'Earth's oxygen thermometers'
Simulating how ocean sediment and continental ice cores record past changes in Earth's temperatures.

There are two stable forms of oxygen atoms (isotopes) useful for research into past changes in Earth's climate; lighter oxygen-16 (^{16}O - with 8 protons and 8 neutrons in the nucleus) and the slightly heavier oxygen-18 (^{18}O - with 8 protons and 10 neutrons). Of these ^{16}O is the most common, being about 500 times more abundant in nature than the heavier form. In ocean waters this ratio varies with changes in seawater temperature. A chemical analysis of oxygen atoms within the calcium carbonate ($CaCO_3$) shells of marine microfossils, or water samples (H_2O) from ice cores, provides a way of estimating past Earth temperatures. (Fig 1).

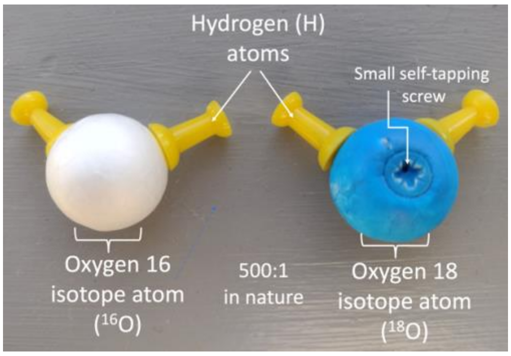

Fig 1: Models of two water molecules simulating different oxygen isotopes. (*Pete Loader*)

The simulation

Oxygen isotopes in water molecules can be simulated using polystyrene balls of two colours (here white and blue) with a small weight (a screw or drawing pin) inserted into the blue ^{18}O isotope balls to make them heavier. Both coloured balls are mixed in a transparent container (representing ocean seawater) with a 50:50 balance of white to blue (for easy comparison). Students are to be reminded that each of the white ^{16}O balls is 500 times more abundant in nature than the blue ^{18}O balls. (The hydrogen atoms are omitted in the simulation for simplicity)

- Ask students what they predict will happen if the ocean container is shaken up and down vigorously - *lighter balls are more likely to escape than heavier ones*.
- Demonstrate this, allowing any balls to escape into an upturned box lid representing clouds.
- Explain that this represents the evaporation of water from the ocean to the atmosphere and storage in clouds.
- Show that inevitably the 'ocean water' will fractionate with a greater proportion of the lighter white balls escaping more readily into the 'clouds' than the heavier blue balls which dominate the water of the ocean. (Fig 2**).**

Fig 2: Oxygen isotope fractionation during evaporation. (*Pete Loader*)

Two scenarios can then be explored: one with the Earth subject to warmer **interglacial** conditions, as now, (with few ice sheets on the land) and one during **glacial** conditions (with extensive ice sheets on the land).

Interglacial periods (with few ice sheets on the land which are centred at the poles)

After vigorously shaking the container the collected water in the 'clouds' is transferred to another container representing precipitation onto land as rain. An inspection of the balance of ^{18}O:^{16}O shows there to be a higher proportion of ^{16}O balls reaching the land which contrasts to the higher proportion of ^{18}O balls in the ocean. However, as this water ultimately returns to the ocean via rivers, the proportion in the ocean remains as normal (50:50 in this simulation).

Return the balls from the 'land' back to the ocean to demonstrate this.

Explain that any marine microorganisms will therefore include this ratio in the $CaCO_3$ of their shells during this time. When these creatures die, their shells accumulate on the ocean floor as sediment and record the oxygen balance of the ocean (here 50:50). Demonstrate this by taking a representative sample of balls from the ocean in a transparent plastic cup to represent a sample obtained from a core drilled into the ocean sediment.

