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Hydrothermal alteration of Ni-rich sulfides in peridotites of Abu Dahr, Eastern Desert, Egypt: Relationships among minerals in the Fe-Ni-Co-O-S system, f_{O_2} and f_{S_2}

Ali H. Abdel-Halim[1,*]

[1]Department of Geology, Faculty of Science, Minia University, Minia 61519, Egypt

Abstract

The Neoproterozoic peridotites of Abu Dahr, Eastern Desert of Egypt, consist mainly of highly depleted harzburgites that have experienced multiple stages of serpentinization (lizarditization and antigoritization) and carbonation/listvenitization in a forearc environment. The Abu Dahr forearc harzburgites are more oxidized than oceanic mantle, with the oxygen fugacity (f_{O_2}) values ranging from FMQ+0.41 to FMQ+1.20 (average = +0.60 FMQ), and were equilibrated at temperatures of 910–1217 °C and pressures of 4.1–7.8 kbar. This study has documented for the first time the presence of various Ni-rich Ni-Fe (-Co) sulfide and metal phases along with Fe-oxides/oxyhydroxides in serpentinized-carbonated peridotites of the Abu Dahr forearc. Here I concentrate on the relationship between redox state and Fe-Ni-Co-O-S minerals with emphasis on the role of hydrothermal processes in upgrading magmatic sulfide tenors, desulfurization (sulfur-loss) of magmatic pentlandite and hydrothermal upgrading of the sulfide phases in Abu Dahr forearc environment. The minerals involved are high-Ni pentlandite ($Fe_4Ni_5S_8$), cobaltian pentlandite ($Fe_{3.47}Ni_{4.78}Co_{0.75}S_8$), heazlewoodite ($Fe_{0.07}Ni_{2.93}S_2$), godlevskite ($Fe_{0.26}Ni_{8.73}Co_{0.01}S_8$), millerite ($Fe_{0.01}Ni_{0.98}Cu_{0.01}S$), awaruite ($Ni_{75}Fe_{21}$) and native Ni ($Ni_{93}Fe_5$), and nickeliferous magnetite and goethite. Chalcopyrite is a rare mineral; other Cu-phases, Fe-sulfides and Ni-arsenides/phosphides are not present. Texturally, Ni-sulfide and alloy minerals occur as interstitial disseminated blebs of either solitary phases or composite intergrowths with characteristic replacement textures, documenting strong variations in oxygen and sulfur fugacities (f_{O_2}-f_{S_2}). Sulfide assemblages are divided into three main facies: (1) pentlandite-rich; (2) godlevskite-rich; and (3) millerite-rich. Textural relationships imply the following sequence: (a) primary pentlandite → cobaltian pentlandite, with partial replacement of the latter by awaruite and/or heazlewoodite along with magnetite; (b) heazlewoodite is replaced by godlevskite, which in turns is replaced by millerite; (c) Ni-rich awaruite breaks down to millerite; and finally, (d) magnetite is completely replaced by goethite. The sulfide mineralogy reflects the magmatic and post-magmatic evolution of the complex. The primary magmatic processes gave rise to pentlandite, whereas the secondary Ni-sulfides together with the metallic alloys formed in response to changing f_{O_2} and f_{S_2} conditions associated with post-magmatic serpentinization and carbonation. Serpentinization-related Ni-Fe-Co remobilization from magmatic olivines resulted in; (1) upgrading the Ni-Co tenors of pre-existing primary pentlandite, and desulfidation to form low-sulfur sulfides (mainly heazlewoodite) and awaruite under extremely low f_{O_2} and f_{S_2} conditions; (2) in situ precipitation of secondary Ni-sulfides in the presence of extra sulfur as aqueous H_2S derived from the desulfurization of magmatic pentlandite or native Ni when f_{S_2} approaches 0; (3) transformation from low-sulfur pentlandite- and godlevskite-rich assemblages to the high-sulfur millerite-rich assemblages related to later carbonation with increasing f_{O_2}; and (4) partial dehydration of antigorite serpentinites under high-pressure conditions (>1 GPa) generated Ni-rich awaruite in equilibrium with the prograde assemblage antigorite-metamorphic olivine at higher f_{O_2} and f_{S_2} within subduction channel. The mineralogical, chemical, and thermal similarities with other serpentinite-related Ni-sulfides worldwide suggest that Ni minerals in the Fe-Ni-Co-O-S system record changing f_{O_2} and f_{S_2} during progressive serpentinization and carbonation.

Keywords: Abu Dahr forearc, Ni-rich sulfides, oxygen and sulfur fugacities, replacement textures, serpentinization and carbonation, desulfurization, subduction channel.