Intercumulus massive Ni-Cu-Co and PGE-bearing sulphides in pyroxenite: a new mineralization type in the layered gabbroic sequence of the Beja Igneous Complex (Portugal)

Ana P. Jesus, António Mateus, José Munká, Álvaro Pinto

Abstract. Coarse-grained pyroxenite cumulates occurring within an olivine lherzolite/pyroxenite gabbroic suite host a new sulphide mineralization type in the Beja Layered Gabbroic Sequence, Portugal. The sulphides formed in an intercumulus phase as a result of the coalescence of disseminated blebs of pyrrhotite with abundant pentlandite and chalcopyrite exsolutions, gradually disrupting the silicate matrix. Intra- and inter-granular vugs are sealed by Ni-rich minerals of the lamproite group, with decreasing Co content from earlier to later generations. The deposition of Ni in Co-rich pyrrhotite represents the late mineral infill in the lamproite veins. Pyrite vugs and subhedral grains in the pyrrhotite groundmass display gradually lower Ni contents with time. Chalcopyrite is the latest sulphide phase, sealing micro-fractures and replacing pre-existing sulphides. EMPA data revealed concentrations up to 1500 ppm of Pt, Pd, Au, Ag, Co and Sn in pentlandite, chalcopyrite and Ni minerals of the lamproite group.

Keywords. Layered gabbros, pyroxenite, intercumulus, massive sulphides

1 Introduction

The Beja Igneous Complex is an intrusive belt that can be followed for ca. 100 km along the southwestern border of the Ossa Morena Zone in Portugal (Fig. 1). The Beja Igneous Complex records syn-augitic Variscan magmatic activity, extending from Upper Devonian to Late Viséan (Dallmeyer et al. 1993). Three units are classically defined within the Beja Igneous Complex: 1) the Beja Layered Gabbroic Sequence (LGS), mainly consisting of olivine-bearing gabbroic rocks, rimmed by heterogeneous dikes resulting from variable extents of magma mixing and crustal assimilation; 2) the Cuba-Alvito Complex comprising granodioritic and gabbroic rocks; and 3) the Balsema Porphyry Complex, a late, shallow intrusion consisting of porphyritic granitoids (Andrade 1983; Santos et al. 1990; Silva et al. 1970).

In order to assess the metallogenic potential of the Beja Layered Gabbroic Sequence, significant efforts were made to determine its internal architecture and related ore-forming systems. Two main styles of mineralization have been recognized previously (Jesus 2002; Jesus et al., 2003b): 1) massive Fe-Ti-V oxide accumulations within ultramafic cumulate lenses; and 2) anastomosing (locally stockwork) Cu-Ni sulfide vein arrays within strongly developed metasomatic halos. This paper is the first documentation of a new type of mineralization: intercumulus massive Ni-Cu-Co sulphides hosted by a pyroxenite cumulate facies.

2 Geological framework

Detailed mapping of the Beja Layered Gabbroic Sequence (Figs. 1) has revealed NW-trending magnetic layering that dips approximately 30°SW, typically associated with a magmatic injection. Field and geochemical criteria are used to define the Beja Layered Gabbroic Sequence (BLS), which is characterized by a distinct mineralogical and textural signature.

Figure 1: Location of the Beja Igneous Complex (BIC) with indication of the major geotectonic units of the SW Portugal Belt: Central-Baixo Tejo Zone (MBZ), Beja-Alentejo Zone (BAZ), Ossa-Morena Zone (OMZ), South Portuguese Zone (SPZ), and Sotavento-Tejo Zone (STZ). 1) Balsema Porphyry Complex (BPC); 2) Beja-Alvito Complex (BAC); 3) Balsema Porphyry Complex (BPC); 4) Beja Layered Gabbroic Sequence (LGS); 5) Undifferentiated Variscan Granitoids; 6) Undifferentiated Variscan Granitoids; 7) Beja-Achacosa Ophiolitic Complex (BOC); 8) Meta-sediments and meta-volcanics of the Palha de Júlio Group; 9) Meta-sedimentary and meta-volcanic sequences of the Beja Igneous Complex.
teria suggest that the intrusion had a multistage history. This resulted from the input of several batches of magma, which each correspond to a distinctive series of gabbroic rocks.

Five main magmatic series were defined, from NW to SE: Sobrantes I, Sobrantes II, Odivelas I, II and III. The contact between Sobrantes I and II is tectonic. Sobrantes I is composed of coarse-grained anoroclastic (leucogabbro) tacholite and fine-grained wehlranite, whereas Sobrantes II comprises fine-grained leucogabbro to leucogabbros. The transition to Odivelas I is covered by Cretaceous sediments. Odivelas I consists mostly of olivine leucogabbro and includes in its lower section an intercumulus-enclaves zone of sanidinitic T-magnetite + ilmenite, what massive type I T-V ores have developed (Jesus et al. 2003b). Odivelas II is a rhythmic succession of olivine gabbro with discontinuous anorthosite layers at its uppermost section. Odivelas III comprises a rhythmic sequence of well-layered olivine (leucogabbro). Interactions of Erze-grained pyroxene layers contain disseminated sulphide and sulpho-arsenide blebs, as well as anastomosing veins of pyrrhotite + chalcopyrite + pyrite + mackinawite, which have late-stage metamorphic haloes. These veins comprise type II mineralization (Jesus 2002; Jesus et al. 2003a), the contact between Odivelas II and III series is obscured by sedimentary cover.

