Mantle Pb Isostope Evolution Patterns

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Much of the information on mantle isotopic evolution is based upon Sr, Nd, Hf and Pb. Pb has the advantage of paired isotopes and of forming galena deposits that are often immune to contamination. Here we use galena data to study evolution from 4.48 (time of core formation) to 2.7 Ga, and carbonatite data between 2.7 and 0 Ga. Data from galenas with ages of 3.81, 3.23, 3.45 and 2.7 Ga paired with Canyon Diablo troilite Pb at 4.56 Ga define closed system evolution patterns that extrapolate to modern values of 17.59±0.11 for ^{206}Pb/^{204Pb} with mu= 8.0 and 38.05±0.12 for ^{208}Pb/^{204}Pb with 4.1 for 232Th/238U. Between 2.7 to 0 Ga we choose carbonatites from the Canadian Shield carbonatites that are known to yield regular evolution patterns over that period for Sr. The carbonatite Sr data fit the estimated bulk silicate Earth ('BSE') trajectory at ca 2.7 Ga, where they branch off to lower ^{87}Sr/^{86}Sr values that characterize depleted mantle sources. Nd differsfrom Sr with ratios that already plot off its "BSE" value ('CHUR') at 2.7 Ga, also indicating depleted mantle components. Like Sr, the Pb data from the Canadian Shield carbonatites with ages 0.1–2.7 Ga show a branching in their evolution patterns at ca. 2.7 Ga., but in the direction of enriched components. The youngest Canadian carbonatites have the highest ^{206}Pb/^{204}Pb ratios of the suite, averaging 19.64. Young, 0–0.3 Ga carbonatites from around the world describe a field ranging between 18.6—20.0 for ^{206}Pb/^{204}Pb, which we take to define an end member for the branch population. The range for ^{208}Pb/^{204}Pb of the group is 38.8–39.6. We draw the following conclusions from these results:

(1)The opposing behaviors of Pb and Sr in the post-2.7 Ga carbonatites rules out continental crustal involvement since both Rb and U are highly "lithophilic" compared to their daughter elements.

(2) The Pb, Sr and Nd data for the young carbonatite group all closely fit the proposed mantle component, FOZO, a possible mantle component entrained in plumes.

(3) The galena data provide a reasonable evolution curve for bulk-silicate Earth the past 4.48 Ga.

Thermodynamic Control on Thermo-Fluid Dynamic Mantle Flow Model

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Thermodynamics has been successfully applied to predict variations in extensive and intensive properties in magmatic and metamorphic systems. Understanding of composition and chemical evolution of rocks is largely obtained through the application of the thermodynamic principles which are also constrained in a feedback interaction by geochemical natural observations. The time scale of evolution of rocks within this framework is of course unresolved. On the other hand, fluid flow models have been applied to simulate mantle dynamics and also magma transport. These geodynamic models are controlled by thermal, mechanical and kinematic parameters usually assumed to be loosely dependent from mantle petrology and geochemistry. However, the evidence for a chemically heterogeneous mantle are unequivocal. Numerical flow models are also primarily constrained by geophysical observations (i.e. gravity, topography, tomography).

In an early work Allegre (1982: Tectonophysics) defined the concept of chemical geodynamics as the integrated study of the chemical and physical structure and evolution of the solid Earth. In this work we extend and refine this idea in a more quantitative way. We consider a 2-D two-phase model (semplified from the general two-phase flow model by Ishii, 1975) which is coupled with the chemical and mass evolution of the transported materials. Along with the usual flow equations, chemical transport equations are solved for the bulk composition in the solid matrix and the melt. The distribution of the chemical elements and the equilibrium assemblage is determined in time and space by the direct minimization of the Gibbs free energy where T, P and the bulk compositions are retrieved from the dynamical model. A simplified version of the self-consistent thermodynamic database of Ghiorso and Sacks (1995: CMP) for solid phases and melt is used in the CMAS system (extension to the CFMAS system is under development). The main assumption in the dynamic-thermodynamic model is the chemical equilibrium in space among the mineral phases and the melt within the frame of the time and space grid size. This two stage flow model allows to produce a better control on the parameters for the mantle flow dynamics (density, viscosity etc.), now related to the mineral abundance and chemical composition. At the same time it is also possible to produce a time depended geochemical model and include geochemical observations as an additional control to the mantle dynamic model.