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Does asteroid 4 Vesta, with watery 1 Ceres and the Galilean moons, record the Ringwood-mode iron core construction now predicated for Earth and even apply to the other terrestrial planets?

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I reason that Vesta, the source of HED but too small for appreciable magmatic resurfacing after accretion had ended, preserves valuable clues as to how the Earth and the other terrestrials were built.

Setting the scene. Core formation in the terrestrial planets has long been attributed to the percolation of molten iron accreted from the solar nebula, either inward from the surface or from a magma ocean at depth. But it has been found [1,2] that the 56Fe/54Fe ratio in Earth peridotites still has a chondritic ratio, which rules out that Fe percolation has occurred.

So we must revert now to Ringwood's model (1960-1978) e.g.[3] for core formation. This uses the nebula to reduce hot FeO in lavas erupted in volcanoes at the protoplanet's surface. The Fe, which then drains to the bottom of the magma chamber and solidifies, is subsequently 'load-subducted' rapidly to form the core. For Earth's core alone this would generate ~400 earth-ocean volumes of reaction water, a Solar System benefit already foreseen by Ringwood, water being low in star-forming clouds. The heat for the volcanism is internal (accretion, gravitation, radiogenic) so orbital distance in the presence of nebular opacity is immaterial; and important for making the cores in the Galilean moons, otherwise labelled as being at the 'snow line' in the disc.

In order to work, prior iron accretion to form the body must have been in oxide form. Thermodynamically this is correct if the nebula is cool (<600K [4]), and should be achieved naturally if the protoplanetary disc material were acquired while the protoSun traversed a further dust cloud (typical 10K or less) [5,6]. Related 'contamination' of the outer Sun, an unmixed star, would explain why its spectrum nearly matches the planets.

Ringwood-mode core formation needs nebular presence for the reaction, so it would cease at nebular departure on exit from that cloud, leaving the body's mantle replete with reaction water. For Earth, we see this in the 4374Ma detrital zircons from water-requiring granitoids [7], and its continuing abundance in water-rich ringwoodite at the bottom of the upper mantle [8].

Vesta as a record of Ringwood-mode (RM) core formation. Based on its 220km diameter core [9] and a 500km mean overall diameter, the water generated by RM core formation would have given it a water-laden atmosphere containing an effective surface water layer over 30km deep. Current flows in this, presumably below a frozen lid, appear to have carved early deep channels in

the uncoherent regolith, well seen as a.m.-conserving spiral channels (5.3hr rotation period) outboard of the later southern impact. Circum-equatorial similar grooves all seem to predate the impact cratering, made possible by loss of the water/ice.

Character of an RM volcano interior. We can construct a vertical section from the meteoritic record, with eucrites at the top, diogenites in-between, pallasites (stony-iron) below and finally irons at the bottom. Eucrites are lavas whose FeO reduction reaction with the nebular H is recorded by clouding in the pyroxenes and plagioclase [10]. Pallasites are typical magma-chamber cumulate high-Mg olivines surrounded by an FeNi matrix which arrived by percolation from above. Lower still, the Fe/Ni 'irons' represent the pool below the lower-density olivines. Thus all these have been accessible to impact without breaking up long-solid iron cores. The >50-fold variety of observed FeNi compositions in 'irons' [11] could thus be natural volcanic variation, even on a single body, without invoking the rupture of so many separate cores.

Finally, we suppose that Ceres and the Galileans, being further out, have (bar Io) managed to retain their Ringwood-mode water. For Europa [12,13], in particular, the ratio of core to preserved water seems close to the Ringwood-mode expectation.

On the compulsive evidence [1,2] and our evidence [3,4] for Earth, it seems that Ringwood-mode core formation may have applied throughout the Inner Solar System.

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