Stable isotopes in paleontology and paloclimatology

Back to basics

- Parts of an atom
- Electrons, protons, neutrons

- What does the number of _____ determine?
  - Protons What element it is – atomic number
  - Electrons The charge – what it bonds with
  - Neutrons The atomic mass

- What's the difference between isotopes and ions?

  Ions: same element, different charge
  Isotopes: same element, different mass

Stable & Unstable isotopes

- Unstable isotopes
- Spontaneously fall apart, emitting particles and energy (radioactivity)
- Stable isotopes
- Remain as they are indefinitely
- Carbon: ^{12}C, ^{13}C stable, ^{14}C unstable
- Oxygen: ^{16}O, ^{18}O stable, ^{17}O unstable

What are isotopes good for?

- Unstable: dating (because they decay at a predictable rate)
- Stable: different isotopes of the same element are taken up differently depending on physical and biological conditions

Fundamental premises

1. Elements occur in the Earth System in multiple isotopes, both stable and unstable.
2. Proportions of stable isotopes in the Earth System are constant over the entire system, but vary within different parts of the system.
   - The ratios of stable isotopes were set when the Earth formed, with slight changes as things fall to Earth.

Fundamental Premises

3. Lighter isotopes are more reactive than heavier isotopes
   - Lighter isotopes are more likely to be lost by diffusion or evaporation
   - In higher temperatures, lighter isotopes are preferentially lost
   - Biological systems will differentiate between isotopes

Fundamental Premises

4. Isotope abundances are expressed as:

$$\frac{Ratio_{sample} - Ratio_{standard}}{Ratio_{standard}} \text{ X } 1000$$

$$\delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right) * 1000\ ‰$$

Fundamental Premises

5. Standards
   - Carbon – PDB
   - PeeDee belemnite from the PeeDee Limestone in Texas – now all used up, so standards is by reference to a known comparison
   - Oxygen – SMOW
   - Standard mean ocean water (H_2O)

Oxygen isotopes

- ^{16}O is the norm – 99.8%
- ^{18}O is normally present in the ocean in very small amounts (0.205%)
- ^{16}O is lighter, so water containing ^{16}O is preferentially evaporated
- So seawater and freshwater have different isotopic signatures (ratios)

Stop for worksheet

What are oxygen isotopes good for?

- Temperature and climate
  - Evaporation Enriched
  - Preciptiation Depleted
- Salinity proxy
  - Higher salinity Enriched
- Latitude & biogeography
  - Equatorial Depleted
  - 30^{o} high pressure Enriched
  - 60^{o} low pressure Depleted

Enriched

What are oxygen isotopes good for?

- Glaciation Enriched
- Determining age in organisms that grow by accretion

  Enriched layers in warm seasons, depleted in cold
- Determining diet of organisms
- Marine Enriched
- Terrestrial Depleted

- Terrestrial paleoenvironments
- Near shore Enriched
- Inland of mountains Depleted

Oxygen isotopes in biological systems

- Organisms preferentially use ^{18}O, so are normally somewhat enriched compared to the environment.
- When temperature decreases, they use more ^{18}O and it tends to clump up.
- When temperature rises, the ^{18}O is more energetic, and therefore more reactive. Organisms take up more ^{16}O in warm temps, and the isotopes become more mixed.

What are oxygen isotopes good for?

- Dinosaur warmbloodedness
- How does temperature vary throughout the bodies of warm and cold blooded animals?
- So how should oxygen isotopes vary?

Warmblooded: isotopes should be fairly uniform from core to extremities

Coldblooded: lower ^{18}O in core, higher in extremities

Carbon isotopes

- Atmospheric carbon is 99+% ^{12}C, less than 1% ^{13}C
- Living systems preferentially take up ^{12}C
- Photosynthesis:
  - Different pathways use different $^{13}C/^{12}C$ ratios
  - Grasses use one pathway, shrubs use another

Time out for worksheet

Some generalizations

- Surface waters Enriched
- Bottom waters Depleted
- Abiotic carbonate rocks Enriched
- Biologic carbonate rocks (shallow water) Depleted
- Terrestrial vegetation Depleted
- Soil Depleted

What are carbon isotopes good for?

- Vertical upwelling – brings up more organic material from the bottom.
  - Upwelling areas Depleted
- Terrestrial v marine diets – use different pathways
- Mass extinction – decrease in plant activity in surface waters Depleted