<u>Glacial periods (with extensive ice sheets advancing from the poles to cover the continents).</u>
This time the collected water from the ‘clouds’ is transferred to another transparent container on the land representing snowfall onto an ice sheet. An inspection of the balance of ^{18}O:^{16}O again shows there to be a higher proportion of white ^{16}O balls reaching the land compared to the higher proportion of blue ^{18}O in the ocean. This time, however, the ^{16}O-rich water will be trapped in the ice sheet and not returned to the ocean.

Explain that the shells of microorganisms accumulating in ocean floor sediments during this time will therefore show a higher concentration of ^{18}O in the $CaCO_3$ of their shells than during interglacial periods. Demonstrate this by taking a representative sample of balls from the ocean in a transparent plastic cup to represent a sample from a core drilled into the ocean sediment. (Fig 3).

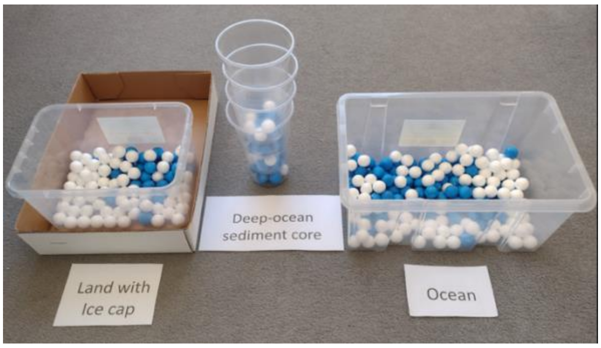

Fig 3: ^{16}O trapped in ice cap and recorded in ocean sediments (*Pete Loader*)

Both simulations are then repeated 3 or 4 times to represent the growth and reduction of ice sheets during glacial/interglacial conditions. Each time a new sample (in a plastic cup) is placed on top of the previous one to represent the sequence that might be found in a deep-ocean sediment core. (Fig 4).

Ask students to draw a graph of these different ratios against core depth (see ELI – ‘*Interpreting Earth temperatures from simulated deep-sea and ice cores*’). This provides evidence of changes in Earth’s temperature over time, reflecting the presence, volume, and extent of ice sheets on the land. (Fig 5).

<u>Ice-core analysis</u>
Ask students to predict the likely changes in the oxygen ^{18}O:^{16}O isotope balance that might be recorded in an **ice core** from an ice sheet at the poles as the Earth’s temperature first cools, and then warms, over time - *the ratios in an ice core will be opposite to that in deep-ocean sediments – the colder the temperature the **less** ^{18}O it contains (and vice versa*). (Fig 4).

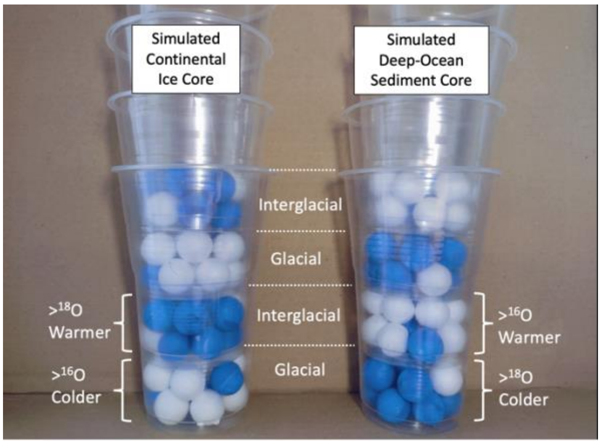

Fig 4: Simulated continental Ice core compared with a deep-ocean sediment core (Pete Loader)

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The back up

Title: ‘Earth’s oxygen thermometers’

Subtitle: Simulating how ocean sediments and continental ice cores record past changes in Earth’s temperatures.

Topic: Simulation of how oxygen isotope analysis of deep-ocean sediments and continental ice-cores provides a record of past changes in Earth temperatures.

