

Late volatile addition to Earth

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It is known for some time that relative to CI chondrite, Earth's mantle is depleted in elements more volatile than Mg and Si. Early workers attributed this to volatile loss from Earth's mantle during accretion. In recent years, however, consensus has been emerging that the opposite may be true: that the inventories of the Earth's mantle in moderately and highly volatile elements and compounds, including Earth's hydrosphere and atmosphere, may be late additions, to a silicate earth initially far more refractory than the present-day upper mantle.

We report metal-silicate experiments at 1 to 5 GPa over a temperature range from 1773 to 2573K to quantify how selected refractory and volatile elements may have partitioned between silicate and Fe metal melt. We study the partitioning of two refractory elements (i.e. W and Cr) and four elements (i.e. Pb, Cd, Sn, Se) from the volatile inventory of the Earth's mantle. Except for Se, all elements regardless of volatility become more siderophile with increasing temperature, reflecting the effect of thermal reduction. By correlating measured metal/silicate partition coefficients with the relative abundances of these elements in the mantle, the physical state of the mantle can be reconstructed when the respective element abundances were established; W and Cr at magma ocean conditions around 2550K, and Pb, Cd, Sn, and Se to a mantle that must have been largely crystalline at the time of volatile addition, with core melt segregation inactive.

The experiments provide independent support for a latter-day volatile addition. Had Pb, Cd, Sn, and Se been present at magma ocean conditions, they would have been seriously depleted in abundance relative to the abundances in lithophile volatiles with similar condensation temperatures, far more than observed; Pb by up to two orders of magnitude relative to its present-day mantle concentration. Our Ds confirm that a large proportion of the volatile element inventory of Earth's mantle, including its water content, was part of a late volatile component, most likely material from the asteroid belt and added to a relatively cool mantle, at a time when core formation was completed. There is little basis to assume that the apparent Pb deficit in the silicate Earth is to be sought in the core. Rather, the ²³⁸U/²⁰⁴Pb ratio (μ) of Earth's mantle reflects late addition of Pb, to a highly refractory proto-mantle seriously depleted in volatiles. A late (post-core) addition of Pb via a CI-type impactor, to a refractory mantle highly depleted in lead, may also be key to solving the first lead paradox.

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Surface characterization of biotite from a mesh bag field study

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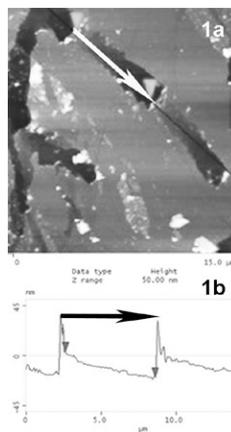
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Direct fungal-mineral contact has been proposed to play an important role in soil mineral dissolution. Indeed, nanoscale observations in controlled laboratory settings have demonstrated both physical and chemical interactions with biotite at the scale of the individual fungal hyphae [1, 2]. We incubated biotite flakes in the soil, to test if similar fungal-mineral interactions could be observed in the field. The biotite was incubated in spruce forest soils for two years at three sites with serpentinite, leucogranite and amphibolite bedrocks and contrasting tree nutrient status. Mineral surfaces were examined with scanning electron microscopy and atomic force microscopy. Ectomycorrhizal biomass was determined by Ergosterol analyses.

Microscopy revealed patchy biofilms on the biotite surfaces (19 to 44%) with the highest values found at the low Mg site (leucogranite). Direct hyphal attachment was only 3 to 5% with the lowest values found at the low Mg site, which was supported by the the lowest Ergosterol concentrations at this site. We saw shallow channels, similar to hyphae in size

and branching pattern on most of the flakes (Figure 1a). The channels widened with time, probably from dissolution, and at each "pulse," the channel deepened in the direction of growth (Figure 1b). We propose that this morphology reflects the pulsive growth of the hyphal tip, inducing shear stress to the top T-O-T biotite layers.

These observations support the laboratory results that fungal hyphae exercise both chemical dissolution and physical force at the hyphal-mineral interface.



[1] Balogh-Brunstad *et al.* (2008) *Biogeochem.* **88**, 153–167.

[2] Bonneville *et al.* (2009) *Geology* **37**, 615–618.

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