Mineral Deposit Research: Meeting the Global Challenge

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Mineral Deposit Research: Meeting the Global Challenge

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Factors controlling palladium and gold contents in the Aksug porphyry Cu-Mo deposit (Russia)

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**Abstract.** Two stages of economic copper mineralization can be distinguished in the Aksug porphyry Cu-Mo deposit. The first stage, consisting mainly of pyrite and chalcopyrite, is accompanied by abundant rutile and monazite. The second stage, consisting mainly of chalcopyrite, is associated with the telluride AuFe2 (merenskyrite), electrum (18 wt% Ag) and monazite. Mineralogical, geochemical and textural data indicate that precious metals are closely associated with zones of propylitic alteration vein-type chalcopyrite and a strongly evolved mineralized system.

**Keywords:** Palladium, gold, REE, Cu-Mo porphyry, Aksug

1 Introduction

Porphyry Cu-Mo deposits are among the world's most important sources of Au and PGE. However, the published data on PGE contents and their distribution in ores of these deposits are limited (Economou-Eliopoulos and Eliopoulos, 1996, 2000, 2001; Stibrany et al. 2000, Tarkian and Stibrany, 2000), in particular, for deposits from Russia (Kovalenker et al. 1996; Sotnikov et al. 2001). Our study of the composition of flotation and sulphide concentrates as well as mineralized rock samples from the Aksug porphyry Mo-Cu deposit provides new information concerning the precious metal contents of porphyry ores.

The Aksug porphyry Cu-Mo deposit occurs in the northeastern part of Tuva republic (Fig. 1). The deposit was discovered in 1952 and explored from 1982 to 1985, and is not active now. Estimated reserves and grades are 2.26 Mt Cu @ 0.67 wt %, 52 kt Mo @ 0.015 wt %, 39 t Ag @ 0.12 g/t, and 370 t Au @ 1.09 g/t (Lebedev and Kuzhuget 1998).

2 Geological setting

The Aksug deposit is hosted by the Aksug granite pluton, composed mainly of sodic, calc-alkaline quartz diorites and tonalites, with subordinate diorites and gabbro (Fig. 1). The pluton has been cut by stocks and dikes of quartz diorite, tonalite and granodiorite porphyries (the Aksug series). Low-grade (0.1 to 0.2 %Cu, ~0.03% Mo) molybdenite-pyrite-chalcopyrite mineralization is related to stage I granodiorite porphyries. Emplacement of a second generation of granodiorite porphyries (stage II) superimposed high grade chalcopyrite – bornite – molybdenite ore (0.3 to 1.0 % Cu; 0.01–0.02% Mo) onto the low-grade proto-ore.

A general sequence of mineral assemblages at the Aksug deposit has been distinguished in: (1) quartz-pyrite with hematite, (2) quartz-molybdenite with pyrite and chalcopyrite, (3) quartz-chalcopyrite with bornite, pyrite, and molybdenite, (4) fahlore, enargite, galena, and sphalerite, (5) quartz-calcite (Sotnikov et al. 2001). Quartz-sericite and propylitic alteration are predominant at the deposit, while the early potassic alteration is subordinate. All magmatic rocks of the Aksug ore region have strontium isotopic compositions consistent with a predominantly mantle source regime ($^{87}Sr/^{86}Sr$)0.70454–0.70496. $^{40}Ar/^{39}Ar$ dating of plagioclase from tonalite porphyries returned an age of 404–401 Ma (Sotnikov et al. 2003).
Table 1: Pd, Pt and Au contents of wall-rock samples and flotation concentrates from the Aksuq porphyry Cu-Mo deposit.

