

## 12.001: Introduction to Geology

### Exercise 1:

Calculate the composition of the Earth's Mantle as estimated from the sun's composition.

We can assume the following:

- (1) The Earth has the same composition as the Sun (or C1 chondrites) except for the volatiles (which the earth lost while the surface was a magma ocean).
- (2) The Earth consists only of the core and the mantle (which is a fair assumption as the crust makes up less than 1% of the Earth.) The core makes up 32.5 % of the Earth by mass and the mantle makes up the remaining 67.5 %.
- (3) The Earth's mantle is composed of FeO, CaO, Al<sub>2</sub>O<sub>3</sub>, MgO and SiO<sub>2</sub> (which actually do make up ~ 98% of the mantle. The core is 75 wt. % Fe and has none of the other elements we are considering (the rest is nickel and some lighter elements including sulfur – the exact composition of the core is still very poorly understood!).

Set up a simple set of equations assuming mass balance and calculate the composition of the Earth's mantle from the C1 composition given below. How does it compare to estimates of the Earth's mantle based on actual samples from the mantle?

### C1 composition (volatile free)

SiO <sub>2</sub>	34.06 wt%
MgO	24.43 wt%
FeO	37.18 wt%
Al <sub>2</sub> O <sub>3</sub>	2.39 wt%
CaO	1.94 wt%

Estimates of the Earth's mantle composition based on actual mantle samples:

SiO <sub>2</sub>	45.40 wt%
MgO	36.77 wt%
FeO	8.10 wt%
Al <sub>2</sub> O <sub>3</sub>	4.49 wt%
CaO	3.65 wt%

Good luck...

Note: This mass balance exercise may seem like a rough and ready approach, but it really is how people think about the composition of the Earth, albeit in a more complex scenario involving all of the elements – you can think of it as a relatively simple linear algebra problem, complicated by the fact that each element in your matrix has a unique chemical behavior and so must be individually understood before the problem

can be solved. This exercise touches on a number of the “big questions” in geology. The details of two of these are given below to give you some idea of areas of current research. **This is not a part of the exercise.** If anyone is interested in reading more about the questions, please ask!

### **How and to what extent were volatiles lost during Earth’s formation?**

Volatile elements, i.e. those that form gases at relatively low temperatures (in planetary science, this is typically less than a few hundred degrees at very low pressure ( $\sim 10^{-4}$  atmospheres)), were lost from the Earth during its formation due to the high temperatures generated by impacts, release of gravitational potential energy, and radioactive decay of short-lived elements. As more and more planets are discovered outside our solar system, a topic of intense focus in Earth and planetary sciences is the formation of atmospheres, particularly those containing water and carbon. An important part of this is understanding the temperatures involved and the potential mechanisms for volatile loss or the retention of volatiles in an atmosphere. The results of this affect the validity of hypotheses arguing for water being retained during Earth’s formation vs. those suggesting that water was brought to Earth later by H<sub>2</sub>O-rich asteroids (comets). Geochemical modeling, particularly understanding the distribution of volatile elements within the Earth and other planets, is a key part of this research.

**What is the composition of the Earth’s core?** We cannot sample it! We know that it is largely composed of Fe metal with some Ni. This information comes from comparisons of the seismic velocity of Fe metal with the seismic velocity of the Earth’s core, as well as analyses of iron meteorites, which are thought to represent the cores of broken-up asteroids. However, it was discovered in the 1950s that Fe metal alone could not account for the seismic velocity of the Earth’s core, and that around 10-15% of the mass of the core must be made up of lighter elements. The most convincing candidates at present are S, O and Si. Determining the relative importance of these three elements is critical to understanding such problems as:

- The physics of how the Earth’s core formed
- Understanding how oxidized the Earth’s interior is, which is important not only for people interested in planetary formation, but also for understanding the Earth’s early atmosphere, and particularly the cycling of carbon through the Earth’s deep interior.
- The abundance of other elements in the Earth’s core. Another outstanding problem is that so-called “siderophile” elements, which alloy strongly with Fe metal, are more abundant in the Earth’s mantle than we would expect, given that they should be almost entirely in the core. This is interesting because the siderophile elements include some of the Earth’s most valuable elements – gold, platinum, iridium, rhenium. Where these are in the Earth (and other planets, moons and asteroids) is surprisingly important for the future of precious metal prospecting, particularly now that many people are considering mining extraterrestrial objects for precious elements!

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