Geomechanical conditions of extraction of gold-bearing ore reserves under the bottom of an open pit mine in Malomyr quartz deposit

MI Potapchuk*, VG Kryukov, BG Saksin and DI Tsoi

Institute of Mining, Far East Branch, Russian Academy of Sciences, Khabarovsk, Russia

E-mail: *potapchuk-igd@mail.ru

Abstract. Based on the studies into the engineering geology, geodynamic zoning, geomechanical stability and stress–strain behavior of rock mass, the authors substantiate the mining technology for Malomyr Mine.

1. Introduction
The best part of the territory in the Amur Region and the Khabarovsk Krai is occupied by the northern projection of the Jamusy–Bureya microcontinent with the Precambrian basement. This microcontinent represents a large stiff crustal structure. At its boundary, during geological evolution of the territory, an active zone favorable for localization of Mesozoic gold deposits appeared. This zone is the near-contact belt 50–100 km wide; it features intense tectonics which prepared Mesozoic volcano-plutonic systems and the related mineralization of different size. System-based exploration activities of mining lease owners allowed a considerable increase in the proven reserves at thePokrovskoe, Pioneer and Malomyr projects (site Quartzite). In the course of open pit mining in Quartzite site, extraction of ore reserves under the open pit bottom necessitated updating of modern geodynamic situation and the use of the obtained data for validation of the safe and efficient mining technologies for deeper levels. To this effect, additional research was undertaken, including: the engineering geology studies; geodynamic zoning based on revealed tectonics patterns; zoning based on geomechanical stability of rock mass with regard to integrated influence of lithology and geotechnology; stress–strain analysis of rock mass [1, 2] at different stages of mining operations.

2. Malomyr ore field overview and distribution of major principal stresses
Quartzite site is located inside the Selendzha area in the Amur Region. The nearest settlement is Stoiba at a distance of 36 km southward. Ore mineralization represents lenses and veins of different dimensions (length from 70–90 to 200–240 m, thickness from 1–3 to 15–25 m), sufficiently consistent long the strike and dip. The ore bodies governed by east-to-west structure have dips of 70–85°, the ore bodies governed by north-to-south-structures dip eastward at 60–80°. In ring faults, the discontinuities have centroclinal steep occurrence. Some bodies (ore body 55) are represented by breccias with quartz and quartz–carbonate cement, or quartz tectonic breccias with zones of vein silicification and carbonatization.

Geological heterogeneity of Malomyr ore field predetermines its location at the junction of two large tectonic structures—Amur–Okhotsk zone of Mongol–Okhotsk Fold Belt and Bureya Massif.
represented by Turan block [3–6]. Mongol–Okhotsk system separates two geoblocks of Amur Lithosphere Plate: Amur block including Bureya Massif and Aldan–Stan block. The geodynamic zoning and morphostructure analysis of the surface relief show that the zone of the deposit is subjected to the compressive stresses, and the major stress $\sigma_1$ has the south–west–westward orientation. The axes of the focal mechanism of compression from the immediate earthquakes are oriented orthogonally to the modern movement of the crust by GPS observation data. At the depths of 320 m below ground surface, the gravitation stresses are governed by overlying rock weight.

The common structure in the ore field is Malomyr dome including Quartzite and Central site. The dome adjoins the Diagonal fault which cuts out the southeastern part of the dome. The dome is 2.6×2.3 km in size and represents an oval extended in the north–west–eastward direction. This structure is delineated by thinning of areas of granite-like metasomatic rocks, from the data of the relief morhometry and image decoding (Figure 1).

Figure 1. Geology of Malomyr ore field.
The northern half of the dome, versus its south, contains more plagiogranites (granite-like metasomatic rocks). It allows suggesting the asymmetrical structure of the dome, with the lower-profile roof in the south. For another thing, the northern half of the dome features the developed geothermal methamorphism finished with ore emplacement. This means that feeders in this territory have been functioning for a long time.

The northern half of the dome includes two small intrusive named as Elovь and Kanavinsky (as the cognominal streams). The south part of the dome contains Malomyr intrusive bounded by the Central fault on the south, left-hand bank of the Taborny Stream in the west, east-to-west Malomyr fault in the north and partly by the Kanavinsky fault in the east.

During open pit mining, it has been found that faulting and rock mass quality greatly affect mining safety. The spatial position of the ore bodies in Quartzite site is conditioned by the faults of the orthogonal and ring faults. Main ore body 55 (ore-bearing zone 10 to 30 m thick) is located at the juncture of the east part of Elovь intrusive and west part of Kanavinsky intrusive, at prevalence of the ring structure of Elovь intrusion dome. Ore bodies in this zone dip both westward and eastward, and generally have a vertical strike. Bodies at the structures oriented east westward have mostly the northern dip, bodies at the structures oriented north southward have the eastern dip.