<table>
<thead>
<tr>
<th>Sample number</th>
<th>Sample description</th>
<th>Au ppb</th>
<th>Pd ppb</th>
<th>Pt ppb</th>
<th>Cu ppm</th>
<th>Mo ppm</th>
<th>Pd/Pt</th>
<th>Cu/Mo</th>
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<tr>
<td>s-0463b</td>
<td>sericite/quartz, sericite</td>
<td>30</td>
<td>11</td>
<td>17</td>
<td>1550</td>
<td>8</td>
<td>0.65</td>
<td>194</td>
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<tr>
<td>s-0464</td>
<td>potassic/K-feldspar, quartz</td>
<td>51</td>
<td>9</td>
<td>17</td>
<td>2090</td>
<td>10</td>
<td>0.53</td>
<td>209</td>
</tr>
<tr>
<td>s-0468</td>
<td>silicification-sericite/sericite, quartz</td>
<td>47</td>
<td>12</td>
<td>21</td>
<td>2950</td>
<td>55</td>
<td>0.57</td>
<td>17</td>
</tr>
<tr>
<td>s-0474</td>
<td>silicification-sericite/sericite, quartz, albite</td>
<td>200</td>
<td>12</td>
<td>21</td>
<td>2400</td>
<td>55</td>
<td>0.57</td>
<td>44</td>
</tr>
<tr>
<td>s-0486</td>
<td>silicification-potassic/K-feldspar, sericite, quartz, albite</td>
<td>72</td>
<td>20</td>
<td>34</td>
<td>1010</td>
<td>72</td>
<td>0.59</td>
<td>14</td>
</tr>
<tr>
<td>s-0487</td>
<td>potassic/K-feldspar, quartz, albite, biotite</td>
<td>26</td>
<td>23</td>
<td>20</td>
<td>350</td>
<td>43</td>
<td>1.15</td>
<td>8</td>
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<td>s-0488</td>
<td>silicification-sericite/sericite, quartz, albite</td>
<td>24</td>
<td>31</td>
<td>21</td>
<td>154</td>
<td>128</td>
<td>1.48</td>
<td>1</td>
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<td>s-0497a</td>
<td>potassic/K-feldspar, quartz, albite</td>
<td>36</td>
<td>12</td>
<td>24</td>
<td>3800</td>
<td>&lt;1</td>
<td>0.5</td>
<td>&gt;3800</td>
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<tr>
<td>representative ore sample, flotation and sulphide concentrates</td>
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<tr>
<td>47T/1</td>
<td>sulphide ore (chalcopyrite, pyrite, molybdenite, silicates)</td>
<td>178</td>
<td>17</td>
<td>29</td>
<td>10 840</td>
<td>224</td>
<td>0.59</td>
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<td>47T/2</td>
<td>copper flotation concentrate</td>
<td>5450</td>
<td>62</td>
<td>96</td>
<td>196 500</td>
<td>960</td>
<td>0.64</td>
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<td>47T/3</td>
<td>copper-molybdenum flotation concentrate</td>
<td>2740</td>
<td>83</td>
<td>76</td>
<td>102 000</td>
<td>14 080</td>
<td>1.1</td>
</tr>
<tr>
<td>s-2932b</td>
<td>copper (chalcopyrite) sulphide concentrate</td>
<td>1210</td>
<td>920</td>
<td>25</td>
<td>53 600</td>
<td>85</td>
<td>37</td>
</tr>
</tbody>
</table>

Figure 2: Pd/Pt versus Cu/Mo values in mineralized wall-rock samples of the Aksuq deposit.

3 Analytical methods

Pt, Pd and Au contents of concentrates and rock chip samples were determined at both X-ray Assay Laboratories (XRAL), Ontario, Canada, and the National University of Athens, using ICP/MS and AAS (heated graphite atomizer), respectively, after preconcentration by the Lead Fire Assay technique from samples of mineralized rocks and sulfide concentrates. The amount analysed was 30g. Detection limits are 1 ppb for Pd and Au, and 10 ppb for Pt. The Cu and Mo contents were determined by the AAS method in the National University of Athens with a detection limit of 1 ppm.

Analyses of PGM were carried out by a (SEM) JEOL JSM-5600 combined with an Oxford Link ISIS Series 300 EDX at the National University of Athens. Accelerating voltage and beam current were kept at 20.0 kV and 0.5 nA, respectively.

4 Platinum, palladium and gold distribution

4.1 Pt, Pd and Au contents of the mineralized porphyry

Pd and Pt contents in wall rock samples with minor mineralization (Cu: 0.01–0.4 wt.%, Mo: 0–0.01 wt.%), from the different alteration types, range between 9 and 31 ppb, and from 17 to 34 ppb, respectively (Table 1). Average PGE contents in mineralized rocks of the Aksuq deposit are 17 ppb Pd and 22 ppb Pt. Gold contents in mineralized rocks are generally low, ranging from 24 to 200 ppb, with an average of 60 ppb.

The variation of Pd/Pt ratios in wall-rock samples is small (0.5–1.5). Even though the data base is relatively small, it seems likely that higher Pd/Pt ratios in wall rock samples (1.5–1.5) are linked to the samples with lower Cu/Mo value (1–8; Fig. 2). In wall rock samples Pd correlates positively with Mo ($r = 0.83$) and negatively with Cu ($r = -0.70$), Pt shows weak positive correlation with Mo ($r = 0.31$) and no correlation with Cu ($r = -0.03$). Evidently, there is no consistent relationship between alteration type and Pt, Pd and Au content.

