Lecture 16

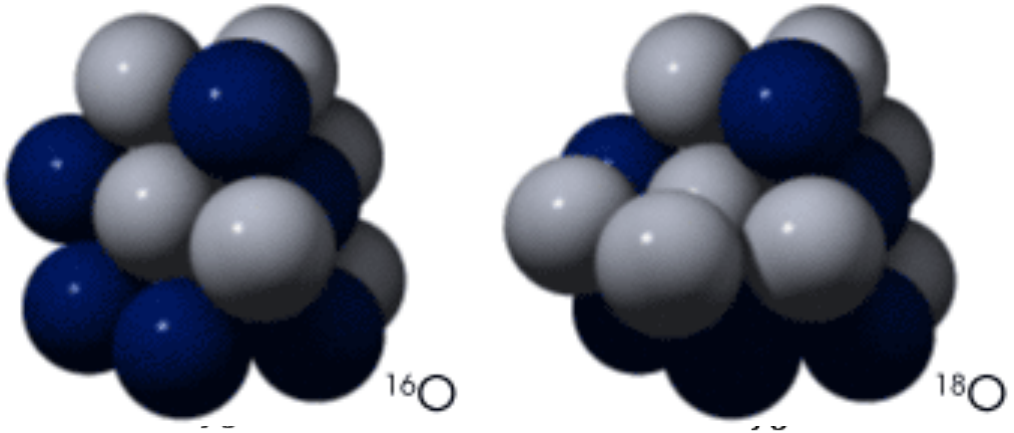
Oxygen Isotopes

Appendix I: p. 359-361; Ch. 6.2 p. 100-101

- How can we tell the temperature in the geological past?
- What are isotopes?
- Compare two isotopes of oxygen in ice cores, coral reefs, and sediments.

Introduction to Isotopes

Atoms of all matter on Earth are made up of a nucleus and electrons.
Atoms with the same number of electrons and protons, but different numbers of neutrons, are called ISOTOPES



atoms: **electrons: very little mass and negative charge**
nucleus - mass and positive charge

number of electrons:
determines the behavior of an atom in chemical reactions
determines which element it is

an atom is neutral in charge, therefore:
number of charged particles in the nucleus (protons) =
number of electrons

there are also non-charged particles in the nucleus (**neutrons**)

different isotopes
the same number of electrons,
the same number of protons,
but different numbers of neutrons

Isotope Geochemistry

Isotopes are forms of a chemical element that have the same atomic number but differ in mass.

Oxygen is made up of two isotopes: Oxygen - 16 (also known as ^{16}O → 8 protons + 8 neutrons; a "light" oxygen);

Oxygen - 18 (aka ^{18}O → 8 protons + 10 neutrons; a "heavy" oxygen).

16 and 18 are atomic masses of isotopes ^{16}O and ^{18}O.

The relative amounts of these two isotopes in a sample of water, ice, rock, plant, human, etc. is a function of climate/environment

