Influence of underground mining of Taseevskoye field on landscape and open-pit remining

M V Kostromin and Yu T Popova
Transbaikal State University, 30, Aleksandro-Zavodskaya St., Chita, 672039, Russia
E-mail: kostrmv@yandex.ru

Abstract. The Baley ore body unites Taseevskoye and Baleyskoye gold mines. The internal structure of Taseevskoye field is defined by the system of longitudinal and cross deformations splitting the Baleyskaya depression into a series of large blocks. One of the main features of open-pit remining of the First ore zone of Taseevskoye field is that mining operations will continuously happen in a zone dangerous in terms of caves. Caving systems in underground mining lead to displacement of some mineral resources to underlying horizons. Hence, the main provisions are defined to study regularities of earth surface displacement within a field. Depending on the correlation of parameters the earth surface is not deformed or deformed as failures, cracks or smooth movements. The development of depression in the direction and speed increases towards the second mining. Thus, within the contours of the designed pit the rock massif is located in the zone of deformations with developed displacement under the influence of underground mining operations. Contours and sizes of dangerous zones are defined for open-pit mining operations in the zone of displacement.

1. Introduction
The Baley ore body (area – 40 km²) located in Zabaykalsky Krai 350 km southeast of Chita includes Taseevskoye and Baleyskoye gold fields.

Until 1964 the Baley ore field was developed by open-pit and underground methods. Now the Baley mine is temporarily abandoned.

The Taseevskoye field has been developed since July, 1948. The field was found in 1941 and during the period from 1948 to 1994 16.3 million tons of ore, from which 6.4 million ounces of gold at gold content of 12.2 g/t, were extracted here. This gold was extracted from the epithermal system of cracked gold-bearing quartz veins located on a circular site with the diameter of 1000 meters.

The field was mainly developed via the underground method, which was concentrated on three main reef systems. A wide mineralized zone with lower gold content located within argillic alteration envelope surrounding fissure veins was left undeveloped [1].

The ores of Taseevskoye field are processed at Taseevskaya factory. The Taseevskoye field represents a large ore site of gold-quartz mineralization located in the central part of the central block of the Baley fault trough composed at the highest levels of Jurassic and cretaceous tuffogenic and sandy-conglomerate deposits and at the bottom it is composed of folded Proterozoic rocks [2].

The field resembles a magnificent long deposit, a stretched mineralization band located northeast (300 m wide and up to 2 km long). About 50 vein-shaped bodies grouped in seven ore zones and having abrupt steep pitches in the northwest are discovered within its limits. According to Protodyakonov’s
scale, quartz ores belong to the 14th category of hardness, their volume weight makes 2.4 t/m$^3$, fragmentation index –1.0, humidity – 1.87 % [3].

The Taseevskoye field is presented by several almost parallel ore zones were currently the first, second, third, fourth and intermediate ore zones are in operation. The lower boundary of A+B+C reserves in place is the horizon of 516 m. The internal structure of Taseevskoye field is defined by the system of longitudinal and cross deformations splitting the Baleyskaya depression into a series of large blocks. In turn, each of them is split by more or less dense network of deformations thus explaining the generally high level of tectonic break of the area. Thus, the fractural tectonics within the considered site of the field is diverse starting from a standard karst and ending with large disjunctive dislocation like faults and shifts stretching in various directions [4].

2. Opening of a field and the system of development
The Taseevskoye gold field was opened by vertical shafts. The northeast flank of Taseevskoye field is opened from a surface with a shaft to the horizon of 300 m, and a “blind” mine shaft 4 from the horizon of 216 m to the horizon of 466 m. Ore bodies in all horizons are opened with main crosscuts with the section of 8.1–9.0 m$^2$. The mines are fixed as follows: wooden support with spacing or as a longwall with incomplete frames, arch concrete, rock bolting. All types of supports are used here depending on the stability of rocks [5].

