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On the relative timing of listwaenite formation and chromian spinel equilibration in serpentinites

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Abstract

Ultramafic rocks exposed at the Earth's surface generally record multiple stages of evolution that may include melt extraction, serpentinization, carbonatization, and metamorphism. When quantitative thermometry based on mineral chemistry is applied to such rocks, it is often unclear what stage of their evolution is being observed. Here, in peridotites with extensive replacement of silicate minerals by carbonates (listwaenites), we present a case study that addresses the timing of carbonate formation relative to closure of exchange reactions among relict primary minerals.

Massive and schistose serpentinized peridotites of Neoproterozoic age outcrop at Gabal Sirsir, South Eastern Desert, Egypt (northwestern corner of the Arabian-Nubian Shield or ANS). Petrography, bulk composition, and mineral chemistry are all consistent with a strongly depleted mantle harzburgite protolith for the serpentinites. Bulk compositions are low in Al_2O_3 and CaO and high in Mg# [molar Mg/(Mg+Fe) = 0.89–0.93]. Relict spinel has high Cr# [molar Cr/(Cr+Al)] and low Ti, while relict olivine has high Mg# and NiO contents. Based on compositions of coexisting relict olivine and chromian spinel, the protolith experienced 19 to 21% partial melt extraction. Such high degrees of partial melting indicate a supra-subduction zone environment, possibly a forearc setting.

Along thrust faults and shear zones, serpentinites are highly altered to form talc-carbonate rocks and weathering-resistant listwaenites that can be distinguished petrographically into Types I and II. The listwaenitization process took place through two metasomatic stages, associated first with formation of the oceanic crustal section and near-ridge processes (~750–700 Ma) and subsequently during obduction associated with the collision of East and West Gondwana and escape tectonics (~650–600 Ma). In the first stage, Mg# of chromian spinel in the serpentinites continuously changed due to subsolidus Mg–Fe^{2+} redistribution, while the Mg# of chromian spinel in the Type I listwaenites was frozen due to the absence of coexisting mafic silicates. During the second stage, the Type II listwaenites formed along shear zones accompanied by oxidation of relict chromian spinel to form ferritchromite and Cr-bearing magnetite in both serpentinites and listwaenites. The high Cr# of chromian spinel relics in both serpentinites and listwaenites preserves primary evidence of protolith melt extraction, but divalent cations are more easily mobilized at low temperature. Hence, relict chromian spinel in listwaenites shows significantly higher Mg# and lower MnO than that in serpentinite, suggesting that nearly complete alteration of ultramafic rocks to form listwaenite took place prior to re-equilibration between chromian spinel and the surrounding mafic minerals in serpentinites. Furthermore, the ferritchromite in the serpentinites has higher Mn content (1.1–2.1 wt%) than that in the listwaenites (0.6–0.9 wt%), indicating its formation after carbonatization since carbonate minerals are a favorable sink for Mn.

Keywords: Arabian-Nubian Shield, neoproterozoic, serpentinite, listwaenite