Age range of pupils: 15 years and above

Time needed to complete activity: 20 minutes

Pupil learning outcomes: Pupils can:
- show how the relative proportions of two isotopes of oxygen (^{18}O &^{16}O) in nature affect the density of ocean sea water;
- explain why the balance of ^{18}O:^{16}O isotopes in ocean sediments provides a proxy of Earth’s temperature at the time of their formation;
- explain that higher ^{18}O (lower ^{16}O) concentrations in deep-ocean sediment cores provides evidence of colder glacial conditions on Earth whilst warmer interglacial conditions are represented by lower ^{18}O (higher ^{16}O).
- plot a graph of warmer/cooler Earth temperatures from a simulated deep-ocean sediment core
- explain why an analysis of the ^{18}O:^{16}O ratio of ice-core data is opposite to that in deep-ocean sediment cores, with reference to fractionation during the water cycle.

Context: Conflicting evidence of the proportions of ^{18}O relative to ^{16}O isotopes in deep-ocean sediments and ice cores can lead to misconception. This simulation is a simplification of the processes involved that provides evidence of climatic changes in Earth’s temperature.

Following up the activity: Students can progress to the Earthlearningidea, '*Oxygen isotope sweet simulation. Demonstrating how the oxygen isotope proxy records past Earth temperatures*' and the corresponding Earthlearningidea, '*Interpret Earth temperatures from simulated deep-sea and ice cores. Using sweets to simulate oxygen isotope ratios in cores'* to get a different, more sophisticated approach to this topic.

Underlying principles:

- Two stable isotopes of oxygen (^{18}O &^{16}O) occur in nature with a ^{18}O:^{16}O ratio of about 1:500. This record of the ^{18}O:^{16}O balance is stored within the carbonate of shells in deep ocean sediments and water molecules in ice sheets.
- The isotopic composition of ocean water changes with temperature and the growth and decay of ice sheets.
- As ocean water evaporates during the water cycle a process of natural fractionation occurs, with more lighter ^{16}O water molecules precipitated onto the land leaving the ocean with a higher proportion of heavier ^{18}O water molecules.
- During warmer **interglacial** periods the ^{18}O:^{16}O balance is maintained as rainwater is quickly returned to the ocean by rivers.
- During colder **glacial** periods the balance is upset because atmospheric moisture is not returned as quickly to the ocean because it is trapped within ice sheets.
- This balance is recorded within the shells and skeletons of marine organisms. These are enriched in ^{18}O during colder glacial periods when the ice volume on the land is large, and reduced in ^{18}O during warmer interglacials. (Fig 5).
- The ^{18}O:^{16}O balance in ice cores is the opposite. Relatively higher ^{18}O represents warmer interglacial periods (and vice versa).

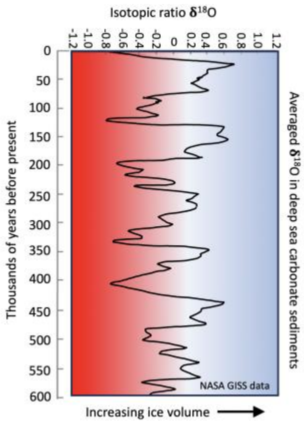

Fig 5: Changes in ^{18}O ratios recorded in oceanic carbonate sediments (NASA GISS data)

Thinking skill development: The simulation allows a pattern to be developed through construction; cognitive conflict is caused because a higher ^{18}O content in a sediment core indicates the opposite temperature to that in an ice core. Metacognition requires the development of bridging skills between the simulation and reality.

Resource list:

- 2 cm polystyrene balls (or equivalent)
- paint (to distinguish between the isotopes if needed)
- self-tapping screws/drawing pins
- see-through plastic containers (see photograph)
- trays/cardboard box lids (represent the land and catch the balls)

Useful links:
https://www.earthlearningidea.com/PDF/275_Oxygen_isotopes.pdf
https://www.earthlearningidea.com/PDF/276_Oxygen_isotope_cores.pdf

Source: Written by Pete Loader of the ELI Team and based on an idea by Duncan Hawley, previously published as Earth Learning Ideas (see useful links).