STEP'UP

ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
ET PHYSIQUE DE L'UNIVERS, PARIS

Subject offered for a contract starting October 2017

SUBJECT TITTLE: Origin of the late accretion history of terrestrial planets, onset of plate tectonics and conditions of core formation estimated from platinum stable isotopes

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Financing: Doctoral contract with or without teaching assignment

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Understanding the accretion history of planetary bodies is key to elucidating the timing and processes associated with the differentiation of terrestrial planets into different chemical distinct envelope (e.g. metallic core, oxidised mantle, gaseous atmosphere). The abundances of highly siderophile elements (HSE) have played a critical role in constraining models of planetary accretion and differentiation. For example, the apparent overabundance of HSE in Earth's mantle forms the basis of the late-veneer hypothesis, in which the last 0.5% of Earth's mass was accreted from chondritic material after core formation was complete (e.g. ref. 1). Addition of this material can explain the elevated mantle HSE abundances and their broadly chondritic relative proportions[1], and provide a mechanism for the delivery of volatiles to Earth [2]. However, this hypothesis is dependent on metal–silicate partitioning data, which are known to vary at different conditions relevant to core formation and alternatively the elevated HSE abundances in Earth's mantle may be the result of core formation at high-temperatures and –pressures [3]. The late-veneer hypothesis is also supported by small excesses in ^{182}W, the decay product of short-lived ^{182}Hf, observed in some of Earth's oldest rocks[4,5]. However, the timing and scale of veneering of the early Earth are poorly constrained and the origin of these Archean enrichments is controversial[6]. Moreover, the utility of the ^{182}W tracer is limited to young planetary bodies, as late accretion signatures may be overprinted from radiogenic ingrowth from the decay of the short-lived ^{182}Hf nuclide ($t_{1/2}$ = 8.9 Myr) in early-formed bodies. Despite this evidence, the timing and scale of the delivery, admixing, and homogenisation of late-veneer material into the terrestrial and Martian mantles remain poorly constrained, although critical to our understanding of early planetary processes and dynamics.

The partitioning of an element between the core and the mantle of terrestrial planets can produce isotopic fractionation (due to the difference in the bonding environment of the element between metal and silicates). For example, this effect has been demonstrated for Si (e.g. ref. 7). It is therefore expected that after core formation the mantle of the Earth should be isotopically fractionated compared to undifferentiated meteorites (which are supposed to represent the isotopic composition of the bulk Earth). Since isotopic fractionation is proportional to $1/T^2$ and decreases with the mass of the elements[8], the isotopic effects are very small, and very precise methods are needed to potentially trace these fractionations. Therefore core formation would leave the archean mantle isotopically fractionated compare to the bulk Earth, and late arrival of meteoritic component should modify the isotopic composition of the mantle to drive it back to the composition of chondrites (and therefore bulk Earth). Following this logic, we have recently developped and employed the high precision stable isotope composition of the highly siderophile element platinum as a novel tool to trace the late accretion history of terrestrial planets (see ref. 9 for the method). In this paper, we characterised the Pt stable isotope composition of a comprehensive suite of inner Solar System bodies, including Earth, and primitive and partially differentiated asteroids. The Pt stable isotope data are acquired by a double spike method coupled with a multi-collector inductively-coupled-plasma mass-spectrometer (MCICPMS) (see ref. 9). These results suggest that core formation on asteroidal parent bodies results in appreciable enrichment in the heavy isotopes of the residual Pt in their silicate mantles. On the other hand, the Pt stable isotope composition of Earth's modern mantle is chondritic, indicating that the signature of core formation has been overprinted by a late-veneer of chondritic material. Conversely, Archean samples from southern Africa and Greenland retain non-chondritic, heavy Pt isotopes, indicating core/mantle equilibrium and preservation of early mantle components that escaped complete mixing with the late-veneer. There are, however, many questions and fundamental unknowns that are raised by this preliminary work: 1) what is the isotopic fractionation factor of Pt (and other HSE) between metal and silicate? 2) How did the late veneer material admix with the mantle? 3) What is the proportion of material admixed into the Earth's mantle at 3.8Ga? and does it relate to the onset of plate tectonics? 4) How does it compare to the dynamic of admixing of late veneer in Mars?

The present PhD thesis will focus on solving these questions by combining experimental petrology (piston-cylinder experiments of metal-silicate partitioning), isotope geochemistry (double-spike Pt stable isotopic measurements of meteoritic such as martian meteorites and terrestrial samples).

To answer these questions the PhD thesis will be split in 2 tasks:

Task 1: Determining the metal/silicate isotopic fractionation factor of Pt and other HSE, using the experimental geophysical laboratory.

Task 2: Analyse the Pt isotopic composition of Martian samples and compare it to the oldest terrestrial samples. Combining these data with the parameters obtained in the task 1 to estimate the physical condition of core/mantle equilibrium in Mar.

This thesis will therefore build up on our unique expertise in high precision Pt isotopic data, experimental petrology and the results will be used to further characterize the timing and scale of mixing of late arrival materials in terrestrial planet and answer fundamental questions.

Schedule:

-1st year: a) The student will learn high-pressure experiment techniques and realize most of these experiments, and characterize the experiments. (Task 1)

b) The student will learn the Pt stable isotopic measurements by double-spike measurements and will perform the measurements on the martian meteorites (Task 2).

c) Submit an abstract for the LPSC on the martian meteorite data (Task 2).

-2nd year: a) finish the high-pressure experiments and start to perform the measurements (Task 1).

b) Write a paper on Pt metal/silicate partitioning (paper 1)

c) Finish the measurements of martian meteorites and will write a paper (paper 2)

d) Present his/her results at LPSC

-3rd year: Write a paper on the metal/silicate isotopic fractionation of Pt (paper 3)

The student will write a paper synthesizing the experimental data/terrestrial, meteoritic and martian data (paper 4)

The student will write up his/her thesis and defend it.

1 Walker, R. J. *Chemie der Erde* **69**, 101-125 (2009). 2 Owen, T. & Barnun, *Icarus* **116**, 215-226, doi:10.1006/icar.1995.1122 (1995). 3 Mann, U. et al. *Geochim. Cosmochim. Acta* **84**, 593-613, doi:10.1016/j.gca.2012.01.026 (2012). 4 Willbold, M., Elliott, T. & Moorbath, S. *Nature* **477**, 195-U191, doi:10.1038/nature10399 (2011). 5 Touboul, M., Puchtel, I. S. & Walker, R. J. T *Nature* **520**, 530-+, doi:10.1038/nature14355 (2015). 6 Rizo, H. *et al. Geochim. Cosmochim. Acta* **175**, 319-336, doi:10.1016/j.gca.2015.12.007 (2016). 7 Georg, R. B., Halliday, A. N., Schauble, E. A. & Reynolds, B. C. *Nature* **447**, 1102-1106 (2007). 8 Bigeleisen, J. & Mayer, M. G. *J. Chem. Phys.* **15**, 261-267 (1947). 9 Creech, J. B. *et al. Geochemical Perspective Letters* **3**, doi:doi: 10.7185/geochemlet.1710 (2016).