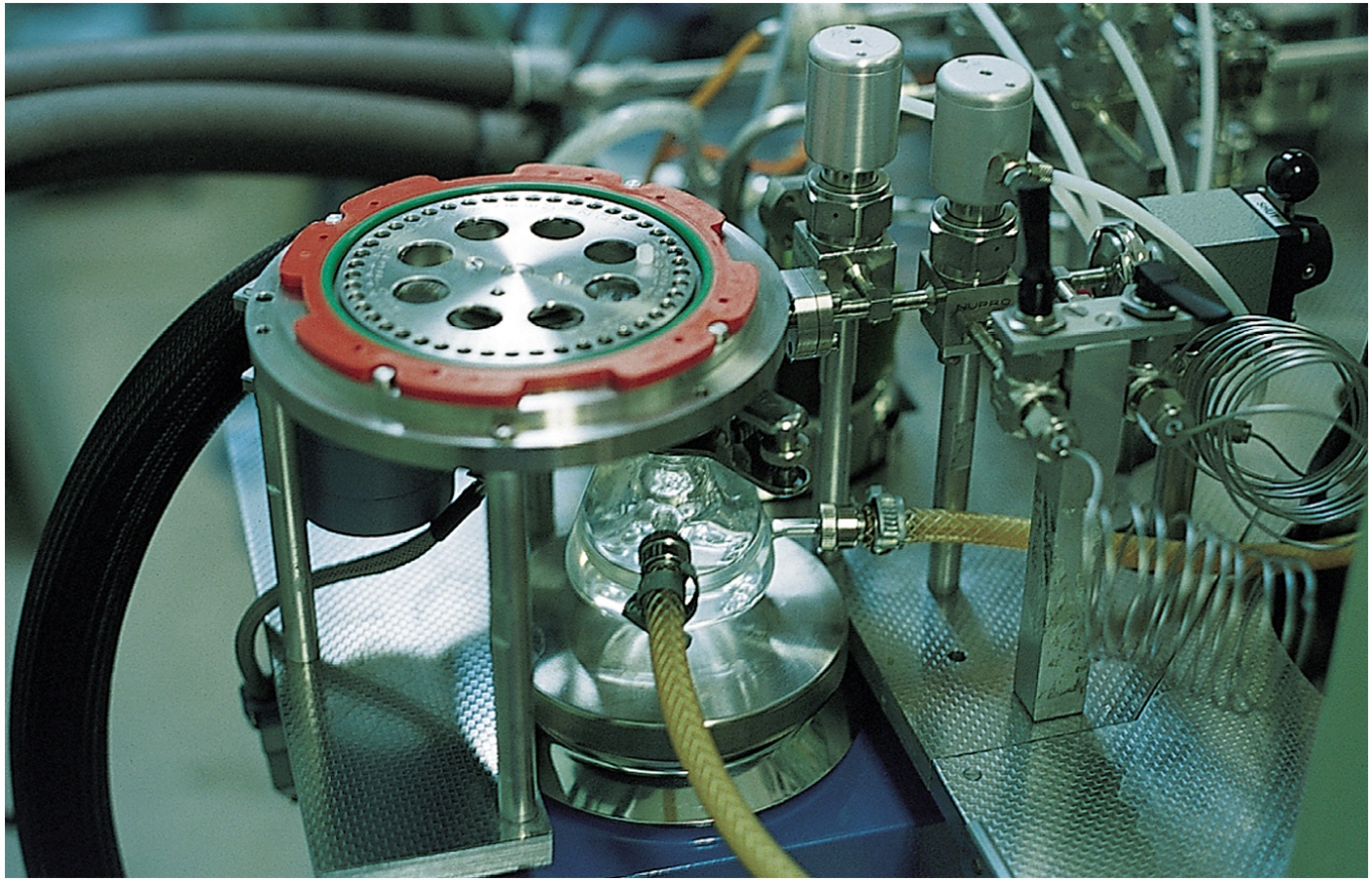
The relative amounts are expressed as either $^{18}O/^{16}O$ or $\delta^{18}O$