A variety of mining-and-geological conditions predetermined the use of several development systems: with ore shrinkage used for development of steep veins with a capacity of 0.8–3.0 m by solid host rocks; overhead stoping with spacer propping – for vein capacity of 0.4–0.8 m of firm walls and 0.4–3.0 m of soft walls with angles of incidence of more than 50°; sub-level caving – for development of large steeply dipping ore bodies with the capacity of more than 3.0 m, in rocks with tectonic faults [6].

Losses within all development systems reach 20–25 %, ore dilution – up to 46.3 %.

Due to huge mineral losses the development of the so-called First ore zone via the open-pit method is planned in the ceiling and rock pillars.

The backfill was developed only in places of underground structures. Rock and low-grade ore filling was used as a stowage material. Underground development resulted in deformations of the massif of the First ore zone. Failures, some of which reach considerable sizes, were formed on the surface. Their volumes change from 600 m$^3$ to 12000 m$^3$ [8].

3. Observations over displacement
Observations over surface and rock displacement within a field began in 1956-57 and were carried out by mining surveyor of the Taseevo mine; in 1960-62 these works were performed by Soyuzmarkshstrest, from 1960 to 1971 the Soyuzmarkshstrest expedition studied rock displacement and defined key parameters of this process. From 1976 to 1981 the observations were made by Chita Polytechnic Institute [8]. Within a design contour of the Taseevskoye pit three displacement zones are defined [9]:

- zone of smooth displacement;
- fractured zone;
- caving zone.

The basic provisions to study regularities of earth surface displacement in Taseevskoye field are the following:

1. Nature and parameter of rock displacement are defined by form and sizes of ore bodies, applied development systems, correlation of sizes of the developed space.

2. Full development of earth surface displacement and minimum angles of displacement are obtained when the sizes of the developed space on the strike and falling of ore bodies are equal or make more than the depth of development.

3. Zones of dangerous displacements and cracks are limited to angles of 50°–70°.
4. The zone of funnels and failures is the most dangerous site of a shift trough. Funnels are formed as a result of the by-pass of loose rocks or stowage material from top to bottom horizons and during development of giant ore bodies [10].

5. Collapses, as a result of which funnels are formed, are stretched dome-shaped perpendicular to interbedding. Depending on the capacity of superincumbent rock and rock front the angle of rapture fluctuates from 75° to 85°.

In terms of the influence of development of some ore bodies on nature and parameters of displacement four main groups may be identified:

1. Ore bodies, which development causes failures, funnels and zones of strong vertical shifts of rocks on the earth surface.
2. Ore bodies, which development causes periodic development of dangerous zones of displacement of the earth surface and formation of funnels over top horizons.
3. Ore bodies, which development is followed by smooth subsidence of a surface with critical sizes of deformation and without formation of failures and large cracks.
4. Ore bodies, which development does not cause dangerous displacement of the earth surface.

The first group includes ore bodies of quite big and very big capacity (up to 20 m and more) developed without filling.

Ore bodies of big capacity developed using stowage material and ore bodies of average capacity (up to 6 m) with the depth of formation of the upper boundary making less than 100 m developed without filling belong to the second group.

The third group is composed of ore bodies of average capacity with the depth of the upper boundary making more than 100 m from the surface developed without filling.

Ore bodies of small (2 m) and average capacity with the depth of the upper boundary from the surface of more than 300 m developed with filling belong to the fourth group.

At present, there are active earth movements in the First ore zone due to undermining of the massif with underground mining operations, which is confirmed by surface subsidence and cavings. Through the development of top horizons (up to 166 m) the removal of failures belongs to the top part of veins. With inclusion of lower horizons there is a shift of newly formed failures towards the hanging layer followed by rock advancing. The Taseevskoye field is presented by rocks of average stability, which besides uncontrolled caving phenomenon, are characterized by their ability to maintain keep dangerous voids under roof arches. Currently, the only reliable method to define voids within a field is to drill exploratory wells [11].

4. Study and analysis conducted by Transbaikal State University

The study conducted by Transbaikal State University show that the earth surface of the First ore zone has no sites with set displacement process. The development of subsidence by direction and speed increases towards second mining, i.e. in northwest direction.

