

GEOSCIENCE

Earth's patchy late veneer

A 'late veneer' of meteoritic material, added after Earth's core had formed, may be the source of our noble metals. Its absence from some parts of Earth's mantle will now force a rethink about this late accretion. [SEE LETTER P.195](#)

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Earth's metallic core is the major repository of the highly siderophile ('iron-loving') elements, which include gold, rhenium and the platinum-group elements. Their strong affinity for iron means that their abundance in Earth's mantle is very low — but not as low as might be expected. One popular explanation for this discrepancy is that a late veneer of primitive meteoritic material was added to Earth's mantle after core formation had ceased¹. On page 195 of this issue, Willbold and colleagues² add weight

to this theory by using an isotope of tungsten to show that the late veneer is missing from some areas of the mantle. Our understanding of Earth's late accretion may need to change as a result.

Energetic collisions between Moon- to Mars-sized planetary embryos during Earth's growth caused widespread melting, facilitating the separation of molten metal from surrounding liquid silicate in a magma ocean. The molten iron sank towards Earth's centre, removing the siderophile elements to the core. However, highly siderophile elements are present in Earth's mantle in much higher

amounts than are predicted from metal–silicate partition experiments at atmospheric pressure³. One explanation is that the affinity of these siderophile elements for iron may have decreased under the very high pressures and temperatures found at the bottom of a deep magma ocean⁴. This model seems to work for some highly siderophile elements⁵, but not for all of them⁶.

An alternative explanation calls for the addition of 0.5–1% of primitive meteoritic material after the core had formed¹. This 'late veneer' might also have included ingredients essential for life, such as water, carbon and other volatile compounds. As is evident from large impact basins on the Moon, Earth continued to accrete material after the giant impact that resulted in the formation of the Moon and the final segregation of Earth's core, some 4.5 billion years ago (Fig. 1). This period of late accretion lasted for about 500 million years and ended catastrophically with a terminal bombardment 4.0 billion to 3.8 billion years ago. Although there is strong visual evidence for late accretion, it is not clear whether the mass added was sufficient to account for the abundance of highly siderophile elements in Earth's mantle.

Willbold and colleagues² approach the problem in a new way by looking for small variations in the abundance of the tungsten isotope ¹⁸²W, generated by the decay of the now-extinct hafnium isotope ¹⁸²Hf. The tungsten isotopic composition of Earth's mantle is different from that of the putative late veneer, which presumably consisted of chondritic meteorites — bits and pieces left over from the earliest stages of planet formation and considered to be the main building blocks of Earth. These differences in ¹⁸²W abundance are the result of core formation, during which hafnium remained in the mantle while tungsten preferentially partitioned into the core⁷. Radioactive decay of ¹⁸²Hf to ¹⁸²W then resulted in an enrichment of ¹⁸²W in the mantle relative to chondrites by about two parts in 10,000 (or 2ε; Fig. 1).

Given the different ¹⁸²W composition in Earth's mantle and in chondrites, the addition of a late veneer should be recorded in the tungsten isotopes. However, the expected effects are vanishingly small. Willbold and colleagues² have made tungsten-isotope measurements of unprecedented precision and show that the abundance of ¹⁸²W in most of the accessible silicate Earth is invariant. However, they find that samples from the Isua greenstone belt in western Greenland are slightly enriched in ¹⁸²W compared with the average for Earth's mantle. The magnitude of this small enrichment is exactly that predicted for the added mass of chondritic material required to account for the concentrations of highly siderophile elements in the mantle. These results therefore provide strong support for the late-veneer model.