^{16}O ~99.8% ^{18}O ~0.2%

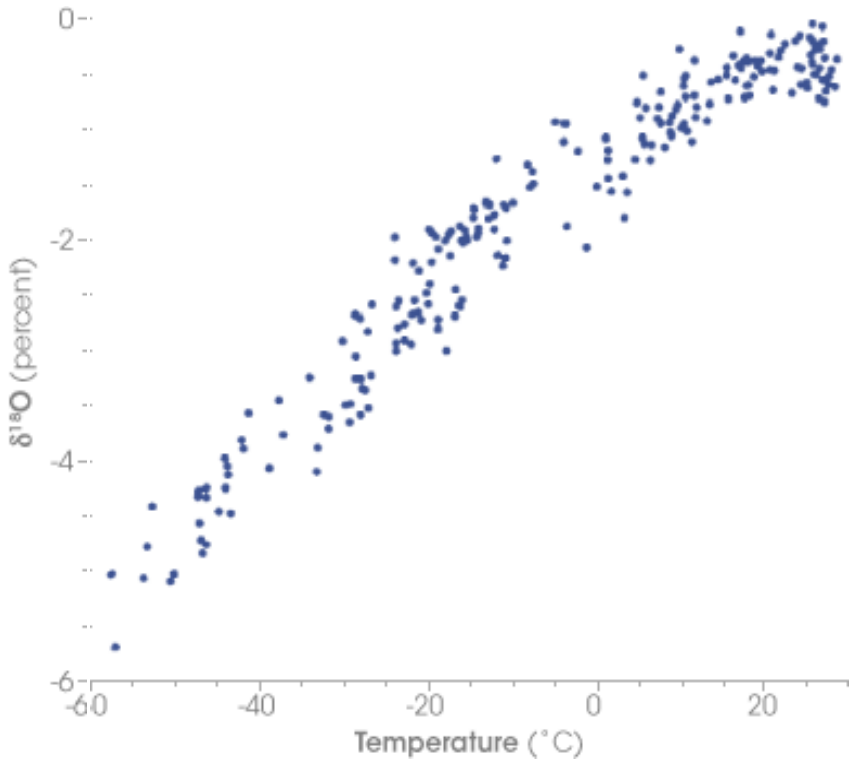
$^{18}O/^{16}O = 1/400 = 0.0025$

Oxygen isotope ratio ($\delta^{18}O$)

$$\delta^{18}O \text{ (in ‰)} = [(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{standard}] \times 1000 / (^{18}O/^{16}O)_{standard}$$



Why does $\delta^{18}O$ decrease with T?



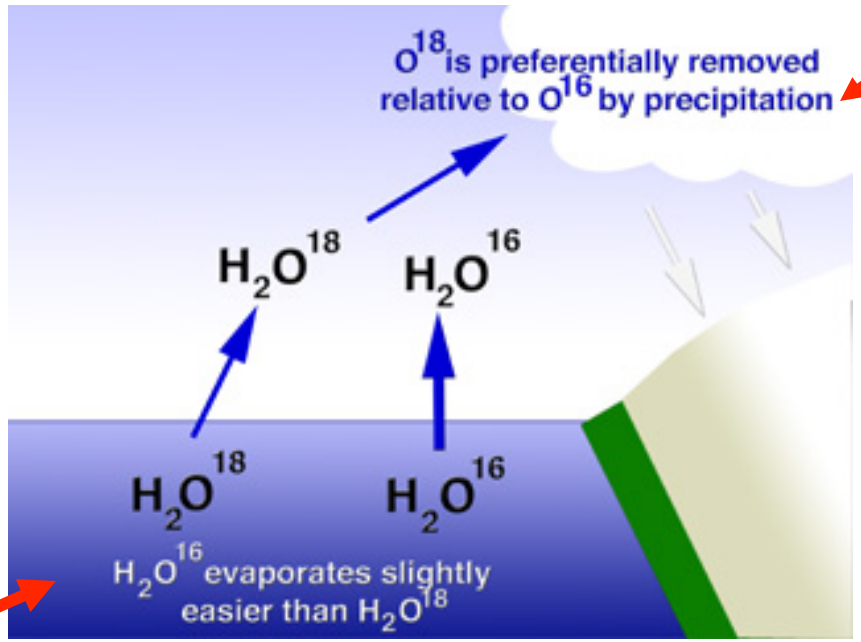
The concentration of ^{18}O in precipitation decreases with temperature. This graph shows the difference in ^{18}O concentration in annual precipitation compared to the average annual temperature at each site. The coldest sites, in locations such as Antartica and Greenland, have about 5 percent less ^{18}O than ocean water. (Graph adapted from Jouzel *et. al., 1994)*

