - \delta_b = \Delta_b^a$$

- Dansgaard determined an empirical estimate of temperature from $\delta^{18}O$ values:

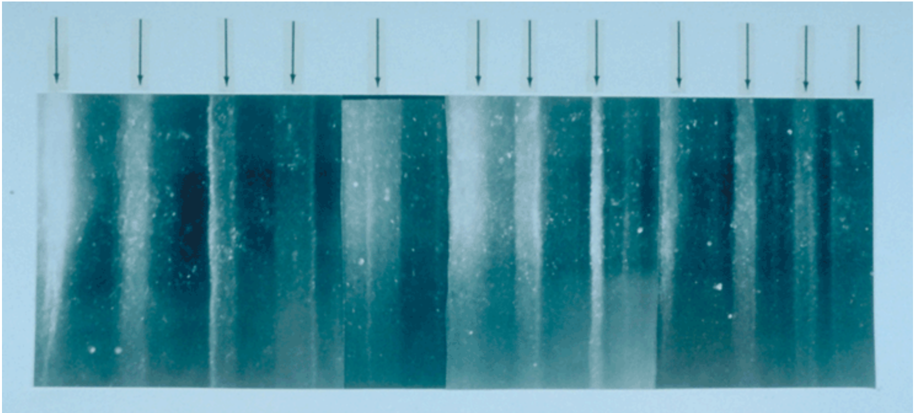
$$\delta^{18}O \approx 0.62 \cdot T - 15.25$$

