Features of iron ore extraction from the Southern Belozerskoye deposit of Ukraine

Volodymyr Bondarenko¹, Sergiy Zubko²

¹ National Mining University, Dnipropetrovs'k, Ukraine, e-mail: v_domna@yahoo.com
² PJSK “ZZhRK”, Dneprorudnoe, Ukraine

Abstract
The mining and geological conditions and mining system of the Southern Belozerskoye iron ore deposit are described. Measurements and analysis of subsidence of the rock mass along the heading of the hanging wall at a depth of 740 m are carried out. Simulations with equivalent materials are conducted and results of modeling are analyzed. Dependencies between room and pillar parameters and the condition and type of surrounding rock are defined. The parameters of the mining system have been rationally justified in weak rock zones. Improved room and pillar mining technology is proposed.

Key words: ore, goaf filling, room-and-pillar system, modeling

Charakterystyka wydobycia rudy żelaza ze złoża Południowo-Biełozirskiego na Ukrainie

Streszczenie
W artykule opisano warunki geologiczno-górnicze oraz system wybierania Południowo-Biełozirskiego złoża rudy żelaza na Ukrainie. Dokonano pomiarów i analizy osiadania górotworu wzdłuż stropu chodnika na głębokości 740 m. Przeprowadzono symulację z wykorzystaniem odpowiednich materiałów i przedstawiono analizę modelowania. Określono zależności pomiędzy parametrami komór i filarów a stanem i typem skały otaczających. Uzasadniono parametry systemu wybierania w strefach słabych skał. Zaproponowano udoskonalony system komorowo-filarowy.

Słowa kluczowe: ruda, podsadzka, system komorowo-filarowy, modelowanie

The Southern Belozerskoye deposit of high grade iron ores is located on the northern side of the Prichernomorskaya lowland in the territory of the Kamenko-Dniprovsky, Vasilevsky and Vesyolovsky areas of the Zaporozhye region. Precambrian deposits of granites, shales, and ferruginous quartzites can be found in the geological structure of the Southern Belozerskoye deposit under a thick layer of sedimentary rocks. In the northern part of the deposit, sedimentary rock has a thickness of 230 m, and it is 280 m thick in the southern part. The ore vein includes ferruginous quartzites and crystalline shales and extends 2.5 km to the south. The depth to which the lower horizons of the deposit are undercut by prospecting shafts amounts to 1200 m.

The "Glavnaya" deposit is most representative of the Southern Belozerskoye deposit. The ore deposit declines in elevation towards the east. The slope of the decline...
of this layer of rock and ore ranges from 60 to 80°, and the deposit has a stratoidal form. The maximum thickness of the deposit is 150 m in the southern part of the shaft mining area, and the minimum thickness is in the northern part – 10 m. The deposit is limited by the "Pogranichnyy" fault to the south.

Quartz-sericite-chlorite shales with a strength of 60 – 90 MPa are present in the footwall. Quartzites layers up to 10 m in thickness are often found at the boundaries between ore and shale interlayers. The hanging wall in the northern part of the deposit is made up of ferruginous quartzites, which are very strong, stable, and fissured, with a strength of 120 – 160 MPa. Rock similar in structure to that in the footwall is deposited in the southern part of the hanging wall.

Hematite-martite and martite-hematite ore deposits are present with frequent transitions from one type to another. The ore has a thin striated texture, and is less massive and uniform. For the most part, the ore has a strength from 20 to 120 MPa with small fissures of low and medium stability.

Mining of the Southern Belozerskoye deposit is carried out by means of progressive mining systems – horizon-room and room-subhorizon mining with goaf filling (Fig. 1). The height of stages is 100 m and 40 m, respectively.

Fig. 1. Variant of a horizon-room mining system with goaf filling:
1 – haulage drift; 2 – haulage cross-cut; 3 – ventilation shaft; 4 – gravity ore pass; 5 – cross-cut; 6 – cut shaft; 7 – filling mass; 8 – stowing cross-cut; 9 – drilling cross-cut; 10 – draw-off horizon heading
Since 2000, the intensity of mining of the Southern Belozerskoye deposit has grown significantly, with the volume of annual production increasing from 3.3 to 4.5 million tons of ore per year. It is planned to finish mining ore reserves in the 301 - 840 m horizon at the mining complex by 2020. Because of this, mining operations in the Southern Belozerskoye deposit will be concentrated in the 840-1040 m horizon.

Under the conditions of room-and-pillar mining of the ore reserves in the 740 - 840 m horizon, a problem with the stability of the rock in the hanging wall was encountered (Fig. 2) for standard room parameters (height – 100 m, width – 30 m). Large room reserves, and accordingly, small specific consumption for mining operations led to a reduction of quality indicators and to an increase of impurities in mined ore.