Source: NASA Paleoclimatology webpage

Isotope Fractionation

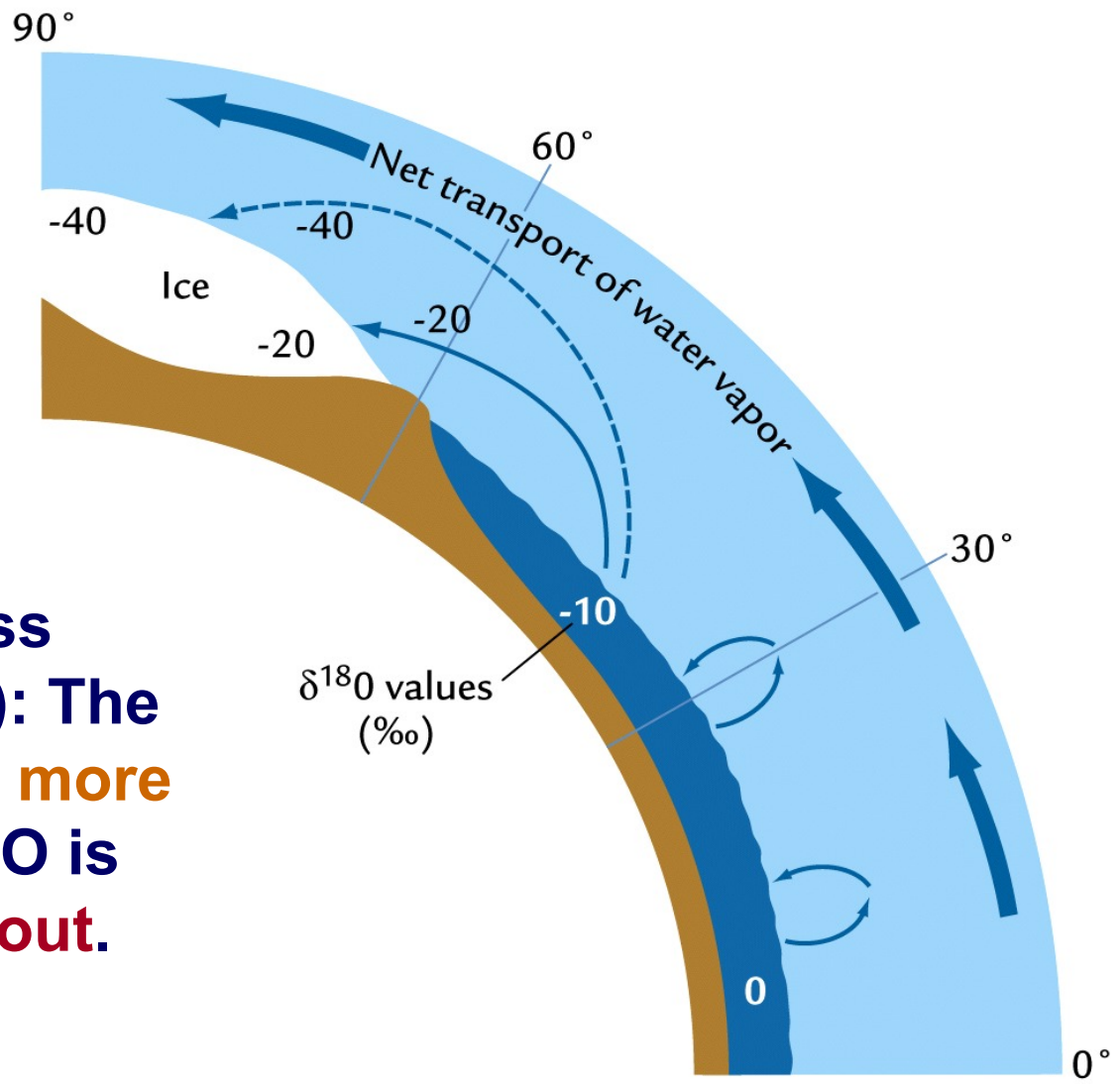
Enrichment process (isotope fractionation): The lighter ^{16}O evaporates first. The heavier ^{18}O condense out first.

^{18}O depleted, ^{16}O enriched → $\delta^{18}O$ more negative



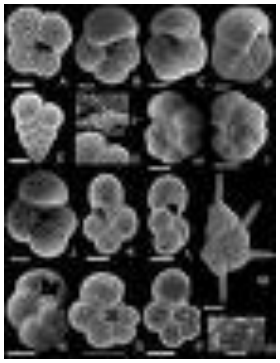
^{18}O enriched, ^{16}O depleted → $\delta^{18}O$ more positive

