In situ measurements of lead and other trace elements in abyssal peridotite sulfides

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ABSTRACT

In the mantle, base metal sulfides have been proposed as the main host for many chalcophile and siderophile elements. This includes elements such as Pb, Se, and Te, which are often used as tracers of processes ranging from planetary accretion to mantle melting. We present in situ measurements of these elements, along with As, Sb, Ag, Au, and Cl, in abyssal peridotite sulfides to provide constraints on the storage of these elements in the mantle. A total of 152 sulfides from 11 peridotites and 1 pyroxenite from the Gakkel and Southwest Indian ridges were analyzed. The sulfides are pentlandites, some of which contain either discrete chalcopyrite domains or Cu-rich intergrowths. Trace-element concentrations in 108 unaltered sulfides range from 2 to 36 ppm Pb, 45 to 250 ppm Se, <4 to 360 ppm Te, <1.5 to 1900 ppm As, 2 to 420 ppm Sb, 2 to 340 ppm Ag, 2 to 770 ppb Au, and 0.2 to 1000 ppm Cl. Tellurium abundances are highly variable within sulfides, which is likely due to the presence of telluride micro- or nano-phases. Based on morphology, composition, and the absence of monosulfide solid solution, the sulfides are interpreted to have formed by fractional crystallization from sulfide melt during conductive cooling of the mantle beneath the ridge axis. The average sulfide Pb concentration of 4 ppm can be reproduced by >90% fractional crystallization from a sulfide melt. The remaining sulfide melt, which is modeled to contain 800 ppm Pb, will dissolve into silicate melt as it rises through the mantle due to the increasing solubility of sulfur in silicate melt as pressure decreases. However, the amount of sulfide melt that remains after fractional crystallization is too low (mode of <0.005%) to contribute a significant amount of Pb to mid-ocean ridge basalts. We conclude that sulfides are not the main host for mantle Pb, even prior to the onset of any melting, and that the majority of mantle Pb is stored in silicate phases.

Keywords: Mantle, Pb, SIMS, sulfide, peridotite; Planetary Processes as Revealed by Sulfides and Chalcophile Elements

INTRODUCTION

Peridotites, which are direct samples of the upper mantle, provide fundamental information regarding the chemical differentiation and evolution of the Earth. One of the most useful tracers of these processes is lead (Pb), because it is the daughter product of radiogenic decay of U and Th. Both U and Th have long half-lives suitable for tracing processes at the million- to billion-year timescales. As a chalcophile element, Pb readily combines with sulfur (e.g., Shimazaki and MacLean 1976; Kiseeva and Wood 2013; Lorand and Luguet 2016) and base metal sulfides have been proposed as a major control on the behavior of Pb in the upper mantle (e.g., Meijer et al. 1990; Hart and Gaetani 2006). The control of sulfide, particularly sulfide melts, on Pb behavior is indicated by the partition coefficients (D) between monosulfide solid solution (MSS; the main sulfide phase in the upper mantle), sulfide melt and silicate melt. For example, D_Pb^MSS/sulfide melt is 0.005 and D_Pb^sulfide melt/silicate melt is 17, whereas D_Pb^MSS/silicate melt is 0.2 at 1200 °C and 1.5 GPa (Brenan 2015). These observations suggest that mantle sulfides are key for understanding the transport, long-term storage, and abundance of mantle Pb.

Despite the affinity of Pb to partition into sulfide phases and the implications for the mantle Pb budget, the amount of Pb contained in sulfides has not been extensively studied. In peridotites, Fe-Ni-Cu base metal sulfides are found at trace levels (<0.06% modal abundances; Luguet et al. 2001, 2003). Meijer et al. (1990) proposed that sulfides are the main host of mantle Pb based on the mass-balance comparison of Pb in bulk peridotites compared to Pb in olivine, orthopyroxene, and clinopyroxene. Using the Meijer et al. (1990) measurements, Hart and Gaetani (2006) proposed that upper mantle sulfides contain 75 ppm Pb prior to mantle melting, based on predicted whole-rock Pb contents and an estimated sulfide modal abundance of 0.05% in the source mantle. Early direct measurements of Pb in sulfides focused on inclusions in diamonds (Eldridge et al. 1991; Rudnick et al. 1993; Bulanova et al. 1996) and found an average of 171 ppm Pb in MSS sulfides from peridotitic diamonds. However, this may not be representative of typical convecting upper mantle due to the involvement of C-O-H fluids in their formation (e.g., Shirey and Shigley 2013). Previous analyses of sulfides from abyssal peridotites, seafloor samples collected at mid-ocean ridges, identified a range of 0.1–12 ppm Pb in 19 sulfides from 10 Gakkel and Southwest Indian Ridge (SWIR) samples (Warren and Shirey 2012). A range of 2–8 ppm...