The survey of the disjunctive tectonics in Quartzite site exhibits nonuniform distribution of faults in the center of the site (Figure 1). Considering varying rock mass quality in this site, and the association of the rock mass quality with the orthogonal and ring systems of faults, four blocks are identified in the site. The works quality is a feature of ore body 55 area between profiles 609 and 622 within structural block III. In this area, metasomatic rocks are distinct at the juncture of the ring structure of Elovь and Kanavinsky intrusion domes, as well as the north–southward Second fault. In is observed that with growing depth (from level 500 m to level 400 m, the rock mass quality worsens from 73 to 100%. The mentioned depth interval in the ore-bearing structure should be given special attention during development heading and actual stoping, due to possible roof falls and caving. The other blocks are characterized with lesser tectonic deformation [2].

Stability assessment of rock mass used the data of core analysis and physical and mechanical properties of rocks from different rating systems [7 –10]. The calculated values, namely, RQD (60 for gangue and 29 for ore), RMR (58 for gangue and 63 for ore) and GSI (9 for gangue and 20 for ore), make it possible to place the test rock mass in stability group 3.

![Figure 2. Distribution of major principal stresses $\sigma_1$ in structure of room–and-pillar system at intermediate operation stage: (a) projection of vertical plane of ore body; (b) section 1–1.](image)

Based on the geological and geomechanical conditions, it is decided to use the room-and-pillar
system with blasting for extraction of ore. In the areas of thin ore bodies, it is selected to apply shrinkage stoping with short-hole blasting. The influence of mining operations on geomechanical conditions during extraction of ore reserves under the open pit bottom in Quartzite site of Malomyr Mine was estimated through the stress–strain analysis of rock mass, which allowed identifying the highest stress areas in rock mass.

The mathematical model shows that the main structural elements in the geotechnologies preserve stability by the criteria of the effective maximal compressive stresses and shear stresses at all mining stages in an extraction block [11, 12]. In case of the room-and-pillar mining, the highest stress concentration is observed on deeper levels (165–210 m) in the periphery of sublevel after extraction of 2/3 reserves from the block (Figure 2). The maximal compressive stresses $\sigma_{\text{max}}$ and the shear stresses $\tau$ reach 50 and 23 MPa, respectively, which is comparable with the limiting compression and shear strengths of rocks.

After complete extraction of ore reserves from the block, redistribution of stresses takes places, and the stresses concentrate in level pillars along raisers. The stress $\sigma_{\text{max}}$ is not higher than 40 MPa in the pillars. In case of shrinkage stoping, higher stress zone appears in the decreasing ore crown. When the ore crown reaches thickness of 15 m, the maximal compressive and shear stresses reach 40 and 27 MPa, respectively. It is inadmissible to reduce the ore crown even more as the effective stresses can exceed the strength characteristics of rock mass.

3. Conclusions

The authors have validated the technologies of room-and-pillar mining and shrinkage stoping for safe extraction of ore reserves under the bottom of an open pit mine based on the geodynamic zoning data and stress–strain analysis of rock mass in Quartzite site.

References

[1] Rasskazov IYu, Kryukov VG, Saksin BG and Potapchuk MI 2017 Geomechanical substantiation of hybrid open pit/underground mining for Pioneer gold project GLAB Special Issue 24 pp 7–15

[2] Geomechanical Research of Rock Mass during Geological Exploration, Accessing and Actual Underground Mining in Quartzite Site of Malomyr Deposit: R&D Report Khabarovsk: IGD DVO RAN 2018 (in Russian)

[3] Eirish LV 2002 Metallogeny of Gold in the Amur Region Vladivostok: Dalnauka (in Russian)

[4] Saksin BG, Rasskazov IYu and Shevchenko BF 2015 Principles of integrated analysis of modern stresses and strains in the outer crust of the Amurian Plate Journal of Mining Science Vol. 51 No 2 pp 243–252

[5] Levi KG, Sherman SI, Sankov VA et al 2007 Modern Geodynamics Map: Aisa. Scale 1:5 000 000 Irkuts: ISK SO RAN (in Russian)

[6] Melnikov AV and Stepanov VA 2014 Gold Ore Placers in the Amur Gold Province. Part 2: Center Blagoveschensk: AmGU (in Russian)

[7] Makarov AB, Rasskazov Iyu, Saksin BG, Livinsky IS and Potapchuk MI 2016 Geomechanical evaluation of room-and-pillar parameters in transition to underground mining Journal of Mining Science Vol 52 No 3 pp 438–447

[8] Hoek E and Brown ET 1998 Practical estimate of rock mass strength Int. J. Rock Mech. Min. Sci. 54 pp 1165–1186

[9] Hoek E and Martin CD 2014 Fracture initiation and propagation in intact rock: A review Journal of Rock Mechanics and Geotechnical Engineering Vol 6 No 4 pp 1–14

[10] Kanagawa T, Hayashi M and Nakasa H 1976 Estimation of spatikal geo-stress components in rock samples using the Kaiser effect CRIEPI Report No 375017 Abiko, Japan

[11] Eremenko AA, Gaidin AP, Vaganova VA and Eremenko VA 1999 Rock-burst hazard criterion of rock mass Journal of Mining Science Vol 35 No 6 pp 598–601

[12] Wael Abdellah, Raju GD, Hani S Mitri and Denis Thibodeu 2014 Stability of underground mine
development intersections during the life of a mine plant *Int. J. Rock Mech. Min. Sci.* Vol 72 pp 173–181