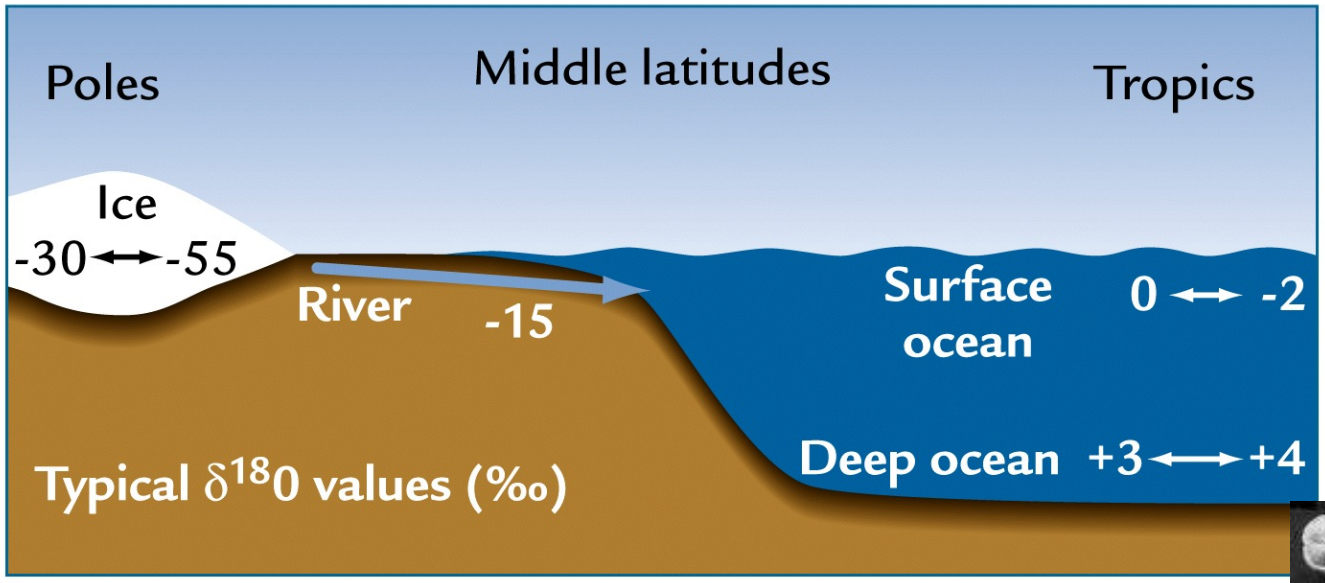
Isotope Fractionation

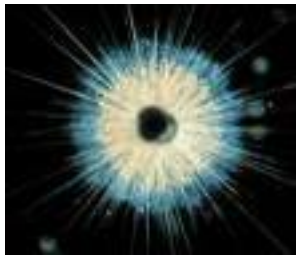


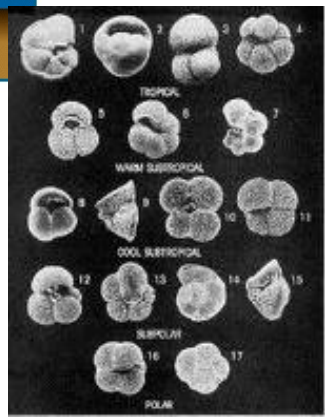
Enrichment process (isotope fractionation): The lighter ^{16}O evaporates more easily. The heavier ^{18}O is easier to condense out.

