GEOCHEMISTRY

# Does U–Pb date Earth's core formation?

**Arising from: B. J. Wood & A. N. Halliday *Nature* 437, 1345–1348 (2005)**

Constraining the timing of the formation of Earth's core, which defines the birth of our planet, is essential for understanding the early evolution of Earth-like planets. Wood and Halliday[1] and Halliday[2] discuss the apparent discrepancy between the U–Pb (60–80 Myr) and Hf–W clocks (30 Myr) in determining the timescale of Earth's accretion and core formation. We find that the information the authors present is at times contradictory (for example, compare Fig. 1 in ref. 1 with Fig. 1 in ref. 2) and confusing and could suggest that the U–Pb clock constrains core formation better than the Hf–W system. Here we point out the limitations of the U–Pb system and show that the U–Pb age cannot be used to argue for protracted accretion and/or core formation (>50 Myr) because this clock only records the processes that occurred during the last 1% of Earth's accretion and core formation in the Wood and Halliday mechanism[1].

For both the U–Pb and Hf–W systems to be able to date Earth's accretion and core formation, we need accurate estimates of the following parameters: the initial Solar System tungsten and lead isotope ratios; the bulk Earth elemental ratios of Hf/W and U/Pb; the present tungsten and lead isotope composition of the silicate Earth; and the present U/Pb and Hf/W ratios of the silicate portion of Earth. Whereas we know all the required parameters for the Hf/W system, several of the parameters for the U/Pb system are highly uncertain and are unlikely ever to be determined accurately enough to infer age resolution of a few tens of millions of years at 4.5 Gyr ago.

First, the U/Pb ratio of the bulk Earth (that is, $\mu_{TOTE}$ in ref. 1) is not well known, as it is a ratio of a refractory and a volatile element. Rocky planetary objects are depleted in volatile elements, including Pb to various degrees. We therefore have no way of knowing *a priori* what the building-blocks of Earth are made of in terms of the U/Pb ratio. The same is not true for the Hf–W system, as both elements are refractory. The bulk Earth Hf/W ratio has been estimated from that of primitive chondritic values with a high degree of confidence[3,4]. Using refractory elements for estimating the bulk composition of planets is one of the cornerstones of modern geochemistry.

Second, because of the long half-lives of $^{238}$U (~4.5 Gyr) and $^{235}$U (~0.7 Gyr), the lead isotope composition of terrestrial rocks varies widely and is continuously evolving. As a result, there is no easy way of deriving a single value for the present lead isotope composition of the bulk silicate Earth that can be used to date early Earth events precisely within the first 30 Myr. The same is not true for the Hf–W system. The now-extinct radionuclide $^{182}$Hf only has a 9-Myr half-life and decayed to $^{182}$W. Every rock on the surface of Earth records a single value of $^{182}$W, which is 2 parts per 10,000 higher than the bulk Earth value (obtained from chondrites).The difference is a consequence of metal extraction during core formation, which also produces a high Hf/W ratio in the silicate portion of Earth. Thus, we have a well-determined tungsten isotope composition for the bulk silicate Earth, but a highly uncertain one for lead isotopes.

The accretion process is not a well-defined point in time and, in fact, is technically still continuing today. The best designation of the 'end' of our planet's formation (>99% mass accreted) is probably the final major event in Earth's accretion process, the formation of the Moon by a Mars-sized impactor. This time is constrained by the tungsten isotope data to be about 30 million years after the formation of the Solar System[4–8]. New tungsten isotope data from lunar samples reinforce this conclusion (see Fig. 3b of ref. 9).

Wood and Halliday[1] invoke the late-stage sulphide phase segregation into the core to explain the inconsistency between U–Pb and Hf–W. However, to account for the increased U/Pb ratio in the silicate Earth by lead partitioning into the core, note that additional mass added to the core after the last Moon-forming giant impact is trivial (<1%)[1]. The U–Pb clock therefore sees one of the 'trees but not the forest' of core formation, as the U–Pb record necessarily misses >99% of the core-formation processes. The U–Pb system is strongly influenced by Earth's surface processes, and the so-called 'Pb paradox' still has many alternative interpretations to core formation[10]. Late sulphide segregation may explain the putative age difference between U–Pb and Hf–W, but it is misleading to portray the U–Pb ages as the time of Earth's core formation[1].

**Qing-zhu Yin*, Stein B. Jacobsen†**
*Department of Geology, University of California, Davis, California 95616, USA
e-mail: yin@geology.ucdavis.edu
†Department of Earth and Planetary Sciences, Harvard University, Cambridge, Massachusetts 02138, USA

1. Wood, B. J. & Halliday, A. N. *Nature* **437,** 1345–1348 (2005).
2. Halliday, A. N. *Nature* **427,** 505–509 (2004).
3. Harper, C. L. & Jacobsen, S. B. *Geochim. Cosmochim. Acta* **60,** 1131–1153 (1996).
4. Yin, Q.-Z. *et al. Nature* **418,** 949–952 (2002).
5. Schoenberg, R., Kamber, B., Collerson, K. D. & Eugster, O. *Geochim. Cosmochim. Acta* **66,** 3151–3160 (2002).
6. Kleine, T., Münker, C., Mezger, K. & Palme, H. *Nature* **418,** 952–955 (2002).
7. Jacobsen, S. B. *Science* **300,** 1513–1514 (2003).
8. Jacobsen, S. B. *Annu. Rev. Earth Planet. Sci.* **33,** 531–570 (2005).
9. Kleine, T., Palme, H., Mezger, K. & Halliday, A. N. *Science* **310,** 1671–1674 (2005).
10. Hofmann, A. W. in *The Mantle and Core: Treatise on Geochemistry* Vol. 2 (ed. Carlson, R. W.) 61–101 (Elsevier-Pergamon, Oxford, 2003).

**doi:**10.1038/nature05358

GEOCHEMISTRY

# How well can Pb isotopes date core formation?

**Arising from: B. J. Wood & A. N. Halliday *Nature* 437, 1345–1348 (2005)**

Timescale and the physics of planetary core formation are essential constraints for models of Earth's accretion and early differentiation. Wood and Halliday[1] use the apparent mismatch in core-formation dates determined from tungsten (W) and lead (Pb) chronometers to argue for a two-stage core formation, involving an early phase of metal segregation followed by a protracted episode of sulphide melt addition. However, we show here that crust–mantle Pb isotope systematics do not require diachronous core formation. Our observations indicate that very early (≤ 35 Myr) core formation and planet accretion remain the most plausible scenario.

Core formation could have entailed a severe fractionation of the U/Pb ratio in the mantle, ultimately causing the average lead (radiogenic