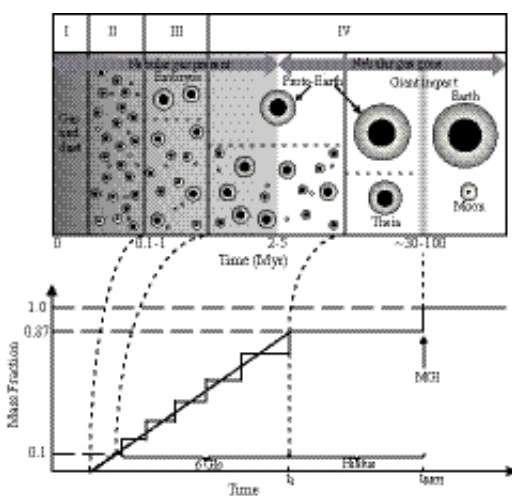


From the Earth to the Moon: Resolving estimates of proto-Earth accretion with lunar-forming impact

November 14 2011, by Stuart Mason Dambrot



The upper part is a schematic illustration of the formation of the Earth with a possible late giant moon-forming impact. There are four accretion stages: I (dust settling), II (planetesimal formation), III (embryo formation), and IV (accretion of terrestrial planets by giant impact). The bodies below the dotted lines represent the left material in Earth's feeding zone. The shaded zone represents the presence of solar nebula that was dissipated at 2-5 million years. An approximate time scale is shown and the lower part of this figure shows schematically the mass accretion history of the Earth. Initially (up to about 10%) the accretion is of planetesimals forming embryos. The main phase of accretion is by giant impacts (approximately six Mars-sized giant impacts or more if some are smaller) and is shown as ending at time t_{PE} . Then, there may have been a significant hiatus, before a potentially late MGI adds the last approximately 13% of the mass of the Earth at time t_{MGI} . The figure is not to scale. Copyright © PNAS, doi:10.1073/pnas.1108544108

(PhysOrg.com) -- One of the more challenging fields of scientific inquiry is planetary formation – and most relevant is that of our own Earth and Moon. The current view, based on chronometry (scientific time measurement) of terrestrial rocks, is that (1) Earth formed via accretion some 30 million years after our solar system, and (2) the so-called Moon-forming Giant Impact (MGI) occurred immediately (in geological time) afterwards. However, simulations and lunar rock examination appear to possibly place MGI as much as 70 million years later. Recently, scientists in the [Department of Earth and Planetary Sciences](#) at Harvard University have proposed a model that explains this discrepancy using chronological isotopic analysis and formation partitioning of siderophile, or iron-loving, elements. The researchers conclude that a late formation of the Moon is possible but requires very fast formation of the Earth prior to the late Moon-forming impact.

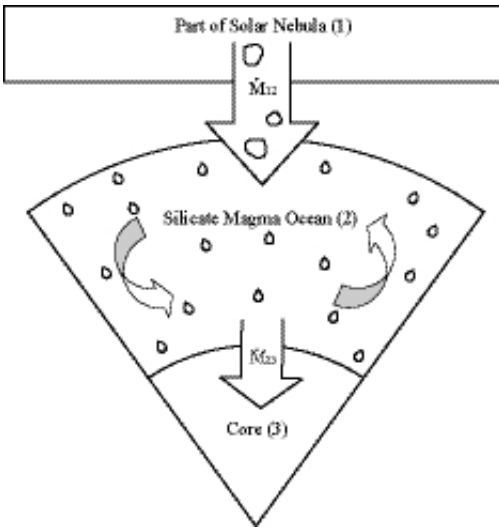
Conducted by Graduate Research Assistant Gang Yu, lead researcher, and [Prof. Stein B. Jacobsen](#), the research post challenges in creating the unique method used to obtain their conclusions regarding geolunar formation timescale. “The most challenging factor in using the Hf-W, or hafnium-tungsten, chronometer is determining how to model core formation processes and their effect on tungsten isotopic composition of our proto-planet’s mantle, which was impossible until recent data on metal-silicate tungsten partitioning (between metallic liquid and silicate melt) were published^{1,2},” notes Yu. “Although tungsten partitioning data is itself available, using chronometry still requires integrated modeling of many different processes, such as planet accretion, radioactive decay and core formation, which is still very conceptually and technically challenging.”

As a result, the team used a variety of innovative techniques to build their new model. The tool they employed to constrain the formation

timescale of our geolunar system is the ^{182}Hf - ^{182}W chronometer – the most powerful available because its half-life is 8.9 million years, which is close to the timescale of formation of the Earth and [Moon](#). “Firstly, we managed to find out a set of differential equations” Yu explains, “which can successfully describe the accretion, radioactive decay and core formation processes simultaneously.” The equations were too complicated to arrive at a simple analytical solution, but they solved it using [MatLab](#) numerical methods.

“Secondly,” Yu continues, “by running the model, we explored all possible parameter spaces for physical-chemical conditions of core formation processes, such as pressure, temperature and oxygen fugacity – and determined the correct values for each parameter by matching well-constrained concentrations of five siderophile elements in Earth’s mantle today – namely, (tungsten, nickel, cobalt, vanadium, and niobium).

