

URANIUM AND LEAD IN THE EARLY PLANETARY CORE FORMATION : NEW INSIGHTS GIVEN BY HIGH PRESSURE AND TEMPERATURE EXPERIMENTS. V. Malavergne<sup>1 and 2</sup>, M. Tarrida<sup>2</sup>; R. Combes<sup>2</sup>; H. Bureau<sup>3</sup>, Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, USA, <sup>2</sup> Lab. Géomatériaux, IFG, Marne la Vallée, France, <sup>3</sup>LPS – CEA-CNRS, CE Saclay, 91191 Gif s/Yvette, France

**Introduction** Geologists and geochemists have been studying the abundance and distribution of the isotopes of U for more than a century. If we want to understand how U is distributed in the Earth or Mars, the abundance and isotope characteristics of Pb (the radiogenic daughter of U<sup>235</sup> and U<sup>238</sup>) are useful parameters. Pb has a relatively low abundance in the primitive Earth's mantle in comparison with meteorites [1]. Pb could be lost during planetary accretion (because of its volatile nature) and core segregation [1]. In parallel, many authors have discussed the possibility that radioactive decay of U and Th might be an important heat source within planetary cores [2, 3]. Previous experimental studies [2] have shown that under reducing conditions U and Th deviated from lithophile character and concentrated in sulfides. Several lines of evidence suggest that the Earth's core and the Martian core possess a significant proportion of light elements [4], [5]. The light components could be constrained from determining the physical conditions of core formation in these early planets. In order to quantify possible fractionation of U and Pb into a metallic core containing light elements, we have performed an experimental study at high pressure (HP) and high temperature (HT) and determined the partition coefficient  $D_{\text{met-sil}}$  of Pb and U (wt% in metal / wt% in silicate) between metal and silicates at HP-HT.

**Experimental and analytical procedures.** Multianvil experiments were performed at 5 and 15 GPa and 1900°C. The partitioning of Pb and U between liquid metal and silicates have been investigated at different oxygen fugacity, with different starting silicate and metal compositions. In order to be relevant to the light elements of the Martian or Earth's cores, we have performed experiments with (Fe, S), (Fe, Si) but also with (Fe, S, Si) metallic phases, as S is a possible candidate for these planetary cores [4, 5], and Si a good candidate for the Earth's core [6]. Samples were analyzed with a Scanning Electron Microscope (SEM) equipped with a energy-dispersive X-ray analyzer (EDX). A CAMECA SX electron probe microanalyzer (EPMA), equipped with wavelength dispersive X-ray spectrometer (WDX) was also used to analyze the samples. In samples #282 and #279, the concentrations of trace elements in metal and in silicates have also been measured by  $\mu$ PIXE operating at 2 MeV and 400pA with a focused 4 x

4 $\mu\text{m}^2$  beam. We obtained a good agreement between these two independent analytical methods. The oxygen fugacity  $f\text{O}_2$  in most experiments has been calculated by using two independent buffers : iron/wüstite (IW) and  $\text{SiO}_2/\text{Si}$ , allowing to link consistently the Fe contents in silicates, the Si contents in metal (when present) and the temperatures of the experiments according to [7].

**Results.** Under the pressure (5 or 15 GPa)-temperature (always 1900°C) conditions of the experiments, the metal was always liquid. In each sample, several chemical profiles have been made with EPMA in order to test local equilibrium. The largest particles of metal observed in the samples (between 200 $\mu\text{m}$  and 50 $\mu\text{m}$ ) in contact with silicates exhibit the same global composition as the tiny metal grains (between 10 $\mu\text{m}$  and 4 $\mu\text{m}$ ) embedded within the silicate matrix. This is a first indication for local equilibrium at the scale of several tens of micrometers in these samples ; a second indication is the absence of chemical zoning in the silicates. Some chemical zoning in the metallic phases have been characterized and are interpreted as quenched melt textures, since it is almost impossible to recover homogeneous quenched metallic phases with our starting metallic compositions as already observed in previous similar studies with (Fe, S) and (Fe, S, Si) metallic phases [8] or with (Fe, Si) phases [9]. Also, [10] and [11] have demonstrated attainment of equilibrium in similar experiments in less than 4 minutes although our experiments have been lasted between 6 and 10 minutes. Our results have been summarized in Fig. 1 as a function of oxygen fugacity calculated from Fe contents in metal and coexistent silicates, at different pressures. Pb remains siderophile at HT-HT and at low  $f\text{O}_2$  and with a metal without S. Its partition coefficient depends on the silicate and metal compositions (see the 2 « high  $f\text{O}_2$  » data from [11] and [12], where the metallic composition is almost pure iron) and also on the pressure. The partition coefficient of U seems to be also pressure dependent and shows a light decrease at HP with the same starting composition.

