

Thallium isotope constraints on Earth's accretion

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The extinct radionuclide ²⁰⁵Pb decays to ²⁰⁵Tl with a half-life of 15 Myr. The former presence of ²⁰⁵Pb in the solar system was recently inferred from a ²⁰⁵Pb-²⁰⁵Tl isochron that was obtained for seven metal samples from the IAB iron meteorites Canyon Diablo and Toluca [1]. New Tl isotope data obtained for eight carbonaceous chondrites are in full accord with this isochron [2].

Several lines of evidence (based on I-Xe and Pd-Ag chronology; e.g., [3, 4]) indicate that the IAB parent body crystallised about 10 to 20 Myr after CAI's. Based on this age, the IAB isochron yields an initial solar system ²⁰⁵Pb/²⁰⁴Pb ratio of about 1.5×10^{-4} and an initial Tl isotope composition of $\epsilon^{205}\text{Tl}_0 = -2.8 \pm 1.7$ [1]. The latter is unlikely to be greater than -2.5, given that the Earth's mantle has a well-constrained present-day $\epsilon^{205}\text{Tl}$ value of -2.0 ± 0.5 [5, 6]. The available data thus indicates that the solar system was characterised by an initial $\epsilon^{205}\text{Tl}_0$ of between -2.5 and -4.5.

Two scenarios emerge if these values and recently determined metal-silicate and sulphide-silicate partition coefficients for Pb and Tl [7] are utilised to model the Earth's accretion and core formation. (1) If $\epsilon^{205}\text{Tl}_0$ is greater than -3.5, then standard accretion models yield unrealistic Tl abundances of >7 ppb for the bulk silicate Earth (BSE). This discrepancy can only be avoided if the Earth either experienced large-scale volatile loss at the time of the Giant Impact or accreted from volatile-depleted material characterised by a ²³⁸U/²⁰⁴Pb ratio of >2. (2) If $\epsilon^{205}\text{Tl}_0$ is less than about -4.0, the present day composition of the BSE can be readily reconciled with standard terrestrial accretion models, providing they feature late-stage segregation of sulphides from the mantle, as was recently proposed by Wood and Halliday [8].

The presently available Tl isotope data for meteorites do not permit a sufficiently precise definition of $\epsilon^{205}\text{Tl}_0$ to distinguish between these two scenarios. This indicates the importance of conducting further Pb-Tl isochron studies, which are able to provide a more precise estimate of $\epsilon^{205}\text{Tl}_0$.

References

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Diffusion of fluids through quartz

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Bulk diffusion of fluids through quartz is a process that may change the properties of fluid inclusions. The estimation of diffusion coefficients is only based on a limited number of studies, which include large uncertainties (up to 80%). Diffusion depends on the solubility of a certain diffusing species in quartz, which defines, however, a second large uncertainty: what is the nature of the diffusing species? and what is its solubility? Moreover, most experimental work has only been done at higher temperatures, within the β -quartz stability field.

This study identifies, firstly, the types of dissolved and diffusing water-related species, of which interstitial impurities, i.e. mainly H₂O molecules positioned between regular lattice sites form the major group that is responsible for changes in fluid inclusions and diffusion in general. This defect cannot be detected after experimentation with IR spectroscopy or secondary ion MS that mainly detect substitutional impurities and small fluid inclusions themselves. Solubility of water in quartz in previous studies has been mainly defined as charge compensating Fe and Al impurities or replacing Si atoms.

A new mathematical diffusion model (according to Fick's laws) is developed using SI conform units, i.e. concentration (mol/L), fugacity (MPa), excluding terms like ppm or wt%, which can be applied to randomly located fluid inclusions in a quartz crystal. This model is directly applied to experimental studies with synthetic fluid inclusion to characterize leakage and re-filling. Hypothetical calculations of re-equilibration rates indicate nearly instantaneous alterations of fluid inclusions properties according to the solubility of water in quartz, using the parameter values obtained from previous studies. Diffusion from or to fluid inclusions can only take place if a concentration gradient is present in the quartz. Locally, these gradients may represent thermodynamic equilibrium conditions due to pressure gradients, and, consequently, diffusion will not occur.

The properties of fluid inclusions are excellent tools for new determination of diffusion coefficients and the nature of diffusing species through quartz. Gradients in chemical potential (or fugacity) between fluid inclusions and pore fluids is a driving force for re-equilibration. In addition, pressure gradients may provoke alterations (see also Bakker and Diamond, 2003). Combination of both driving forces are interpreted as crack-assisted diffusion. New experiments will be performed to estimate the mobility of H₂O, CO₂, H₂, O₂ and Ar through quartz crystals by characterizing the changing properties of known synthetic fluid inclusions.

References

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