Typical $\delta^{18}O$ Values









In the modern tropical oceans, 0 to –2‰ surface waters, +3 to +4‰ deep waters

In ice sheets, –30‰ in Greenland, –55‰ in Antarctica

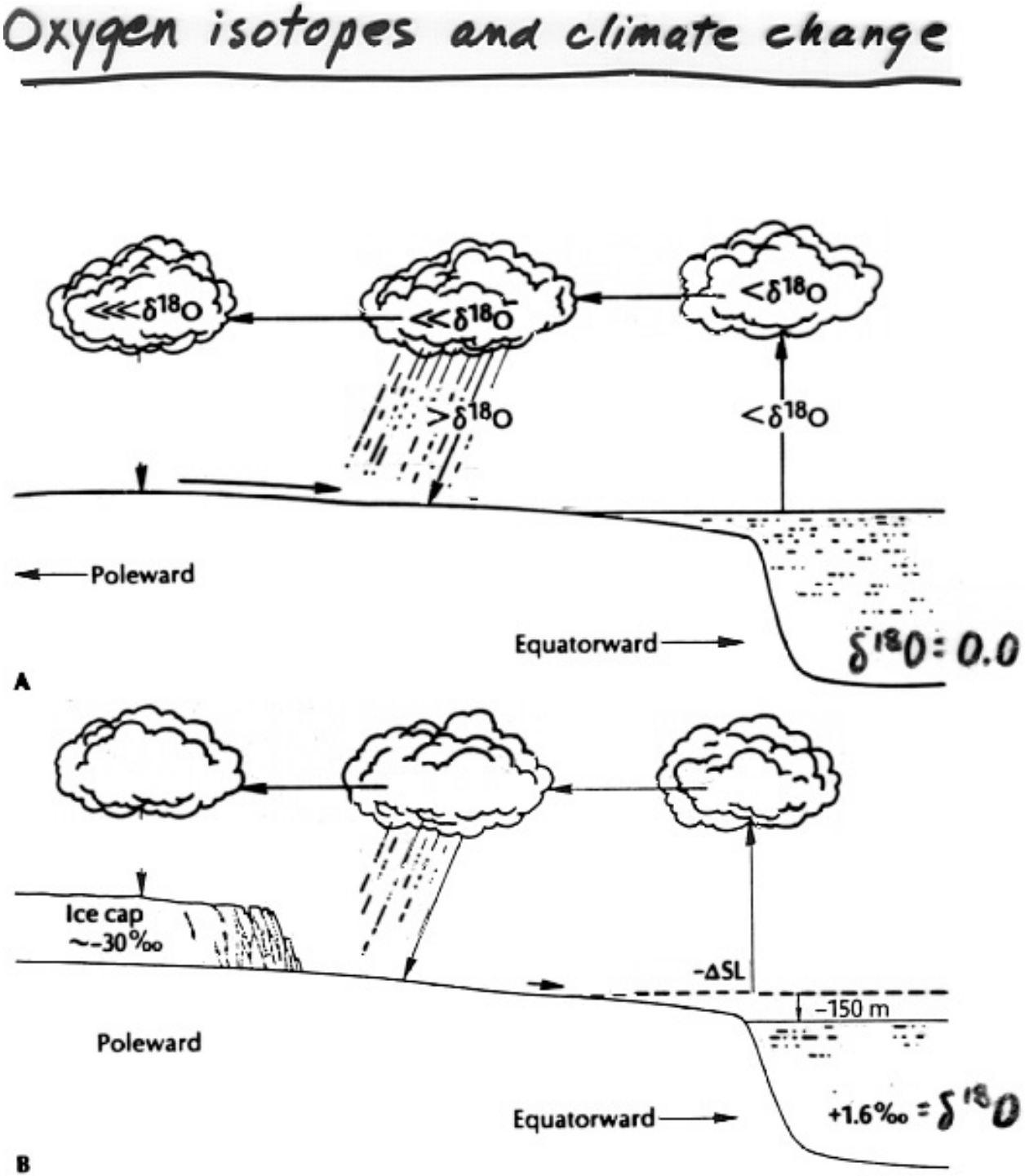
Oxygen isotope ratios as a thermometer

Precipitation has less ^{18}O than ocean, why?

^{18}O content of Precipitation at the give latitude decreases with decreasing temperature.

Why?

The less ^{18}O found in the glacier ice, the colder the climate.