4.2 Pt, Pd and Au in flotation and sulphide concentrates

We have analysed four samples for their noble metal contents (Table 1). Sample 47T/1 is a bulk sulphide ore sample, which was crushed and milled for geochemical analysis. It is considered to be representative of the bulk composition of the orozobdy. Two flotation concentrates (Cu – 47T/2; Cu-Mo – 47T/3) were prepared from the bulk sample. A chalcopyrite-rich rock chip sample of propylitic alteration
was also analysed (sample S-2392b; Table 1). The bulk sulphide ore sample contains 178 ppb Au, 17 ppb Pd and 29 ppb Pt (Table 1). The copper flotation concentrate and copper-molybdenum flotation concentrate have Au, Pd and Pt contents of 5450, 62, 96 and 2470, 83, 76 ppb respectively (Table 1). The chalcopyrite-rich propylitic altered rock chip sample (S-2392b) has relatively high Pd and Au contents (920 and 1210 ppb respectively; Table 1).

We undertook a detailed investigation of the most Pd- and Au-enriched sample (s-2392b) using SEM and the electron microprobe. Our results show that copper mineralization occurred in two stages. Stage 1 consists of pyrite and chalcopyrite and is associated with abundant Ti-minerals (mostly rutile), REE-minerals, such as monazite (Fig 3a, b), F-apatite and zircon. Palladium occurs as Pd-telluride (merenskyite), containing 25–25 wt% Pd and small amounts of Pt. Merenskyite is hosted as small (2–5 μm) rounded to oval inclusions within stage II chalcopyrite, along with electrum (Fig. 3; Table 2). Several Pd-bearing grains occur as intergrowths as well as composite grains with other minerals such as cobaltite, chalcopyrite (Table 2), and as yet and unidentified Au, Ag, As-bearing minerals. Monazite inclusions have also been recognized in stage 2 chalcopyrite, and small grains of Sr-bearing barite (4.6 to 18 wt% Sr) occur along fractures through the metallic minerals, and as disseminations in quartz and silicate minerals.

5 Discussion

The Aksug deposit is associated with a suite of sodic calc-alkaline porphyries, inferred to be derived from volatile-rich, strongly fractionated parent magmas (Kuz’min 1985, Sotnikov et al. 2003). Mineralizing fluids at Aksug were CI-rich and of magmatic derivation (Sotnikov et al. 2003). Mineralization formed under relatively oxidized conditions, as indicated by the presence of abundant anhydrite and low (CO/CH4)/CO2 ratios, as determined by gas chromatography (Berzina et al. 2005). Such conditions favor the transport of Au, Pd and Pt as chloride complexes (Economou-Eliopoulos and Eliopoulos 2000, Wood et al. 1992, Xiong and Wood 2000).

Although the Pd and Pt contents at Aksug are much lower than those reported at Skouries, Santo Tomas, Bega, Elatsite, Majdanpek and Mamut (Economou-Eliopoulos and Eliopoulos, 2000, 2001; Stirnberg et al. 2006, Tarkian and Stirnberg 2000), there are similarities in terms of (a) the occurrence of merenskyite as the main Pd-bearing
mineral (Table 2), (b) the association of merenskyite with chalcopyrite, (c) the association of merenskyite with Au, Ag, As-bearing minerals and (d) the oxidized nature of mineralizing fluids. The low Pd and Pt contents at Aksug (Table 1) may relate to low precious metals of PGE deposition at the trap site.

The positive correlation between Pd/Pt and Cu/Mo in the mineralized samples (Fig. 2) implies that Pd at Aksug may occur as an impurity in molybdenite. The high Pd contents of the molybdenum sulphide concentrate (684 ppm Pd; Table 1) supports this, as does the report of elevated Pd (up to 270 ppm Pd) in molybdenite samples from the Zhireken Mo–Cu porphyry deposit, Russia (Sotnikov et al. 2001).

The PGE and Au distribution in porphyry Cu–Mo deposits is controlled by a complex interplay of several factors. The association of merenskyite with stage II chalcopyrite in relatively Pd-enriched samples, coupled with the lower temperature of formation and higher 87Sr/86Sr values for Aksug compared to other porphyry Cu–Mo deposits of Russia (Sotnikov et al. 2011) suggest that additionally to the physico-chemical conditions of crystallization (O2, CO2 activity), major controlling factors were the compositions of the parent magma and the ore-forming solutions.

Acknowledgements

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References

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