According to surveying, there are about 300 thousand m$^3$ of subsurface voids in the First ore zone.

One of the main features of open-pit remining of the First ore zone of Taseevskoye field is that mining operations will continuously happen in a zone dangerous in terms of caves. Caving systems in underground mining lead to displacement of some mineral resources to underlying horizons [12].

Being conformed with the situation created in the First ore zone it shall be noted that

1. Open-pit remining with the application of standard technological schemes is connected with stabilization of displacement of the rock massif. This process can be quite long for the following reasons:
   a) in the center of a pit there are 7 blocks with concrete pillars on the 216 m horizon, which can temporarily constrain the displacement process, and during blasting operations – cause sudden failure since the development of lower horizons was conducted without fitting;
   b) metasomatites lying under deposits can temporarily constrain the removal of failures to the surface.

Besides, stabilization of rock displacement will require immediate and long preservation of underground works, which will affect planned production at Taseevskoye mine.
2. Transition of underground works to the system with fitting is almost excluded since there is no access to developments, the massif is broken, developments are deformed and filled up. Delivery of fittings to some voids will require penetration of many large diameter wells. All this is technically difficult and obviously not favorable in terms of economic efficiency.

Correct assessment and accounting of displacement degree of a rock massif represent the greatest complexity. Under the influence of underground mining operations on the surface of the First ore zone the displacement trough, within which funnels and failures reaching considerable sizes are systematically formed, was created. Underground mining operations on horizons of 166 m, 216 m cause the repeated addition of loose stowage material from top to underlying horizons thus forming additional voids in the massif [13].

The stated conditions and features of mining operations define nature and parameters of displacement of the earth surface and the entire developed massif. Complex mining-and-geological conditions, unevenness of development of steeply deeping ore bodies (falling, stretching and across the strike, selective development of a vein), discrepancy and lack of information on mining operations of the last years and a big variety of factors create serious difficulties in studying and forecasting the nature of rock displacement and to a certain extent affect the solution of open-pit remining of top horizons [14].

The study conducted by Transbaikal State University revealed many sites of profile lines where surface inclinations considerably exceed admissible values. The qualitative assessment of this phenomenon required the definition of the maximum speed of subsidence in sites with average maximum subsidence of reference points and the calculation of relative inclinations. According to the instruction, a critical inclination is the inclination of 4 mm/m. Table 1 shows the results on local sites of profile lines.

| No. lines | No. reference | Incremental slopes, mm/m | Inclinations 2009–2016 mm/m |
|-----------|---------------|---------------------------|----------------------------|
| I-I       | 32-33         | 0.79                      | 1.25                       | 14.04                                    |
| II-II     | 27-28         | 0.33                      | 0.26                       | 9.90                                     |
| III-III   | 13-14         | 2.40                      | 0.78                       | 10.42                                    |
| V-V       | 13-14         | 1.81                      | 0.67                       | 13.86                                    |
| VI-VI     | 13-14         | 0.93                      | 0.13                       | 15.45                                    |

The analysis of these results shows the concentration of zones of intensive displacement of the earth surface on two areas characterized by the greatest connection with the highest inclinations of the earth surface. All failures and funnels are concentrated on these areas. One of such areas is in the region of crossing profile lines 4-4, V-V with lines 3-3, IV-IV, III-III. The second area of intensive displacement is in the region of crossing of lines 4-4 with lines I-I and II-II.

The area maintaining stable condition of the earth surface without funnels and failures is located between areas with lowered deformations and inclinations. This feature in the nature of displacement of the earth surface can be explained by high quality and safety of a reference point during underground operations on the 216 m horizon. It is fair to assume that there will be no narrowing of areas of active deformations of the earth surface with the formation of a uniform zone of failures. This is also confirmed by failures 5, 6 and 7, which were formed in areas of active deformations of the earth surface.

