WHERE DID EARTH GET ITS ABUNDANT CARBON?

Dasgupta's recent research published in Nature Geoscience suggests a novel solution.

By Linda Welzenbach

Dr. Rajdeep Dasgupta

Since Rajdeep Dasgupta arrived at Rice in 2008, he and his group have worked to understand global volatile cycles, such as the global carbon cycle. Carbon on Earth is generally thought about in terms of the 'global carbon cycle' (- how it cycles between the atmosphere, biosphere, oceans and the uppermost layer of the earth's crust. Dasgupta's investigations look at carbon cycling beyond that - reaching deeper into the earth and far beyond the air we breathe, on solar system time scales, to help us determine the initial concentration and present ubiquitous distribution of earth's carbon. Dasgupta group's recent research gets us closer to understanding earth's initial carbon budget, which is critical to understanding earth's evolution and formation of the biosphere.

The origin of carbon and other volatiles in present-day Earth is not well understood, and several hypotheses exist to try and explain how carbon budget of the Earth got established and where all the carbon essential for life came from. The most popular hypothesis is where the parent material is comparable to meteorites such as carbonaceous chondrites, whose carbon/sulfur ratio (C/S ratio) is close to ratios present in the Earth's mantle. But one critical problem is that although carbonaceous chondrite can elevate the volatile budgets of proto-Earth, it cannot satisfy the elemental ratio of all key volatiles, such as carbon to nitrogen (C/N). Similarly, if Earth is built from carbonaceous chondrite-type materials, core formation would fractionate C from S and the present-day Earth's silicate reservoirs would not have chondritic C/S ratio.

Dasgupta's group is trying to understand how all the life-essential volatile elements on Earth originated, and they have started with carbon and sulfur. They developed a novel model that suggests that the present-day carbon and sulfur concentrations could result if an impact by a differentiated planetary embryo has added sufficient carbon and sulfur to the mantle, and changed the earth's core composition enough to allow carbon to remain in the mantle.

The first part of the problem they had to contend with was finding a way to overcome carbon segregation in the core. To do this, they would have to create experiments with an unconventional (non-terrestrial) core composition to show a reduction in carbon's affinity for iron, thus allowing carbon to remain in the mantle. Dasgupta's group is well acquainted with carbon's behavior in melted alloys of conventional core compositions from previous experiments (e.g., Dasgupta et al., 2013; Chi et al., 2014), so the post-doctoral researcher Yuan Li along with Dasgupta, and Kyusei Tsuno decided to look at how sulfur or silicon in the alloy might alter the affinity of iron for carbon. In order to set up realistic compositional parameters for their impactor, they looked to planetary neighbors whose composition would be relevant, if not entirely for Earth, then definitely within the scheme of all the rocky planetary bodies within the solar system. They selected two planets that might have similar sulfur-rich and silicon-rich alloys as well as conditions necessary to produce the appropriate volatile ratios. Mars is thought to have a sulfur-rich core, and Mercury a silicon-rich core. Mercury also has the added benefit of having a carbon rich (graphite) surface (Peplowski et al., 2016) suggesting that its core composition allowed significant carbon to remain in the silicate portion of the mantle.

Dr. Yuan Li

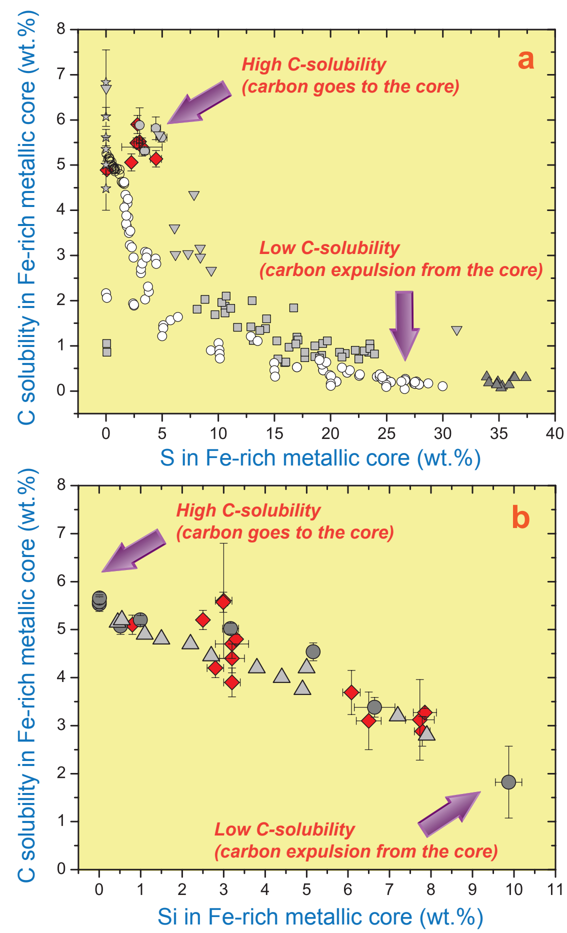

Figure 1. ***Carbon solution in the iron-rich metallic core of rocky planets as a function of sulfur content of (a) and silicon content (b) of the core. The figure has been modified from Li et al. (2016), published in Nature Geoscience.***

Red symbols are data from the recent high pressure-temperature experiments of Li et al. (2016), with literature data in the grey and white symbols. These data led Dasgupta and Li to conclude that carbon can be expelled from the metallic core of rocky planets if the core composition is rich in sulfur or silicon.