- Can be subject to localized variation as well

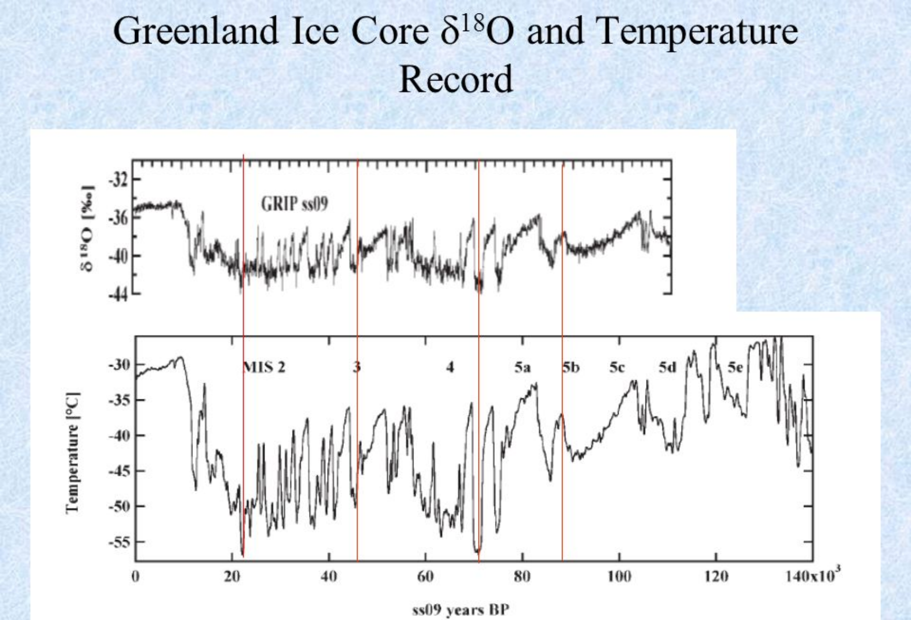
Paleoclimate reconstruction

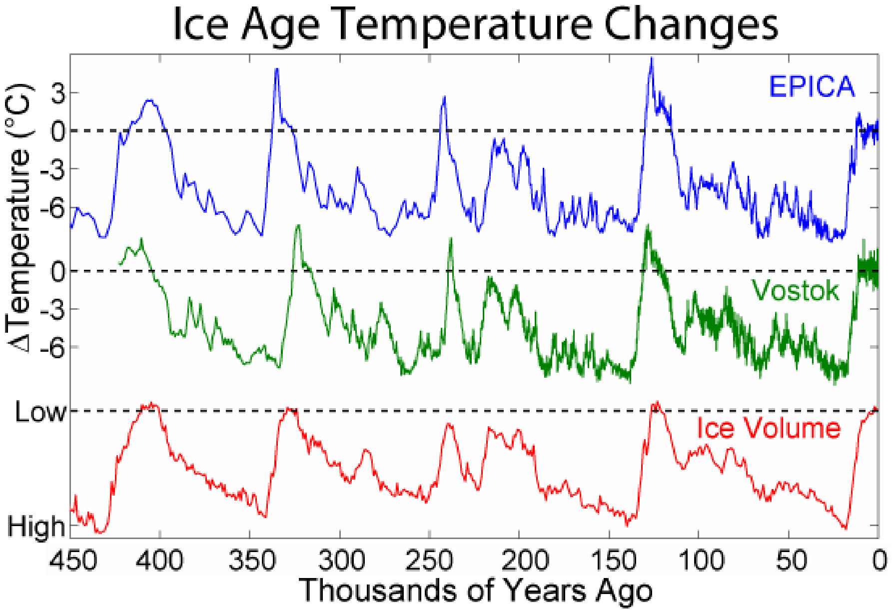


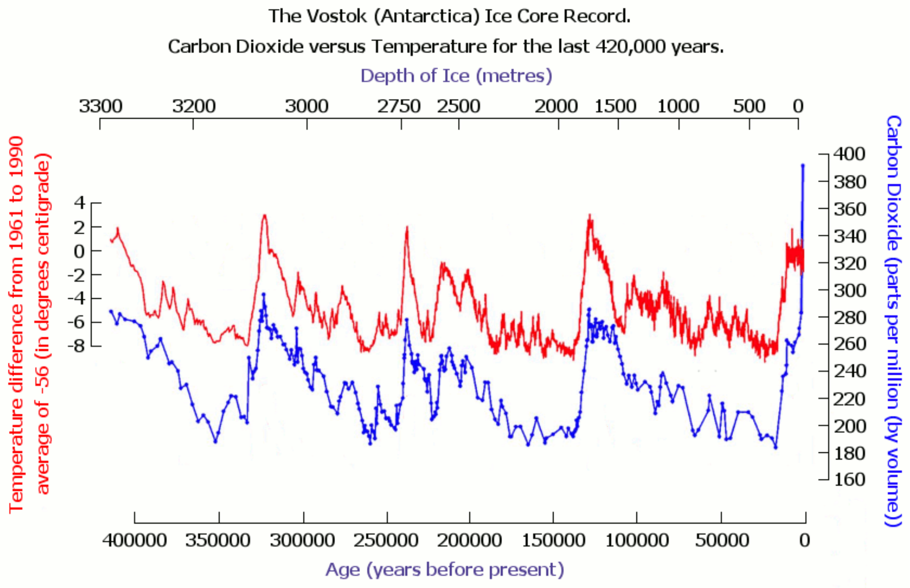




Paleoclimate reconstruction




Ice Age Temperature Changes
EPICA
Vostok
Ice Volume
ΔTemperature (°C)
3
0
-3
-6
0
-3
-6
Low
High
450
400
350
300
250
200
150
100
50
0
Thousands of Years Ago



The Vostok (Antarctica) Ice Core Record.
Carbon Dioxide versus Temperature for the last 420,000 years.
Depth of Ice (metres)
3300 3200 3000 2750 2500 2000 1500 1000 500 0
Temperature difference from 1961 to 1990 average of -56 (in degrees centigrade)
4 2 0 -2 -4 -6 -8
Carbon Dioxide (parts per million (by volume))
400 380 360 340 320 300 280 260 240 220 200 180 160
400000 350000 300000 250000 200000 150000 100000 50000 0
Age (years before present)