Mineralogical Reasons of Au Recovery Variability from North-Western Pit of Varvara Au-Cu Mine (Kazakhstan) and Criteria for Geometallurgical Mapping

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Abstract. Varvara Au-Cu mine deposit is located in Northern Kazakhstan. Mineralization is hosted in volcano-sedimentary, sedimentary rocks, metamorphosed and altered ultramafic and felsic rocks. Variability study was done on 58 composite samples represented five mineral ore types: serpentine-chlorite-talc; carbonate-chlorite-talc; quartz-sulfide; pyroxene-chlorite-prehnite $\pm$ garnet; quartz-feldspar $\pm$ pyroxene $\pm$ amphibole. Five processing ore types were defined: Au, Ni-As, pyrite, Cu and mixed. Mineralogy and geochemical studies revealed separate mineral associations carrying Cu, Ni-As and Au mineralization. Flotation and cyanidation tests were performed for each sample. Au losses with cyanidation cake occurred due to locking in sulfides. Flotation concentrate contamination with Mg-silicates (talc, serpentine) was connected to Au losses. Quartz-sulfide ore demonstrated better recovery by flotation. Cyanidation were most effective for pyroxene-chlorite-prehnite $\pm$ garnet and quartz-feldspar $\pm$ pyroxene ore compositions. Carbonate presence in the serpentine-chlorite-talc ore followed decrease in recovery by both extraction methods. Optimal viable ore treatment method can be chosen based on regression equations using ore chemical composition and color.

Keywords: Typification · Cyanidation · Flotation · Recovery estimation · Geometallurgy

1 Introduction

Varvarinskoe Au-Cu deposit is located in Kostanay region in Northern Kazakhstan and operated by several open pits. It is localized in volcanogenic, terrigenous, carbonate rocks (D_2-C_1) with ultrabasic and granodiorite intrusions (C_2-C_3). Silicification, argillic alteration, scarn processes were wide spread. Retrograde metamorphic changes were typical for ultramafic rocks.

This work was aimed at determining compositional differences in ore types and ore characteristics effected gold recovery by cyanidation and flotation.

2 Methods and Approaches

58 small composite geometallurgical samples from Northwestern open pit were studied for bulk chemical and mineral composition, sample color with RGB-parameters. Cyanidation and sulfide flotation tests were done on the head samples.

Au was assayed with fire assay with atomic absorption finish, multi-element ICP-AES assays after four acid digestion of samples and XRF-analysis, sulfide and total S, total C estimated by LECO AES analysis.

Mineral phase identification and their quantification was done using Eva software and COD database. Quantitative X-ray powder diffraction with Rietveld refinement was done using Topas software at Polymetal Engineering.

Multivariate statistical analysis was performed on filtered data with Aitchison transformation using Pearson correlations with Cytoscape software, PCA and regression analyses. Regression analysis was carried out to predict gold extraction.

3 Results and Discussion

Mineral composition of the samples varied between serpentine-talc-chlorite $\pm$ carbonate, quartz-feldspatic and quartz-sulphide associations. Five main mineral ore types were distinguished based on bulk mineral composition: 1 – serpentine-chlorite-talc, 2 – carbonate-chlorite-talc, 3 – quartz-sulfide, 4 – pyroxene-chlorite-prehnite-garnet, 5 – quartz-feldspar-pyroxene-amphibole.

Flotation and leaching tests revealed five processing ore types: a - gold, b - copper, c - Ni-As, d - pyrite and e - mixed.

