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The U/Pb age of the Earth - a signature of late volatile addition

C. Ballhaus (1), V. Laurenz (1), C. Münker (2), R.O.C. Fonseca (1), F. Albarède (3), A. Rohrbach (4), M. Lagos (5), M.W. Schmidt (6), K.P. Jochum (7), B. Stoll (7), U. Weis (7), and H. Helmy (8)

(1) Steinmann Institut, Uni Bonn (ballhaus@uni-bonn.de), (2) Universität zu Köln, (3) Ecole Normale Supérieure (LST), Lyon, (4) Universität Münster, (5) KIT Institut für Nukleare Entsorgung, Karlsruhe, (6) ETH Zürich, (7) Max-Planck-Institut für Chemie, Mainz, (8) El Minia University, Egypt

The 238U/204Pb ratio of the Earth's mantle is conventionally seen as reflecting lead loss to the Earth's core, implying that lead is siderophile. A contrasting view holds that the depletion in lead may be volatility controlled, arguing that lead is depleted only because it did not condense to the same extent as elements more refractory than Pb. To help solve this issue, we simulated experimentally the distribution of Pb at trace concentration level between a fertile mantle silicate and an S-bearing iron metal melt, over a range of temperature and pressure from 1673 to 2373K and 1 to 5 GPa. Because Pb should be seen within the context of other siderophile and volatile elements of the mantle, we also studied the partitioning of the elements W, Cr, P, Rb, Cs, Cd, Sn, Zn, In, and Tl.

It is noted that the D (metal/silicate) of lead is highly temperature dependent, ranging from 0.2 (1673K) to 65 at 2373K. Hence, under the physical conditions of a magma ocean Pb would indeed have been highly siderophile and would have been depleted seriously to the core. The same holds for the elements Cd, Tl, Sn, and In which are as siderophile at magma ocean temperature as Pb. Other volatiles like K, Rb, and Cs, however, remain lithophile even under the most extreme temperature (2373K) and fO_2 (IW-6) conditions.

The Ds allow to quantify element abundances to expect in the mantle if the spectrum of refractory and volatile elements reflected equilibrium with Fe metal. No plausible set of physical conditions can be defined where the present-day abundances of all moderately volatile elements of the mantle could have been in equilibrium with a metallic iron melt. A large proportion of the moderately volatile elements in the Earth's, including lead, were added late, during the waning stages of core formation. In consequence, the 238U/204Pb may be the accidental result of volatile addition, to a proto-mantle far more refractory than the present-day mantle, and the Pb isotope ratios of the mantle may not date the differentiation of the Earth in silicate mantle and metallic core.