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What is Magnetic in the mantle? Insights into magnetic minerals in mantle xenoliths

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Unaltered lherzolite xenoliths are representative of the lithospheric mantle. Other rock types such as dunites, wherlites, and pyroxenites are generally not volumetrically significant. The respective contributions of rock-forming minerals to induced and remanent magnetization in these rocks are currently poorly constrained. This information can be used to assess the significance of long-wavelength magnetic anomalies, including data not yet collected from the soon to be launched SWARM satellite constellation.

Forty-nine representative, uncontaminated and non-serpentinized xenoliths have been magnetically investigated. These specimens display contrasting magnetic properties (NRM, Mr, Ms) depending on their tectonic settings, oceanic hot-spot, continental mantle plume, island arc and craton.

The main paramagnetic silicates (Ol, Cpx, Opx, etc…) typically account for a significant percent of the peridotite magnetic properties. The low-field bulk magnetic susceptibility of pristine, unaltered mantle xenoliths ≈ 500 ± 60 x 10-6 [SI] and displays a relatively limited variability (all samples fell between 100 and 800 x 10-6 [SI] even across the different settings). The total contribution of paramagnetic silicates to magnetic susceptibility (Kpara-silicates) can be determined from the high-field slope of a saturated hysteresis experiment. Kpara-silicates can also be independently calculated by adding the respective contributions of individual silicates based on their modes, chemical composition and the Bohr magneton numbers of individual cations. Silicates account for between 56 and 97% (average ≈ 85%) of the magnetic susceptibility depending on rock composition. When present, the contribution of chrome spinel, which is paramagnetic in the absence of late-stage exsloution products, remains around 1%.

The remaining contribution to magnetic susceptibility arises from variable amounts of primary magnetite (and pyrrhotite to a minor extent). These mineral phases, although present in tens to hundreds of ppm only, contribute significantly to the rock magnetic properties because they have large intrinsic magnetic susceptibilities (≈ 1 to 4 [SI] for magnetite). Stoichiometric magnetite has been identified as microscopic exsloutions in the lattice of olivine and accounts for 2 to 43% (average ≈ 8%) of the magnetic susceptibility. Whether these pseudo-single domain magnetite grains are in equilibrium with other rock forming minerals or not is still being investigated. Pyrrhotite (up to 600 ppm in some rare specimens), although detectable in low temperature magnetic experiments, does not significantly contribute to magnetic susceptibility.

The contribution of ferromagnetic minerals, such as magnetite and pyrrhotite, to remanent magnetization (Mr) is significant and varies greatly (over 250x between specimens) with tectonic setting. The fact that all specimens contain primary magnetite suggests that these assemblages equilibrated at least at or above the wüstite-magnetite (WM) oxygen buffer and more likely near the fayalite-magnetite-quartz (FMQ) oxygen buffer. The amount of magnetite present in the mantle peridotite assemblage seems to correlate with tectonic setting and may be determined by fO_2 in the mantle.