Multivariate statistics analyses were performed on all available samples parameters including mineral and chemical composition; color (RGB, brightness – IBRT and darkness - dBRT); material fineness ($-71 \mu\text{A}$); Au, Cu, As, Ni, sulfidic S, total S recovery to concentrate and losses to flotation tails (XF) (ϵAuKF , ϵCuKF , ϵAsKF , ϵNiKF , ϵSsKF , ϵSKF ; ϵAuXF , ϵCuXF , ϵAsXF , ϵNiXF , ϵSsXF , ϵSXF) and cyanidation (ϵAuCN , ϵCuCN , $-\epsilon\text{AuCN}$, $-\epsilon\text{CuCN}$), parameters of cyanidation conditions (reagents uptake - NaCNi , CaCNi), cyano-soluble copper – αCuCNr , Au content in cake – AuXvA , characteristics of gravity con (mass pull - $\gamma\text{gk-t}$, pyrite, arsenopyrite, Cr-spinel, chalcopyrite, Ni-minerals contents in gravity con: PyMrcGK , ApyGK , ChrGK , CpyGK , NiMGK).

Pearson correlations revealed occurrence of 3 geochemical and mineral clusters following bulk sample mineralogy (Fig. 1): quartz-sulfide, diorite (feldspatic) and serpentinite. Au losses with cyanidation tails connected with Au locked in sulfides, which was proved with SEM study. S and Cu contents and NaCN consumption were included in the cluster with Au losses with cyanidation. This fact may point to consumption of free CN^- by reaction with S^0 and Cu dissolution, thus leading to deficit of free CN^- . This reaction produced CuCN and rhodanates that could block surface gold particle impeding its dissolution. Concentrate contamination with self-floating Mg-silicates (talc, serpentine) was connected to Au losses with flotation tails.

Principal component analysis exposed 7 principal components, which explained 72.1% of the total variance and described mineral composition, geochemical

Fig. 1. Positive correlations between compositional and metallurgical parameters of samples from Varvara

associations, Au and Cu recovery by flotation and cyanidation (Fig. 2). 5 ore types were well separated in the coordinates of factors 2 and 3, 2 and 4. Quartz-sulfide ore samples demonstrated better recovery by flotation, while cyanidation was more effective for samples with pyroxene-chlorite-prehnite-garnet and quartz-feldspar-pyroxene-amphibole compositions. Carbonate occurrence in the serpentine-chlorite-talc ore reduced recovery by both concentrating methods.

Regression equations for Au recovery by flotation ($R^2 = 0.80$) and by cyanidation ($R^2 = 0.88$) included color parameter (BRT) and elements contents (ppm or wt%):

$$\epsilon_{\text{AuFl}} = 127.32 + 0.17\text{Co} - 0.01\text{Cu} - 4.78\text{Fe}(\%) + 5.19\text{K}(\%) + 0.39\text{Mo} + 0.39\text{Th} + 0.01\text{Sb} - 0.63\text{BRT} + 0.10\text{Zn} + 0.43\text{Mg}(\%) + 0.84\text{SiO}_2(\%) - 0.81\text{Li} - 0.40\text{Rb} - 1.97\text{Te} + 5.03\text{Cs}$$

$$\epsilon_{\text{AuCN}} = 226.60 - 2.86\text{Ca}(\%) + 0.30\text{Co} - 7.00\text{Fe}(\%) - 2.08\text{Sc} - 0.16\text{Sr} + 0.13\text{V} - 0.24\text{MgO}(\%) - 3.37\text{Al}_2\text{O}_3(\%) - 0.55\text{SiO}_2(\%) + 1.98\text{Ga} - 0.42\text{BRT} + 0.27\text{LOI}(\%) + 0.004\text{Cu} + 0.02\text{Ni} - 0.01\text{As}$$

Fig. 2. Factor loadings and factor scores for factors 2 and 4 with interpretation

4 Conclusions

Mineral composition of the samples varied significantly from serpentine-talc-chlorite ± carbonate to quartz-feldspar, skarn and quartz-sulfide associations. Au losses with cyanidation tails connected with Au locked in sulfides. Au losses with flotation tails connected to concentrate dilution with self-floating Mg-silicates (talc and serpentine). Ore sorting can be done based on regression equations of element composition and ore color to direct the ore to more economically viable process.

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