Several suites of gabbroic rocks occur between Ferreira de Alenete and Betingel. These gabbroic suites host Ni-Co- and PGE-bearing sulphide mineralization and can be correlated with Sobrantes I and Odivelas VII series. This new mineralization type occurs over Ferreira do Alenete (Fig. 1) within a thick and rhythmic sequence of coarse-grained olivine leucogabbros (enlodding minor anorthosite) and pyroxenite gabbros. Locally, these pyroxenite gabbros grade to cumulate lenses of pyroxenite, which constitutes the preferential host of Ni-Co-PGE-bearing sulphide mineralization.

3 Ni-Co-Cu mineralization

Pyroxenites hosting the massive Ni-Co-Cu and PGE-bearing sulphide are mainly composed of randomly oriented, subhedral grains of clinopyroxene (En85,Wo15,Fs12), kilometer-sized blebs of pyrrhotite with pentlandite-chalcopyrite exsolution occurs as inclusions within the coarser clinopyroxene grains, forming graphic intergrowths. As the sulphide modal proportion increases, clinopyroxene grains are disrupted, displaying abundant corrosion paths but only mild retrograding effects. Rare plagioclase (An25) occurs interstitially or included within the clinopyroxene sulphide framework. Silicate phases do not show any significant compositional zoning or retrograde textures, suggesting equilibrium conditions of the sulphide phases. Minor magnetite (Fe3O4) + pentlandite + chalcopyrite + pyrite + mackinawite are disseminated in the massive sulphide domain, as well as pentlandite-pyrrhotite-chalcopyrite blebs suggesting Fo3 conditions of late stage (~260°C) crystallization close to QFM.

Groundmass and disseminated pyrrhotite blebs display similar FeS (0.87) and Ni contents (0.01) (atoms per unit formula) suggesting that the massive ores developed by coalescence of monosulphide droplets as sulphide saturation was achieved, pentlandite exsolution has an almost invariant (Co+Ni)/(Fe) ratio of 1.2-1.4 and an average formula Fe1.8Ni0.2Co0.2S2.0 line smelting group minerals (lineolate s.l.) have sealed a network of intra- and intergranular micrometric voids that crisscross the pyrrhotite matrix. Electron microprobe data confirms that these veins have complex compositional zoning that results from multiple stage infilling, as indicated by petrographic observations (Fig. 2).

Early lineolate s.l. Co-rich vein cores are rimmed by a diasaussitic (sometimes absent) Co-poor border, whereas irregular patches with intermediate Co contents are observed in the pyrrhotite matrix; pentlandite occurs on the edges of these patches (Fig. 2B). Ideal metal site distribution according with the (thio-) spinel-like structure of lineolate group minerals shows that the analysed minerals are non-stoichiometric (lineolate s.l. Co-rich) vein cores (Fe)4(Fe1.8Ni0.2Co0.2S2.0) and lineolate s.l. Co-poor vein borders (Fe)4(Fe0.2Ni1.8Co0.2S2.0), and lineolate s.l. patches in pyrrhotite matrix (Fe)4(Fe0.2Ni1.8Co0.2S2.0). The resulting deviation is due to exceeding Fe in the B position, displacing the trend towards a greasy composition.
Table 1: EPMA trace element average contents (ppm) of the sulphide phases (maximum and minimum in parenthesis) normalized for 100 wt%. N = number of analyses, nd = below detection limit.

<table>
<thead>
<tr>
<th>Element</th>
<th>Fe</th>
<th>Ni</th>
<th>Co</th>
<th>Cu</th>
<th>As</th>
<th>Bi</th>
<th>Sb</th>
<th>Se</th>
<th>Te</th>
<th>Ag</th>
<th>Au</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrrhotite</td>
<td>2.1</td>
<td>0.5</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Nickel</td>
<td>5.4</td>
<td>0.2</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Copper</td>
<td>1.3</td>
<td>0.3</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sulfur</td>
<td>50.9</td>
<td>32.7</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>57.0</td>
<td>5.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
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<td>0.0</td>
</tr>
</tbody>
</table>

Fig. 2A). The Limonite IIa Co-rich vein cores present the maximum deviation accompanied by sulphur deficiency, a common feature in manto-stiometric minerals of the Limonite group. Late veinlets of Ni-rich pyrite in the Limonite IIa zoned veins (Fe,Ni,S) indicate trace amounts of Co (275-114 ppm). Millimetric veins of pyrite in the groundmass and occurring as early-formed subhedral grains display grade to lower contents with 1366 to 7300 ppm. Low-stage chalcopyrite occurs in microstructures and has locally replaced earlier-formed sulphides.

Semi-quantitative EPMA data for trace-element abundance in sulphide phases are shown in Table 1. Higher Ag and Au contents were measured consistently from the Fe,Ni of pentlandite, suggesting that pyrite mineral exsolution incorporating these metals may be present. Chalcopyrite has the highest analysed Fe concentration (1034 ppm). Pyrrhotite/Pyr-Au is strongly partitioned between chalcopyrite and pentlandite with (Pyr-Au) displaying higher affinity with the Co-Ni-rich phase. All ‘Limonite II’ phases display negative correlation between Co contents and Fe, Ni contents (Pyr-Au) ratio. Thus, Limonite II composition and Co variations may represent a suitable pathway for high Fe-Ni-Au grades.

4. Conclusions and future research

The results of this study demonstrate the occurrence of primary magmatic Ni-Co-Cu and PGE-bearing sulphide mineralizations in the Beja Layered Gabbroic Sequence, providing new insights into the metamorphic potential of this igneous complex. Further research is underway to fully explore the economic significance of these new findings.

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References