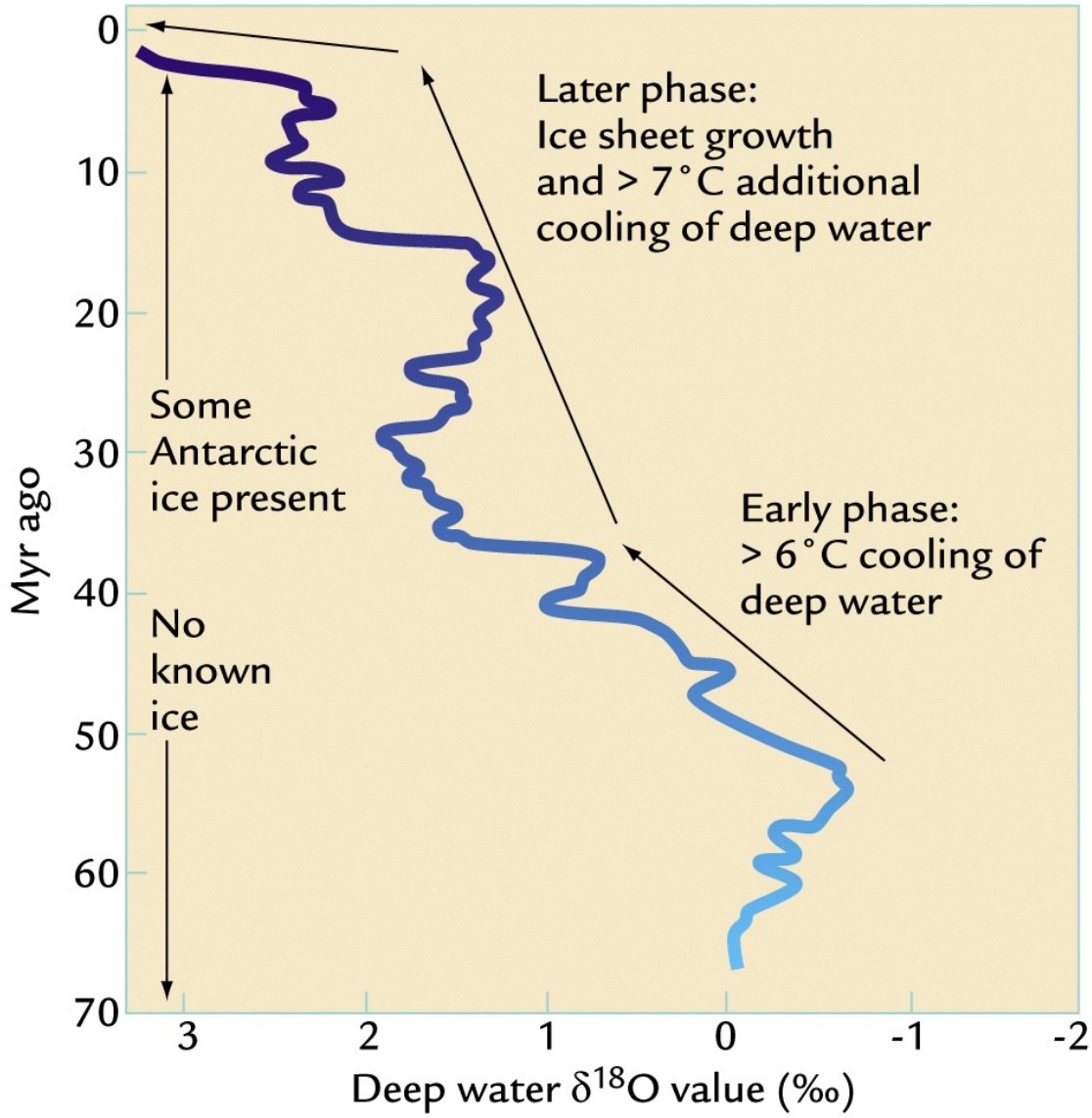


Long-term $\delta^{18}O$ trend in the deep ocean as measured from the calcite shells of foraminifera

