GEOL 415 Assignment 5

Before discussing the enrichment or depletion of the different element groups during the the three fractionation processes, it is important to briefly review the fractionation processes themselves. The three fractionation processes are defined as: differentiation of solar nebula, planetary accretion and finally core formation.

To start of with, differentiation of solar nebula refers to a time period before planetary accretion and comes first. This is a period of condensation of the solar system where the gas around a star condenses, forming a flattened disk of dust surrounding it (in our case, the Sun). The rotating disk of gas and dust is known as the primitive solar nebula and it is from this primitive solar nebula that other planetary bodies form. At this point in time, chondrites are abundant and are essentially what define the time when the solar system was formed. As such, we can use this starting period of time as a way to explain fractionation of chondrite and other elemental groups relative to it.

To follow, planetary accretion refers to a time where small planetesimals form from the primitive solar nebula. Eventually, under gravitational forces, these planetesimals accumulate and grow larger to form planetary embryos. With a large enough time scale, these planetary embryos again experience another evolution to form full scale planets. The two main events during the phase from embryo to full scale planets are: high probability of giant impacts and dispersion of gaseous component of the solar nebula. The latter main event of dispersion is what will later give a full explanation of noble gases and their relative depletion which will be looked at more closely.

Core formation can actually be thought of a process within planetary accretion, being formed during that time period as well. It is a matter of debate with competing models as to when exactly core formation took place though that is not too much of our concern in this response. Silicate metal equilibration took place at high pressures in deep magma oceans within the Earth. These high pressures will actually be discussed later on in more detail on how they affect elements specifically when compared to chondrite. More relevantly, with regards to fractionation and comparing chondrites with other elements being enriched/depleted, core formation helps us understand a group of elements known as the siderophile elements. Siderophile elements are broken into two groups: weakly siderophile (V), moderately siderophile (W, Co, Ni and Mo) and highly siderophile (Au, Re, Os, PGE). There is also even support in respect to also explaining the contrast of refractory lithophile elements as well. These element formations (siderophile and refractory) and their concentrations relative to chondrite will be looked at later but its important to understand briefly what it all means when talking about core formation, which can be briefly summed as deep magma oceans at high temperature and pressure within the Earth.

With the different fractionation processes and their time periods understood at a basic level, we can now look at the different element groups in specific to see how they got depleted/enriched during the different fractionation time periods/settings.

Regarding light and inert gases that have depleted elemental concentration compared to chondrite, this is explained during the planetary accretion phase, most notably during the last stages when an planet embryo begins to form into a planet. As mention, a second key event is the dispersion the gaseous component of the solar nebula. During that phase, a planet begins to transition and release gases as it hardens (terrestrial planets). This gaseous component is made of H, He and N which is what the planet begins to disperse when emitting the gaseous component of the solar nebula. As it loses these gases, this is why we see that the concentration with respect to chondrite is lower of noble and inert gases.

Volatile lithophile elements are also seen as depleted when compared to chondrite. Lithophile elements are those with an affinity for silicates and oxygen. This is explained during the planetary accretion phase as well when planet experiences volatile loss. There are three mechanisms of volatile loss: hydrodynamic, impacting and magmatic outgassing. Hydrodynamic loss is a case where thermally driven atmospheric conditions are created that leads to the escape of a variety of lithophile elements. The impacting mechanism, known as the Giant Impact that created the moon, also lead to the loss of the bulk atmosphere which released these volatile elements. Magmatic outgassing refers to the exchange of gases from magma to atmosphere. This loss of volatiles creates a segregation with refractory lithophile elements that'll be looked at briefly. Using these three mechanisms, the differential solubilities of volatiles can explain the depleted concentrations of lithophile elements.

Silicon is also depleted compared to chondrite concentration and the fractionation process for it was during differentiation of solar nebula or core formation. Silicon, in specific, is a good candidate for fractionation during solar nebula differentiation (Rollison, 2008). One explanation suggests that different chondritic bodies during pre Earth accretion period had different types of composition and so the Earth must have formed from a Si deficient chondritic parents to even begin with, leading to the depletion of silicon from the beginning. Additional support for the depletion of silicon via solar nebular fractionation comes via density study. Earth is denser than chondrites which reflects a difference of Fe/Si ratio. This difference in Fe/Si ratio is said to reflect fractionation of Fe from Si during the condensation period of the solar nebula and so the depletion silicon happened during that stage.

Refractory lithophile elements are in contrast to all the other element groups looked at, in that these elements were actually enriched when compared to chondrite concentration. The explanation for refractory lithophile element enrichment is during the core formation when fractionation takes place. Following a chondritic model, when we adjust for the loss of the volatile lithophile elements as previously mentioned, this leads to a separation of the remaining refractory elements. This leftover refractory elements void and separated due to the loss of volatiles are now are enriched, quoted to be about 1.5 times the CI chondritic value (Rollinson, 2008).

Finally, siderophile elements are divided into three groups: weak, moderate and high. Respectively, these elements are depleted by these amounts as well: weakly, moderately and highly depleted. Siderophile elements are those with an affinity for metallic iron. The depletion of these elements is under core formation fractionation as well. This element group being depleted is a result of metal-silicate equilibration during core formation. Equilibration took place in a high pressure environment in deep magma ocean. In high pressure/high temperature settings, the 'less' siderophile in nature elements are prone to less depletion due to their innate characteristics. Highly siderophile elements in nature are depleted further as shown in figure 2.13, Rollinson 2008.

To conclude, ultimately if one is interested in measuring the extent of a particular element group and its depletion/enrichment via fractionation at a specific time in solar history, in general it is governed by the chemical behaviour of that element during the early stages of Earth formation.

References

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