Hassan M. Helmy · Aberra Mogessie

Gabbro Akarem, Eastern Desert, Egypt: Cu–Ni–PGE mineralization in a concentrically zoned mafic–ultramafic complex

Received: 3 November 1999 / Accepted: 29 July 2000

Abstract The Gabbro Akarem (Late Precambrian) intrusion is concentrically zoned with a dunite core surrounded by lherzolite-clinopyroxenite enveloped by olivine–plagioclase hornblendite and plagioclase hornblendite. Cu–Ni–PGE mineralization is closely associated with peridotite, especially in the inner, olivine-rich core (dunite pipes) where net-textured and massive sulfides (pyrrhotite, pentlandite, chalcopyrite) are found in association with Al–Mg-rich spinel and Cr-magnetite. Primary magmatic textures are well preserved; however, deformation and mobilization due to shearing are locally observed. Platinum-group minerals (PGM) documented from the deposit are: merenskyite (PdTe₂) and michenerite (PdTeBi), as well as palladian bismuthian melanite (Ni,Pd) (Te,Bi)₂. These minerals occur in intimate association with hessite (Ag₂Te) and electrum (Au₀.₆₅Ag₀.₃₁Bi₀.₀₄) in two distinct textural positions: (1) as inclusions in pyrrhotite, pentlandite, and rarely chalcopyrite and (2) at sulfide–silicate grain boundaries and on microfractures in base-metal sulfides (BMS) and olivine associated with serpentine and secondary magnetite. Textural features suggest that PGM were exsolved from monosulfide solid solution over a wide range of temperatures. Late-stage, low-temperature hydrothermal solutions led to redistribution of PGE. Mineralized samples show Ni/Cu ratios ranging from 0.2 to 2 with an average of 1.0. The (Pt + Pd + Rh)/(Os + Ir + Ru) ratio is generally >6 in most samples, and Os, Ru, and Ir are below the detection limit (2 ppb). The PGE contents show positive correlation with S only at low sulfur contents. The PGE patterns of Gabbro Akarem are similar to those of Alaskan-type deposits. Compared with stratiform deposits, Gabbro Akarem is depleted in PGE. The consistently low PGE contents of the mineralization and their uniform distribution in the ultramafic rocks despite the high sulfur content of the rock is attributed to rapid crystallization of sulfides in a highly dynamic environment.

Introduction

Concentrically zoned (Alaskan-type) complexes are relatively small intrusions, elliptical in shape, and composed of a dunite core surrounded by olivine clinopyroxenite, magnetite–hornblende clinopyroxenite, and gabbro (e.g., Taylor 1967; Cabri 1981; Nixon et al. 1990; Fershtater et al. 1997). This type of intrusion is common in southeastern Alaska, Russia, Australia, Canada, Colombia, and Venezuela, ranging in age from Cambrian (Serpentine Hill Complex, Canada, Brown et al. 1988) to Early Miocene (Alto Condoto, Colombia, Tistl 1994). Most of the Alaskan-type complexes are located along major structures and their petrogenesis is still a matter of debate (Garuti et al. 1997; Efimov 1998). The details of the emplacement histories of concentrically zoned complexes vary depending on locality. However, there is general agreement that the intrusion of a hot, ultramafic mush was a key factor in their evolution (Findlay 1969; Irvine 1974). The emplacement of concentrically zoned complexes into shallow crustal levels seems to be controlled by large transverse movements along major lineaments during crustal extension and subsequent ascent from a mantle plume (Tistl and Salazar 1993; Chashchin 1998) in a dynamic environment. Helmy and El Mahallawi (1999) propose that the rapid rise of a hydrous mantle magma along major fracture zones accompanied by...
internal circulation and strong vertical stretching, up to the center of the rising magmatic body, led to the concentric zoning of these complexes.

Platinum-group element mineralizations have been described in a number of these complexes where the dunite cores contain native platinum or Pt–Fe and Pt–Ir alloys commonly associated with chromitite (e.g., Razin 1976). In the majority of these complexes, the Pt–Fe and Pt–Ir alloys are not associated with primary magmatic base-metal sulfides (Cabri 1981) but occur as inclusions in chromitites. Cu–Ni–PGE mineralizations are not common in concentrically zoned complexes; only one example was described from the Salt Chuck intrusion, Prince of Wales Island (Loney and Himmelberg 1992).