The predominant deterioration of the roof of horizontal headings testifies to horizontal stress exceeding vertical stress. Changes of blasting parameters made during mining of the southern part of the ore body: leaving of thick ore pillars separating the room from the rock of the hanging wall; descending blasting; transition to operation
through two pillars didn't solve the problem of stability. The physical and mechanical properties of rock in the hanging wall - shale, had a considerable impact on this problem. In this regard, it is necessary to make a transition to mining ores in the hanging wall using rooms with adjusted parameters of the mining system. However, it is difficult to secure mining of rooms with geometrical parameters in the existing network of mine headings, including ventilation shafts and haulage drifts.

Thus, the geological conditions of mining in the Southern Belozerskoye deposit are continuously deteriorating. Problems associated with increasing the depth of mining by another 100 m and then by 200 m require the adoption of new technological solutions concerning, above all, room parameters and the sequence of room mining. Therefore, special attention must be paid to the influence of mining and geological conditions on the parameters of the mining system as the depth of mining operations and strength of the rock mass increase. These parameters include room sizes and mining times, pillar sizes and parameters of the blasting complex, floor structure and other technological parameters [1].

Conducted analysis shows that it is necessary to define the dependence between room and pillar parameters and the type and condition of the host rock. Management of processes affecting rock pressure will secure stable and efficient operation of the enterprise.

Comprehensive studies of geomechanical processes in the stoping impact zone are currently being conducted at the mining complex. Zones of intensive and general impact of stoping rooms are determined using deep benchmarks, ultrasound prospecting and seismic scanning. Thanks to the unloading method, it was determined that the stress state of the untouched rock mass is not complicated by tectonics and corresponds 40 % from gravitational stress state, and drained areas of ore deposits are unloaded.

Values of subsidence and horizontal displacement are determined in the drifts and cross-cuts of the hanging wall quarterly by surveying measurements as stoping work progresses. Measuring stations are located in the cross-cuts of horizons at 605, 640, 715 and 740 m as well as in the drifts of the hanging wall at 740 and 840 m horizons. Observations conducted on a quarterly basis made it possible to determine the character of rock mass displacement around existing and filled rooms.

The results of measurements are presented in Fig.3 and Fig. 4. Readings of measuring points are shown on each graph according to the results of previous and current samplings. The part of the graph with measuring points that changed their original positions as a result of rock mass subsidence compared to the previous sampling are marked in red. Rooms in which stoping was carried out during the period between samplings are marked in yellow on mining plans (with specification of production volume).
Fig. 3. Values of rock mass subsidence along the hanging wall heading at the 740 m horizon as of 24/07/07

Fig. 4. Values of rock mass subsidence along the hanging wall heading at the 740 m horizon as of 07/10/08
Conducted studies showed that values of rock mass subsidence reached 70 mm – 195 mm in the section from 10 n to 10 s. The rate of rock mass subsidence in other sections reached a value of 6 mm/month. Conducted analysis of the character and forms of manifestation of rock pressure made it possible to determine that displacements of the contours of the stoping area occur in rooms located near the hanging wall of the ore deposit. Rooms of the deposit’s footwall are located in a zone of a lower stress state due to the protective (unloading) effect of filling of rooms that have already been mined and rooms that have been established, therefore, their structural elements preserve stability, being in a zone of reduced stress. Thus, displacement of the stoping area’s contours were practically not observed in rooms at the ore deposit’s footwall.

In effect, the significant impact of room mining times on the start of caving of the contours of the stoping area was not determined. Conducted research led to the conclusion that stoping times and volumes extracted from rooms applied until now do not have a significant impact until the beginning of caving. The main factor or criterion is the sequence of performing stoping operations in rooms, the most effective of which is stoping with leaving of an ore pillar under the roof to support unstable rocks in the hanging wall. Extraction of this pillar is performed last.

In the first stage, the authors conducted studies on models made from equivalent materials in order to investigate deformation processes of the rock mass adjacent to the mined-out space in the case of a different room mining sequence, according to methodology [2].

Average parameters of the deposit and the host rock (average geological section) were accepted for modeling of deposit mining:
- deposit thickness is 100 m;
- deposit slope angle is 70º;
- slope angle of the floor of the hanging wall room is 55º;
- room height is 100 m;
- hanging wall is represented by unstable shale rocks;
- footwall is represented by shale rocks.

According to the research methodology, modeling consisted of three stages: mining of the footwall room model, filling of footwall room, and mining of the hanging wall room model. Deformation of the room model was not registered during modeling of footwall room mining and creation. Models for simulation of hanging wall room mining are shown in Fig. 5.

