Earth viewed from a late Moon

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Research on the origin of the Earth has been one of the more vigorous areas of geosciences in recent years, fueled in part by powerful new geochemical techniques. It is now becoming clear that the Moon provides a more important archive of geochemical information on the early Earth than hitherto realised. At a time of renewed interest in lunar exploration it is worth considering some of the geochemical issues that might be addressed in such missions.

The Moon is thought to have accreted in a Giant Impact with a planet that added the final ~10% of the Earth's mass. Now it is also thought likely that this energetic event facilitated mixing and isotopic equilibration between the protolunar disk and the Earth. The Moon then represents the isotopic composition of the fully formed Earth immediately after the Giant Impact. We can use this to date the Moon and develop an understanding of subsequnt changes that took place on Earth. The initial Sr isotopic composition of the Moon is very well defined. If this was inherited from Earth, which has Rb/Sr~0.03, then the Moon's apparent age is 4.47±0.02 Ga in perfect agreement with some previous estimates based on ^{207}Pb-^{206}Pb dating of lunar rocks. A Moon-forming event ~100 Ma after the formation of the solar system is significantly later than previously determined using ^{182}Hf-^{182}W but it has recently been shown that all W isotopic differences between lunar samples and the composition of the bulk silicate Earth are probably of cosmogenic origin.

This late age is similar to the ^{129}I-^{129}Xe age of the Earth's degassing, and the ^{207}Pb-^{206}Pb age of the Earth. As such, the data provide evidence that a relatively late Moon-forming Giant Impact was the key event that resulted in atmospheric loss and the final stages of core formation. The late age of the Moon also means that the Earth's W isotopic compositon can now be explained without resorting to metal-silicate disequilibrium during accretion.

The time window between the Moon-forming Giant Impact and the age of the oldest terrestrial zircon dated thusfar (4.44±0.01Ga) now appears to be short (probably <50 million years) implying rapid subsequent cooling of the Earth.

A Neoproterozoic oxidation event?

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Geological and geochemical evidence converge to indicate a rapid rise in atmospheric oxygen levels (P_{O2}) at ~2.45 Ga (to $>10^{-5}$ the present level; [1]). Oxygen levels through the remainder of the Proterozoic are poorly constrained, but it is widely held that a second oxygenation event increased P_{O2} to roughly modern levels sometime in the late Proterozoic, possibly triggering the evolution and diversification of animals [2]. Canfield and Teske [3] presented the first firm geochemical data in support of a Neoproterozoic Oxidation Event (NOE) and argued that it occurred sometime between ca. 800 and 542 Ma based on an increased spread in δ^{34}S in sedimentary pyrites at that time. A series of recent studies have pointed to an oxygenation event sometime in the Ediacaran Period, consistent with a connection between rising P_{O2} and the first appearance of metazoa. Similarly, a compilation of pyrite and sulfate δ^{34}S data for the Neoproterozoic, along with modelling results, indicates that the marine sulfate reservoir, and inferentially P_{O2}, increased significantly between ca. 610 and 580 Ma [4]. However, these data, in combination with carbon isotope ratios in marine carbonates and geological evidence, also suggest that P_{O2} fluctuated considerably throughout the Neoproterozoic, with a major rise occur-ring well in advance of the first Cryogenian glaciation.

[1] Bekker, A. *et al.* (2004) *Nature* **427,** 117-120. [2] Runnegar, B. (1982) *Alcheringa* **6,** 223–239. [3] Canfield, D. & Teske, A. (1996) *Nature* **382,** 127–132. [4] Halverson, G. & Hurtgen, M. (2007) *Earth Planet. Sci. Lett.* **263,** 32–44.