Another advance in their model, Yu adds, is that they treat MGI timing as a random variable, which is very likely to be true in reality. “In the past, it was always assumed that the Moon-forming Giant Impact occurred right after the completion of the continuous growth stage of proto-Earth. Instead, we treated the giant impact timing as a random variable, making it possible to study the relationship between the timescale of Earth formation and MGI timing.” By matching current tungsten and strontium isotopes levels with lunar rocks, the researchers found that there could be a gap between the proto-Earth formation and the Moon-forming Giant Impact.



Sketch of the box model for the accretion and core formation model used in this work. The Earth is considered to grow by accreting objects from the solar nebula (reservoir 1) with a mass flux \dot{M}_{12} . As the Earth grows, the accreted material is added to the silicate mantle (reservoir 2). The metallic core reservoir (3) is segregated as small metal parcels (equilibrated at some P and T in the magma ocean) from the mantle during accretion (with a mass flux \dot{M}_{23}) and once in the core the metal is considered isolated (no back reaction) from the mantle. There is no direct mass transport flux from the solar nebula to the metallic core ($\dot{M}_{13} \approx 0$). The whole mantle maintains homogeneity by rapid convection. Copyright © PNAS, doi:10.1073/pnas.1108544108

Other innovations might also be developed and applied to the current experimental design. “What we have done is mostly modeling work based on a large amount of published geochemical and astrochemical data,” Yu points out. “No experiments were involved. However, there is still something interesting about the model that can be tested and improved in the near future regarding the core formation process during the Moon-forming giant impact, which we modeled it following a traditional and possibly simplified view. It was believed that during the giant impact, the core of the impactor was totally molten and emulsified to small droplets which slowly sank through the Earth’s mantle into the

Earth's core, reaching a chemical equilibrium between the droplets and mantle."

At the same time, a different core formation process opinion has arisen from recent simulation results. "It has been suggested that when the impact angle is high, the core of the MGI impactor can be totally or partially merged with the Earth's core directly without reaching chemical equilibrium," Yu observes. "If true, the process will have different effects on the tungsten isotopic composition of Earth mantle with our model, which could lead to a different timescale. It is therefore worth expanding our model to include this possible special case and test how significantly the degree of core merging during the giant impact can affect the formation timescale of Earth-Moon system."

Yu also describes the direction the team is planning for their research - revising the model to study the formation timescale of Mars. "Compared with Earth," says Yu, "Mars has a much smaller mass ($\sim 1/10$ of Earth's mass) and volume, so there's a long-standing question of whether Mars is a normal but smaller planet with a formation timescale similar to Earth's, or is a leftover planetary embryo that survived from the last stage of planet formation processes with a faster timescale than the Earth. We believe that our model can answer the question." If it does, this will impact the current understanding of planetary evolution, the origin of the solar system, and possibly the origin of life.

There are wider implications of their findings for geology, chronometry and exoplanetary research as well. "Our study implies that the main growth of Earth happened extraordinarily fast and was completed within 8-12 million years after the beginning of the solar system, making it very likely that major mass of the Earth grew in the presence of nebular gas which is estimated to be present only during the solar system's first 5-10 million years. This finding supports the core accretion model for formation of giant gas planets such as Jupiter and Saturn, and will also

provide a new starting point for understanding the origin of the Earth's atmosphere and the evolution of the oxidation state in [Earth's](#) mantle and other geostrata.”

In terms of scientific measurement, Yu notes that “Besides the ^{182}Hf - ^{182}W chronometer, the ^{107}Pd - ^{107}Ag (palladium-silver) decay system is another powerful chronometer to constrain the timescales of condensation and evaporation of volatile elements in planets. Since both palladium and silver are metal-loving elements, the core formation effect for the chronometer is also significant and cannot be ignored – but lacking knowledge about core formation effect on Ag isotopic composition in planet's mantle does limit the application of the ^{107}Pd - ^{107}Ag decay system and the precision of its result. After some revisions, our model actually can be directly applied to this isotopic system.” This means that their model can serve as a benchmark method for isotopic chronometry in cosmochemistry studies.

Finally, Yu concludes, “Looking for exobiology and exoplanets is highly interesting task. Since planets don't emit light they're much more difficult to be observed – so in order to find mature exoplanets suitable for life, we need to first find the right stars. Given that our study can provide the information about the evolution history of terrestrial planets after the birth of a star – in our case, of course, the Sun – it can offer a guideline for finding stars with an age indicating a higher probability of their having mature planets, which will thereby facilitate the effort of the exoplanetary searches.”

More information: Fast accretion of the Earth with a late Moon-forming giant impact, Published online before print October 17, 2011, *PNAS* October 25, 2011 vol. 108 no. 43 17604-17609, [doi: 10.1073/pnas.1108544108](https://doi.org/10.1073/pnas.1108544108)

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¹ Cottrell E, Walter MJ, Walker D (2009) Metal-silicate partitioning of tungsten at high pressure and temperature: Implications for equilibrium core formation in Earth. *Earth and Planetary Science Letters* 281:275–287, [doi:10.1016/j.epsl.2009.02.024](https://doi.org/10.1016/j.epsl.2009.02.024)

² Cottrell E., Walter M., and Walker D. (2010), Erratum to Metal-silicate partitioning of tungsten at high pressure and temperature: Implications for equilibrium core formation in Earth" *Earth and Planetary Science Letters* 289, 631-634 (2010), [doi:10.1016/j.epsl.2009.11.040](https://doi.org/10.1016/j.epsl.2009.11.040)

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