The Gabbro Akarem Cu–Ni deposit was discovered during a regional geochemical survey project in the South Eastern Desert of Egypt (Bugrov and Shalaby 1973). Disseminated and massive sulfide mineralization occurs in a dike-like mafic-ultramafic intrusion of Late Precambrian age. Plagioclase hornblende, olivine-plagioclase hornblende, and peridotite, in decreasing order of abundance, are the main rock units. Geological mapping, geochemical and geophysical exploration, and diamond drilling (15 drill holes with a total of 1,888 m) were conducted by the geologists of the Aswan Mineral Survey Project (1973–1974, Carter 1975; Shaban et al. 1977). The Cu–Ni mineralization is closely associated with the peridotites. Ore reserves are estimated to be 700,000 tonnes containing 0.95% combined Ni and Cu (Carter 1975). No mining activities have been initiated so far. Relevant studies on the mineralogy and geochemistry of the Gabbro Akarem mineralization are those by Hafez and Abdel-Kader (1982), Rasmy (1982), and Niazy et al. (1985). More recently, Sharara et al. (1999) have studied the mineralogy, mineral chemistry, and isotope geochemistry of the deposit. They concluded that Pd, Rh, and Ir are present within the Fe–Ni–Cu sulfides, while Au and Pt form discrete mineral grains; no platinum-group minerals were described. PGE distributions are explained by fractional crystallization of a monosulfide solid solution from parental sulfide liquid.

The Gabbro Akarem intrusion is elliptical in shape and shows concentric zoning with a dunite core enveloped by lherzolites, pyroxenites, olivine-plagioclase hornblende, and plagioclase hornblende. In addition to the concentric zoning and elliptical shape, the Gabbro Akarem rocks are dominated by olivine, clinopyroxene, hornblende, and Fe$^{3+}$-rich spinel (Helmy and El Mahlawi 1999), features which are identical to Alaskan-type complexes (e.g., Taylor 1967; Mues-Schumacher et al. 1996; Efimov 1998). The aim of this paper is to: (1) describe the geology of the Cu–Ni–PGE deposit; (2) study the mineralogy of the mineralization with special emphasis on PGE mineralogy; (3) study the geochemistry of ore and rock samples; and (4) relate the genesis of the mineralization to the magmatic history of the intrusion.

**Geologic setting**

The Gabbro Akarem area is located 130 km east of Aswan in the South Eastern Desert of Egypt (Fig. 1). This region is part of the Proterozoic Shield cropping out east of the Nile River, and comprises metasediments, mafic to intermediate metavolcanics, granitoids, and abundant ultramafic rocks. Pelitic and semi-pelitic metasediments (metamorphosed under amphibolite and greenschist facies conditions) are known from different areas. They are considered to be the oldest rock units in the Eastern Desert of Egypt (see also Hassan and Hashad 1990). The metavolcanics are either pillow basalts as a member of the ophiolitic association or andesitic rocks with island arc chemical characteristics (Stern 1981). Granites and granitoids constitute an important rock group that covers about 40,000 km$^2$ of the shield rocks in Egypt.

Mafic-ultramafic rocks cover about 5% of the South Eastern Desert (Dixon 1979). These rocks are either tectonically emplaced (ophiolitic) or magmatically intruded. Intrusive mafic-ultramafic rocks are minor and are known from a few localities in the South Eastern Desert (e.g., Zabargad island, Bonatti et al. 1981; Gebel Dahanib, Takla 1971; Dixon 1979, 1981a, b; Abu Hammamid, Hafez et al. 1991; Gemina Gharbia, Khudeir 1995; and Gabbro Akarem, Carter 1975; Khudeir et al. 1996). The Zabargad peridotite is considered a tectonically uplifted fragment of sub-Red Sea lithosphere (Bonatti et al. 1981). Other complexes are emplaced along major fault zones trending ENE (Fig. 1; Garson and Ks 1976). Although no absolute ages of the intrusive mafic-ultramafic rocks have been determined, crosscutting relationships suggest that they pre-dated the (G2, 620–580 Ma) calc-alkaline granitoid rocks (Hassan and Hashad 1990). Quartz diorite-granodiorite rocks from the Gebel Dahanib complex (80 km to the southeast of Gabbro Akarem) were emplaced at about 710 Ma (Dixon 1981b).

The Gabbro Akarem mafic-ultramafic intrusion consists of an eastern and western body, 1.5 km apart (Fig. 2). In plan, the size of the western mass is 3 x 0.5 km, formed of plagioclase hornblende, olivine-plagioclase hornblende, and peridotite, in decreasing

![Fig. 1 Location map of the Gabbro Akarem and other concentrically zoned intrusions in the Eastern Desert of Egypt. Deep structures revealed by geophysical studies in the Eastern Desert of Egypt from Garson and Shalaby (1976)]