

Light Lithophile (Li, Be and B), Volatile (H, F and Cl) and Trace Elements Composition of Mantle Amphiboles from Zabargad Peridotite: Insights into the Multistage Subsolidus Evolution of Sub-continental Mantle During Red Sea Rifting

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The peridotite-pyroxenite association at Zabargad Island is important for mantle studies, since it may represent a slice of the ancient sub-continental mantle of the Nubian-Arabian Shield brought to the surface by Red Sea rifting. Ultramafic units experienced several metamorphic and metasomatic episodes, evidenced by the crystallisation of different amphibole generations. A combined SREF (single-crystal structure refinement), EMP, and SIMS characterisation of the amphiboles in representative lithologies was done with the aim to further constrain this complex subsolidus evolution. SIMS analysis for trace (REE, HFSE, LILE), light (Li, Be, B) and volatile (H, F, Cl) elements and EMP analyses for major elements were done on the refined crystals. Amphiboles from porphyroclastic to equigranular spinel-lherzolite (either plagioclase-free and plagioclase-bearing) are titanian pargasites and kaersutites. Titanian pargasites from porphyroclastic lherzolite contain low amounts of the most incompatible trace elements (K, Ba, Rb, Zr, LREE), but are relatively enriched in less incompatible to compatible elements (HREE, V, Sc and Cr; $La_N/Yb_N=0.2$, $HREE=20 \times C1$). The increase of ^{67}Ti couples with the increase of Cr, Zr, V and Sc and with the decrease of ^{67}Al , Sr and H_2O (down to 1.33%). Ti-richest kaersutites also show negative Eu anomaly. LILE are <1 ppm, and F and Cl are <0.07 and 0.02%, respectively. Kaersutites show ^{41}Al disordering between the T1 and T2 sites, which is consistent with higher T or decreasing P at constant (high) T. A titanian pargasite from an equigranular sample is relatively LREE enriched ($La_N/Yb_N=12$; $La_N/Yb_N=0.8$), suggesting metasomatic re-equilibration with alkaline melts. However, its LILE, F and Cl contents are similar to those of amphiboles from porphyroclastic lherzolites. Amphiboles from hydrous Cr-Di pyroxenites are titanian pargasites and hornblendes, with significant K, Ba and LREE, but also Sc, V and Cr contents. Cl-normalised REE patterns are LREE-enriched convex-upward ($La_N/Yb_N=2-3$), which is typical of amphibole segregated in equilibrium with alkaline melts. LILE are always <1 ppm. H_2O is in the range 1.5–1.6%, and the maximum F and Cl contents are 0.22 and 0.13%, respectively. Amphiboles from porphyroblastic amphibole-peridotites are edenites. They are

enriched in LILE, Zr and Cr, but are depleted in Ti. The REE patterns are convex-upward. Be and B are rather high (up to 3.6 and 2.5 ppm, respectively), and H_2O is close to the stoichiometric value. F is $<0.07\%$ and Cl is 0.03%. Amphiboles in blastomylonitic amphibolites are pargasites and hornblendes. They are still enriched in LILE and depleted in Ti, but display trace element fractionation significantly different from that of amphibole peridotites. REE patterns are linearly fractionated ($La_N/Yb_N=6-33$), and sometimes show positive Eu anomaly. Li, Be and B reach 2.5, 5.4 and 7.7 ppm, respectively, and Cl is in the range 0.11–0.22%. Amphiboles from spinel-plagioclase harzburgites are titanian pargasites and hornblendes. Their colours vary from brown to green, according to decreasing Ti, Al and REE, and increasing Si and Cr contents. Spider-diagrams show LREE-depletion ($La_N/Yb_N=0.4-0.6$, $HREE=40-50 \times C1$) and moderate to large Eu, Sr and Ba negative anomaly. These amphiboles are enriched in B and Cl (up to 14 ppm and 0.37%, respectively). The determination of the complete site distribution of major elements, in the light of the present knowledge of amphibole crystal-chemistry, helped to fix the P, T, fH_2 condition of amphibole crystallisation. Our data indicate that amphiboles in porphyroclastic lherzolite crystallised under spinel-facies conditions in the presence of hydrous fluids of mantle origin, and then re-crystallised under decreasing P and adiabatic conditions. Most Ti plays the crystal-chemical role of stabilising the amphibole structure at low fH_2 and high T, providing local charge-balance when H is missing; as a consequence, a high Ti content is not indicative of alkaline metasomatism. The large amount of H, Be and B in amphiboles from porphyroblastic peridotites suggest that the parent fluid had crustal origin. Compositional differences among Cl-rich amphiboles reveal at least two hydrothermal systems involving seawater components, which took place as late thermal episodes. The geochemical signatures of amphibolites are consistent with mixing between seawater-derived fluids and crustal components enriched in feldspar; conversely, amphiboles from spinel-plagioclase harzburgites are probably related to the intrusion of 5 Ma-old dykes of tholeiitic to transitional affinity.