An embarrassment of riches: reconciling our solar system's platinum problem

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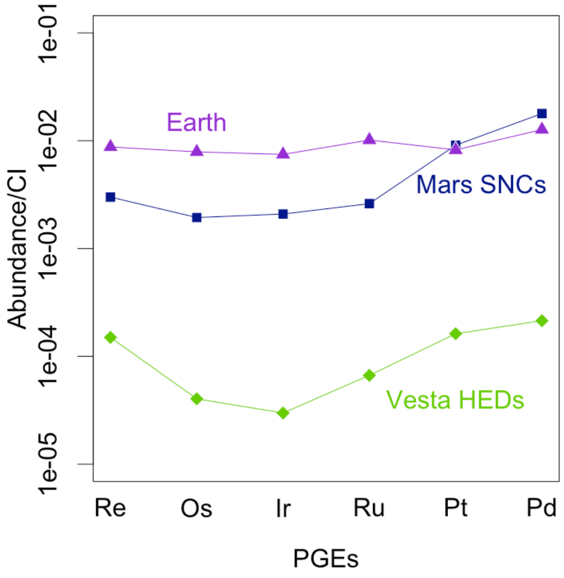

Fig 1: The concentrations of the platinum group elements on the Earth, Mars and Vesta.

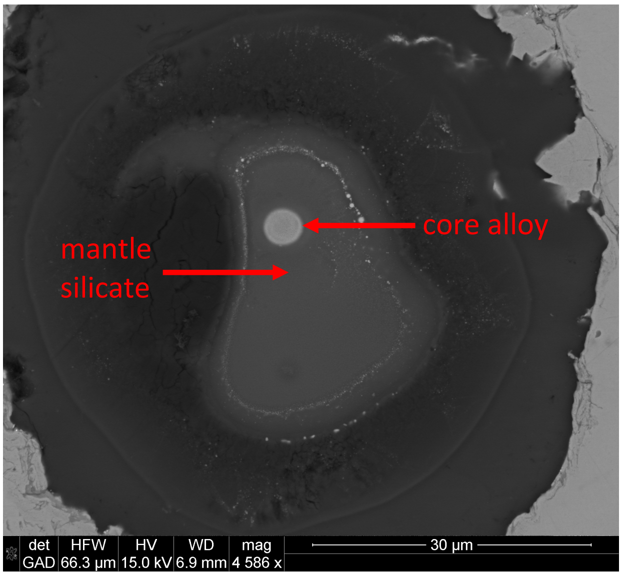

Fig 2: A planetary core in the lab: a recovered experiment from a laser-heated diamond anvil cell experiment.

Project Background

The Earth and Mars have too much platinum. This is also true of the rest of the platinum group elements (PGEs), osmium, iridium, ruthenium, rhodium and palladium, all of which are highly-siderophile elements (HSEs) that strongly partition into the metallic cores of planets during differentiation. Experiments in which liquid core alloy and liquid silicate are equilibrated at high pressures, designed to mimic the process of core segregation during planetary differentiation (Mann et al., 2012) indicate that the concentration of PGEs on Earth and Mars are two orders of magnitude too high, while they are about right on Vesta (Fig. 1), a differentiated planetesimal that survived the process of accretion in the early solar system. However, these experiments were performed in large-volume press apparatus, limited to pressures of <25 GPa, far below the expected average pressures of core-segregation in Earth (40-70 GPa). What's more, the Earth's PGE pattern is flat: i.e. the PGEs appear to be near their original, chondritic ratios. These observations combined have led to the suggestion that Earth's PGE supply was topped up by a 'late veneer' of chondritic material added long after the main stage of accretion was complete.

However, new experiments on platinum partitioning between liquid metal and liquid silicate at much higher pressures, indicate that a much lower partition coefficient would have governed the partitioning of platinum at the conditions of core-mantle segregation (Suer et al., 2021) . If true, then we have the *opposite problem*: the concentration of PGEs in Earth's mantle would be *too small.* The solution could lie in the fact that PGEs are also chalcophile elements: they love to dissolve in sulfur rich metallic melts. Such sulfur 'mattes' are hypothesized to form very late during the crystallization of Earth's magma ocean, as the dwindling silicate magma becomes increasingly rich in sulfur (Rubie et al., 2016; Steenstra et al., 2022). If these mattes reach the core, then they could strip out the PGEs that have survived partitioning into the initial, sulfur-poor core alloy, and again reconcile the mantle PGE budget with the experiments. However, experiments of this type extend to only 11 GPa (Laurenz et al., 2016).