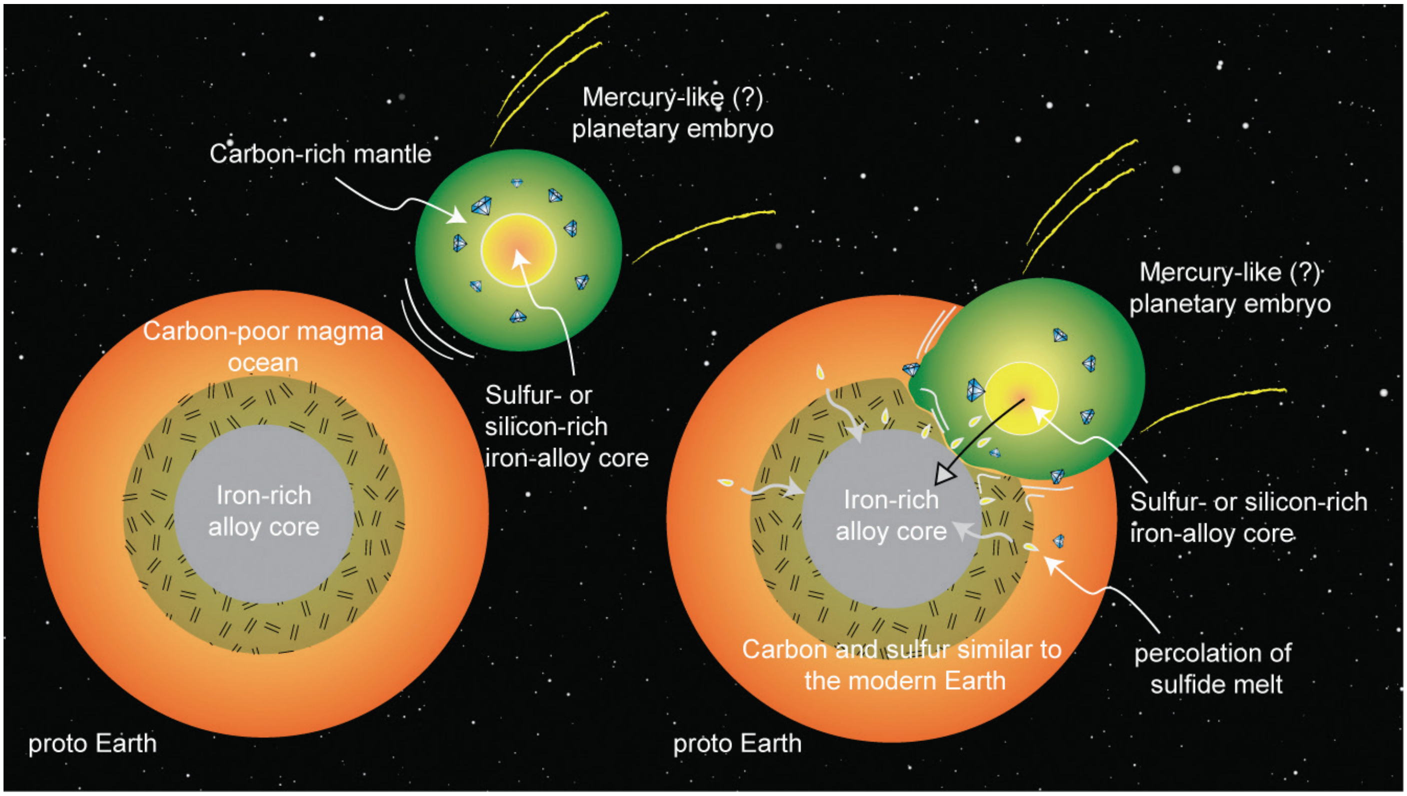

Figure 2. ***Cartoon of the giant impact of a highly reduced or a sulfur-rich differentiated planetary embryo approximately 100 million years into proto-Earth's differentiation.***

The mantle of the accreting body would be carbon-rich, as indicated by 'graphite' or 'diamond' in the cartoon above. This is achieved by carbon saturation in the core of the impactor and subsequent expulsion of graphite or diamond. The core of either of the impacting body would merge with the proto-Earth's core and mantle + crust of the impactor would mix with the mantle of the proto-Earth. Excess sulfur in the mantle may get rained to the Earth's core as sulfide melt.

Using the planetary compositional parameters, new high pressure-temperature experiments and previous data showed that carbon could be excluded from the core if the iron alloys were enriched in either silicon or sulfur (Fig. 1). When varying the initial concentrations of carbon, Li was then able to compute the relative concentrations of carbon and sulfur to arrive at current carbon concentrations and C/S ratios in the present silicate mantle.

The Messenger mission to Mercury collected surface composition data that showed that the carbon concentration on the surface of Mercury is well within the extrapolated mantle carbon concentrations from Dasgupta's results, making a Mercury-like embryonic (MLE) planet a good analogue. The MLE with its silicon-rich core, would have collided with and immediately been absorbed by Earth (Fig. 2). Accretion of a planetary embryo is well established by the Earth-Moon formation hypothesis, but because of the MLE body's mass, the dynamics would not allow complete mixing of the core with the mantle. The core of that planet would go directly to the core of the earth, and then carbon-rich mantle and crust would mix with Earth's mantle, thus allowing the carbon to remain within the mantle to achieve the abundances we see today. In the case of the sulfur-rich core of a planetary embryo, the carbon in the resulting silicate mantle would be higher. The results and the model that were published on this work (Li et al., 2016) are provocative, but more work will be needed to address the mantle concentrations for many of the other key life-essential elements.

References and Further Reading:

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