The analysis of deformation of the earth surface shows that displacement has not finished yet. Subsidence of the earth surface increases and it is followed by sudden failures and funnels. The stability of the earth surface is defined by the system of development applied during underground works and depends on mining-and-geological and physicomechanical factors: strength properties of rocks, capacity of an ore body (Figure 1).
Depending on the correlation of the above parameters the earth surface is not deformed or deformed in the form of failures, cracks or smooth displacement. With the increase of the development depth and at relatively unchanged sizes of the developed space by falling and stretching the deformation of the earth surface decreases due to their smoother distribution in a displacement trough. The speed of caving development on average makes 2.5 m/month. At such speed the voids on the horizons of 166 and 216 m shall be removed. However, the comparison of volumes of voids and failures shows that this did not happen. Such delay in removal of voids is explained by heterogeneity of the massif with faster displacement of the cave roof along weak rocks and with delay in places where rocks have high mechanical strength. Since some underground voids are not removed, we can expect the formation of new failures on a surface of the First ore zone.
5. Conclusion

Thus, within the contours of the designed pit the massif is located in the zone of deformations with developed displacement under the influence of underground mining operations [15].

Materials of observations and analytical study of the nature of displacement of the earth surface and the massif allow concluding the following:

1. The process of displacement of the surface of the First ore zone continues intensively.
2. There is the increase of the displacement trough by falling of an ore body and in the northeast direction.
3. Within a displacement trough there are two zones of increased deformations and inclinations. Between these zones there is an area of the earth surface without failures and funnels, and it is possible to assume that the narrowing of active deformation zones with the area of smooth depression and formation of a uniform zone of failures is unlikely to happen.

Contours and sizes of dangerous zones are defined for open-pit mining operations in the zone of displacement.

References

[1] Yurgenson G A 2011 Shallow gold and silver deposits, condition of formation and mineralogical and geochemical technology of their deep search and assessment Scientific notes of Transbaikal State University 1(36) 136–45
[2] Spiridonov A M, Zorina L D, Letunov S P and Prokofiev V Yu 2010 Fluorite mode of ore formation of the Baleyskoye gold and magmatic system (East Transbaikalia) Geology and geophysics 51(10) 1413–22
[3] Sekisov A G and Manzyrev D V 2009 Mineralogical-geochemical and nanostructural features of gold-bearing ores of the Zabaykalsky Krai fields Bulletin of Chita State University 2 25
[4] Yurgenson G A 2003 Typomorphism and ore formations (Novosibirsk: Nauka)
[5] Rylnikova M, Kalmykov V and Ivachov N 2003 Combined Mining of copper pyrite deposits Russian Mining 4 21–4
[6] Kaplunov D P, Kalmykov V N and Rylnikova M V 2003 Combined geotechnology (Moscow: Ore and metals)
[7] Tsarkov V A and Dobroskokin V V 2000 Current trends of gold extraction from radical ores Mining J. 5 81–2
[8] Goris J M 1996 Cable Bolt Support Technology in North America. Ground Control Mining. Cable Bolt Supports The 15th Int. Conf. on Mountain Pressure (Golden, Colorado, United States) pp 135–7
[9] Shpilko S I 2005 Choice of polymer materials for anchor rods Engineering and technology of open-pit and underground mining 331 116–20
[10] Dzhigrin A V, Burchatsky V M and Shpilko S I 2007 Results of the study of physical-mechanical properties of composite materials used for the production of polymer anchors Coal 11 97–101
[11] Eremenko A, Eremenko V and Viktorov S 2009 Technological Problems of ore Mining in Siberia Proc. of the 6 Int. Conf. on Physical Problems of Rock Destruction ed Jian Zhao (Beijing, China) pp 270–3
[12] Zvyagilsky E L 2000 Calculation of depression parameters of a vertical pit mouth of the recovered mine Geotechnical mechanics 18 26–31
[13] Weakly L F 1982 Ore moving logistics for room and pillar mines in the vilvr nym-trend Mining Engineering 4 403–4
[14] Dawson L R 1995 Developing Australia’s First Block Cave Operation at Northparkes Mines Endeavour Australasian Institute of Mining and Metallurgy 26 155–64
[15] Richard H C 1984 Long rock bolt support at the new broken hill consolidated limited Pras Austral 251 21