**Discussion.** A first important conclusion for this study is that Pb remains siderophile even with a metal without sulphur. A direct comparison with previous studies is not straightforward because these partition

coefficients depend on the composition of the silicates and metals, they also depend on the pressure, temperature and redox conditions. Particularly, the comparison with the  $D_{\text{met-sil}}^{\text{U}}$  of [3] is very difficult since these authors acknowledged the fact that some of their samples were not equilibrated and didn't give the real  $f\text{O}_2$  of their experiments. Their values for  $D_{\text{met-sil}}^{\text{U}}$  were between 0.002 and 2, over the temperature range 1150°-1350°C and the pressure range 1 bar – 15 kbars. The other interesting point of this previous study is that their stronger U content in metal was obtained with Si-bearing metal, such as our study. Anyway, these authors emphasized that U became siderophile under low oxygen fugacity.

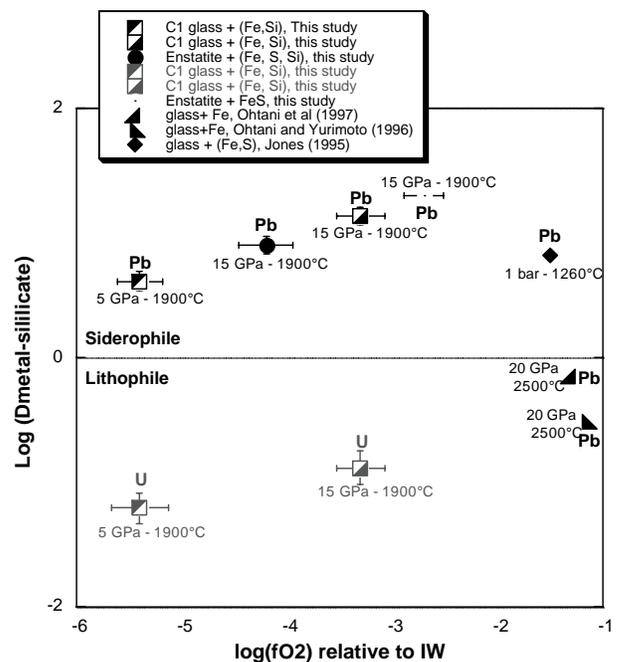
Our Pb and U partition coefficient obtained at 15 GPa, 1900°C and  $\Delta\text{IW} = -3.2$ , with « C1 glass + (Fe, Si) » as starting materials, may be used to constrain the U and Pb content in the Martian or Earth's cores. The Pb content of the Earth's mantle is given by different studies (e.g. [14, 15]). We have made the assumption that the silicate mantle have been in equilibrium with the core. We have obtained a Pb content for the Earth's core from 2.4 to 0.6 ppm. These results agree with of the models proposed by [16]: 0.4 ppm or [17]: 7.4 ppm. U content in the silicate Earth's upper mantle or in the Martian mantle are given by [15] and [18]. With a metal in equilibrium with these silicates, it could be possible to incorporate between 1 to 6 ppb of U in the Earth's core and around 2ppb in the Martian core. The Earth's core heat production is estimated around 7 TW [19]. 1 or 6 ppb of U in the Earth's core would produce less than 1 TW. This value is well below the required heat production but more experimental work should be done to be able to refine this value.

**Conclusion.** At HP-HT, Pb remains siderophile even with a metal without sulphur while the lithophile character of U seems to lightly decrease. These first results heighten the importance of doing more experimental work at HP-HT and  $f\text{O}_2$  relevant to the early Earth and Mars.

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**Figure 1:** Summary of experimental partition coefficients of this study for Pb and U and previous results (Ohtani *et al*, 1997, Ohtani and Yurimoto, 1996 and Jones, 1995). The experimental partition coefficients are plotted vs  $f\text{O}_2$  relative to IW at different pressures. Similar symbols (triangle, square or circle) represent a same starting composition.



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