The importance of Willbold and colleagues'

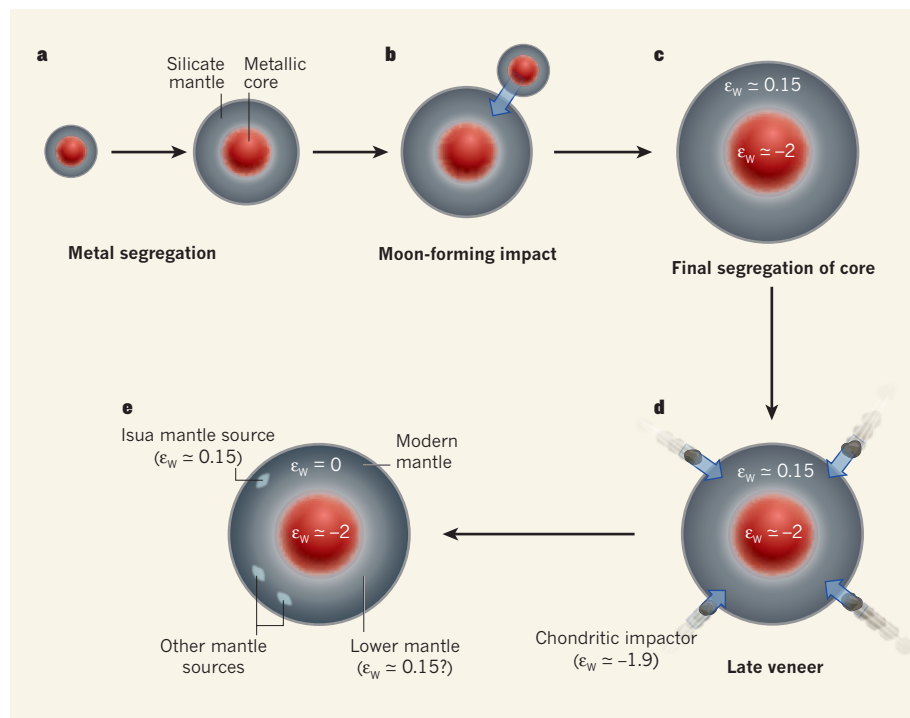


Figure 1 | Earth's accretion and effects of the late veneer. **a–c**, Accretion and core formation (4.567 billion to about 4.5 billion years ago). **a**, Siderophiles are removed from the silicate mantle to the metallic core. **b**, Moon-forming impact and end of Earth's main accretion. **c**, Final segregation of the core: mantle is depleted of highly siderophile elements, now concentrated in the core; ϵ_W ($\epsilon^{182}W$) denotes tungsten-isotope enrichment as parts per 10,000 relative to the modern terrestrial mantle. **d,e**, Late accretion (about 4.5 billion to 3.8 billion years ago) following core formation. **d**, Highly siderophile elements are replenished in the mantle by a late veneer of chondritic meteorites. **e**, Addition of the late veneer reduces mantle ¹⁸²W enrichment to an ϵ_W of zero. Willbold *et al.*² propose that rocks from Isua in Greenland have the same ¹⁸²W enrichment ($\epsilon_W \approx 0.15$) as the mantle had before the late veneer formed, indicating that some domains within Earth's mantle may have escaped addition of the late veneer.

study goes far beyond this, however. All of the Isua samples analysed derive from a mantle source that was established very shortly after the final stage of Earth's accretion⁸, so it may not be surprising that they preserve a signature of Earth's mantle before the arrival of the late veneer. As the Isua samples seem to lack the late-veneer component, they would be expected to be very poor in the highly siderophile elements. Surprisingly, they are not, for reasons that are not understood. Nevertheless, their osmium (¹⁸⁷Os) isotopic composition is different from that of chondrites⁹, consistent with the absence of the late veneer in their source.

Tungsten-182 enrichments have also been identified in 2.8-billion-year-old rocks called komatiites¹⁰, which derive from deep-rooted mantle sources. Osmium-187 is the decay product of rhenium-187, and the ¹⁸⁷Os enrichment in these and many other komatiitic lavas¹¹ may reflect rhenium–osmium fractionation during core formation in a deep magma ocean, a signature that has otherwise been overprinted by the late veneer.

Ultimately, it may transpire that the late veneer was deposited in large patches, perhaps by a few big impactors. In that case, some areas of Earth's mantle would not have received such late accreted material and would have

remained isolated from the rest of the mantle throughout the planet's history (Fig. 1). Future studies should use both tungsten and osmium isotopic data to identify such mantle domains: this could potentially distinguish signatures left behind during the final stages of core segregation from those of the late veneer. ■

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