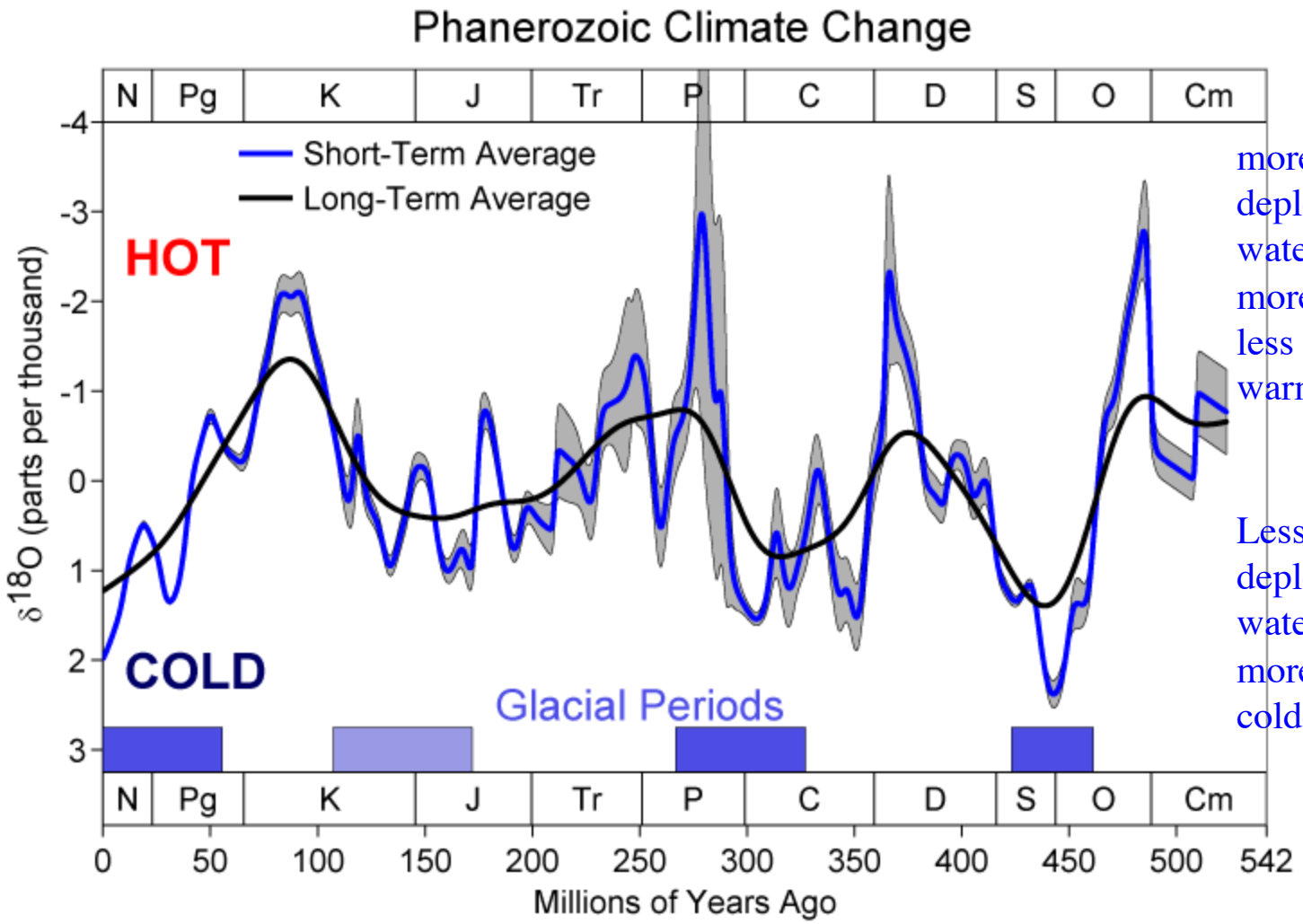
Two factors:

(1) Changes in deep-ocean temperatures

(2) Growth of ice sheets on land (^{16}O enriched)



Oxygen isotope ratios as a thermometer



more O18 depleted ocean water suggests more rainfall, less ice, warmer T.

Less O18 depleted ocean water suggests more ice and colder T.

Summary:

- **What is isotope?**
  - **Atoms with the same number of electrons and protons, but different numbers of neutrons.**
- **What determine isotope fractionation?**
  - **Temperature: colder temperature ➔ more O^{18} depletion (more negative δO^{18})**
  - **Condensation ➔ preferentially remove O^{18} (heavier isotope)**
  - **Evaporation ➔ preferentially remove O^{16} (higher isotope)**
- **What can oxygen isotope tell us about climate?**
  - Past earth's surface temperature and ice formation.