It is likely that all of these processes occurred. How then can we reconcile the very different PGE abundances and ratios in very different planetary objects (Earth, Mars, Vesta)? To do so requires a baseline where we have other constraints on, for example the pressure at which core formation occurred. That baseline is Earth. If we could determine the partition coefficients for all the PGEs at the pressures of core segregation, between metal, sulfide and silicate melts, then we could model the expected mantle concentrations, and thus estimate the size and composition of the late veneer needed to top off the inventory. With that knowledge we have a chance to tightly constrain the sequence of events that led to the accretion of other planetary objects in our solar system, including Mars and Vesta.

Project Aims and Methods

Laser-heated diamond anvil cell experiments will be carried out in the Petrology Group labs at the School of Earth Sciences, University of Bristol using recently developed techniques (Zhang et al., 2024) at pressures up to 100 GPa and temperatures over 4000 K. You will perform partitioning experiments on simplified bulk-silicate Earth compositions, equilibrated with either iron metal or iron-sulfur alloys and doped with PGEs. Once equilibrated, the samples will be quenched by turning off the power to the lasers, extracted and polished, revealing a metallic ball surrounded by homogenous glass that represents the silicate melt (Fig. 2).

The relative abundances of HSEs in the different phases of the experimental products will be determined with two approaches using the state-of-the-art equipment of the Bristol Isotope Group at the University of Bristol. To measure the tiny experiment samples, we will use a high-resolution plasma mass spectrometer coupled with two different introduction schemes. 1) An *in situ* method using an excimer laser ablation system to measure experiment phases containing abundant HSEs. 2) For silicates, where we might expect HSE abundances to be <10 ppm, we will employ a novel mixed isotope spike method and high sensitivity solution plasma introduction. This will allow a more precise quantification of the low HSE abundances in the silicate phases, something which has been poorly constrained in previous studies.

Candidate

The successful applicant should have a background in either Earth Sciences or a related physical science, preferably to MSc/MSci level. A strong interest in Earth or planetary sciences is essential, as too is an enthusiasm for practical, laboratory work and careful, analytical study.

Training

The applicant will be trained in sample synthesis and micro-fabrication techniques, glass making by aerodynamic levitation, laser milling, sputter coating and polishing. Experimental techniques will include the use of infra-red industrial lasers and diamond anvil cells. Post experimental analysis will require training in Raman and photo-luminescence spectroscopy, electron-probe micro-analysis and ultra-violet laser ablation and wet chemistry. In addition, the candidate will gain oral presentation skills within the School and at international conferences, and will gain experience in writing up results for publication.

References / Reading List

- Zhang, H. L., Hirschmann, M. M., Lord, O. T., et al. (2024). Ferric iron stabilization at deep magma ocean conditions. *Science Advances*
- Steenstra, E. S., Lord, O. T., et al. (2022). Sulfur solubility in a deep magma ocean and implications for the deep sulfur cycle. *Geochemical Perspectives Letters*
- Suer, T.-A. et al. (2021). Reconciling metal–silicate partitioning and late accretion in the Earth. *Nature Com.*
- Rubie, D. C. et al. (2016). Highly siderophile elements were stripped from Earth's mantle by iron sulfide segregation. *Science*.
- Mann, U. et al. (2012). Partitioning of Ru, Rh, Pd, Re, Ir and Pt between liquid metal and silicate at high pressures and high temperatures - Implications for the origin of highly siderophile element concentrations in the Earth's mantle. *Geochim Cosmochim Acta*, *84*, 593–613.
- Laurenz, V., et al. (2016). The importance of sulfur for the behavior of highly-siderophile elements during Earth's differentiation. *Geochim Cosmochim Acta*, *194*, 123–138.
- Dale, C. W. et al., Late Accretion on the Earliest Planetesimals Revealed by the Highly Siderophile Elements. *Science*

Application deadline: 14.00 GMT, 25th Feb 2026
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