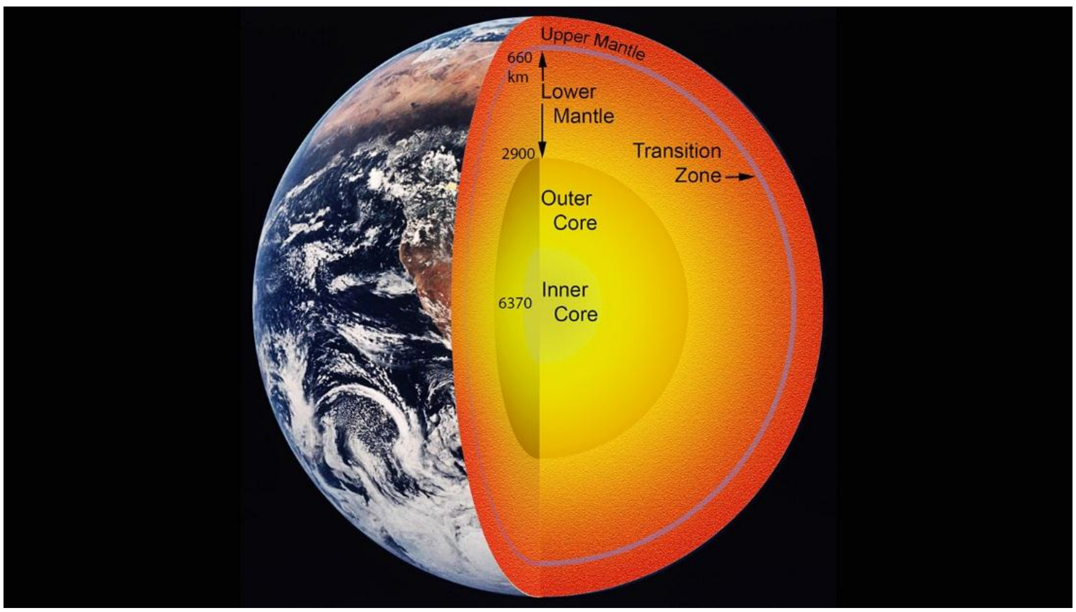
Are the oceans just the tip of the iceberg?

Scientists have known for decades (e.g. Kohlstedt et al. 1996), under synthesis in laboratory experiments, mantle minerals wadsleyite and ringwoodite, both high-pressure polymorphs of olivine (Mg_2SiO_4), can incorporate up to 1-2 weight percent (wt.%) of H_2O into their crystal structures as defects in the crystal lattice. Such "water" is not actually liquid, but forms hydroxyl $(OH)^-$ groups in their crystal structures, which can be measured by infrared spectroscopy.

These minerals are only stable in Earth's mantle transition zone, which extends from about 410 km to 660 km depth (wadsleyite is the stable polymorph from 410 to 520 km, and ringwoodite is the stable form from 520-660 km). This picture shows the mantle transition zone (TZ) for scale in Earth:



In 2014, the chance discovery of a ringwoodite crystal trapped inside a diamond (called, a diamond inclusion) captivated earth scientists because the ringwoodite, which was preserved inside the diamond during its assent from the transition zone and eruption onto the surface, contained 1.5 wt.% H_2O, **near-maximum amounts!** (see Pearson *et al.* 2014).

Although the research presented the first direct evidence for H_2O from so deep in the Earth, the diamond only sampled one tiny piece of the Earth's mantle.

In the paper by Schmandt *et al.* (2014), a dense network of seismometers spread out across the United States (called the USArray), was used to generate a map of seismic wave speeds across a wide region of the mantle transition zone beneath the Western United States.

The “maps” revealed the presence of small amounts of magma, just below the transition zone, indicative of dehydration melting, and suggesting that ringwoodite could be hydrated in Earth on a much larger scale, perhaps globally.

Exercise: Calculate the mass of H_2O that could be “hidden” in the mantle transition zone (TZ) if wadsleyite and ringwoodite contained 1.5 wt% H_2O.

How does your answer compare with the mass of H_2O in the world’s oceans?

Hints: rock in the transition zone is thought to consist of about 60% wadsleyite and ringwoodite. The transition zone constitutes about 7.5% of the planet’s mass.

To find the answer:

1. Find the mass of the Earth.

2. Find the mass of the transition zone (TZ).

3. If the TZ consist of about 60% wadsleyite and ringwoodite, what is the mass of wadsleyite and ringwoodite?

4. What is the mass of water found in this amount of wadsleyite and ringwoodite?

5. How much water is this, considering that the mass of the oceans is around 1.35×10^{21} kg H_2O?

6. Discuss the implications:

    a) Could this water be part of a cycle with the surface?
    b) What percentage of the planet’s mass is H_2O, with versus without this reservoir?
    c) How does your answer compare with the amount of water found in primitive carbonaceous chondritic meteorites, thought to be the building blocks of the planet?
    d) What is the origin of Earth’s water?

Answer:

The mass of Earth is M_E = 5.98x10^{24} kg (this value can be found by the students)

The mass of the TZ is 0.075 x 5.98x10^{24} kg = 4.49x10^{23} kg (i.e. 7.5% of M_E)

The mass of wadsleyite and ringwoodite is then 0.60 x 4.49x10^{23} kg = 2.69x10^{23} kg
(i.e. 60% of the TZ mass is wadsleyite and ringwoodite)

The mass of H_2O in the TZ if wadsleyite and ringwoodite are 1.5 wt% H_2O is:

$$0.015 \times 2.69 \times 10^{23} \text{ kg} = 4.04 \times 10^{21} \text{ kg } H_2O$$

This is the mass of H_2O that could be hidden in the TZ

That means, **three times** the ocean mass worth of H_2O could be contained in just the layer of the mantle from 410 to 660 km depth.