Fig. 5. Modeling of hanging wall room mining at the 940-1040 m horizon according to mining stages: a – formation of cutoff stope; b – extraction of 50% ore reserves; c – extraction of 85% ore reserves; d – extraction of 100% ore reserves
During simulation of extraction of 100% ore reserves in a room situated near a hanging wall (Fig. 5), deformation of the model occurred at the point of contact of the hanging wall with the inclined bottom (stress concentration area). Deflection of the hanging wall model reached 0.173 m, which corresponds to 43.25 m on the actual scale. The formation of fractures in the direction parallel to the plane of the bottom was observed in the sloped bottom of the room model 0.08 m behind the indicator line, which corresponds to 2 m on the actual scale. Investigation of the behavior of the rock mass model around the room made it possible to plot graphs of the dependences between deformation of the rock mass and mining depth (Fig. 6).

![Graph showing deformation of rock mass model as a function of mining depth](image)

**Fig. 6. Deformation of the rock mass model as a function of mining depth**

Further investigation made it possible to find dependencies of rock mass deformation depending on mining depth for rooms located in the hanging wall:

- for hanging wall rock mass

\[ U = 0.75e^{0.001H} \quad m, \quad R^2 = 0.957 \quad (1) \]

Where:
H – mining depth, m;
R – reliability of approximation.

- for ore mass in sloping bottom of room

\[ U = 0.076e^{0.002H} \quad m, \quad R^2 = 0.956 \quad (2) \]

The research described below was based on optic polarizer materials. It included selection and preparation of the material, shaping and loading of the model, and conduct of experiments. According to the model's dimensions, which are determined by the size of the form (cartridge), and taking into account target conditions and
an attempt to achieve the maximum possible size of the investigated objects (mined-out spaces of rooms and the rock mass near them), the simulation was carried out on a geometrical scale of 1:1000.

The entire history of mining and filling of rooms above established horizons was reconstructed with geometric similarity for investigation of stress distribution in the lower horizon. Then, to imitate mining according to the room-and-pillar system, modeling of stoping of rooms at 605 – 740 m and 715 – 840 m horizons with a width of 30 and 15 m was conducted (Fig. 7). For testing of the rock mass model, according to scale, a stoping space corresponding to the shape and size of the mined-out room was carved out according to the stage of its development.

Fig. 7. Isochromes before room mining over a width of 30 m (a) and after mining of the room (b) of the hanging wall at the 740-840 m horizon and room with width of 15 m (c)

Isoclines and isostatics were determined after processing of the results of the study and are shown in Fig. 8. Investigations of tested models made of optically sensitive material by exposure to polarized rays made it possible to obtain stress values in the rock mass near the stoping area. It was determined that stresses exceed maximum allowable stresses in weak rock during stoping of rooms of the hanging wall. When a pillar equal in width to 0.5 of the footwall room's width, is preserved, stresses in rock of the hanging wall are reduced by 2.5 – 3 times, which enables determination of rational hanging wall room parameters.

According to the results of modeling of stoping of rooms at the 605 – 740 m and 715 – 840 m horizons, maximum stress concentration coefficients were determined in the impact zone of rooms. Diagrams of maximum stress concentration coefficients around rooms of the 605 – 740 m and 715 – 840 m horizons during their simultaneous stoping are given in Fig. 9.
Further investigations made it possible to obtain graphs of the dependency between the stress concentration coefficient and the increase in mining depth (Fig. 10) as well as the increase of distance from the room in the direction of rock in the hanging wall (Fig. 11).
After approximation using Microsoft Excel software, the empirical equation of the stress concentration coefficient $K_{kn}$ as a function of mining depth $H$ was obtained:

$$K_{kn} = 0.58e^{0.0009H}, \quad R^2 = 0.983 \tag{3}$$

Further studies made it possible to determine the empirical equation of stress concentration coefficient $K_{kn}$ as a function of the distance from the room in the direction of the hanging wall $L$:

$$K_{kn} = 3e^{-0.01L}, \quad R^2 = 0.982 \tag{4}$$

These dependencies allow for improvement of the methodology [3] of determining the parameters of room mining systems in order to control the stress concentration coefficient and for justification of the parameters of the mining system to improve the technology of mining in a room situated in a hanging wall made up of weak rock.
Conclusions

1. The distribution of rock pressure around stoping rooms in hanging wall rocks and in the ore body in the inclined bottom of rooms was determined by means of optical polarization modeling, models of equivalent materials, and observations conducted on-site. It was determined that:
   - the extent of rock mass deformation that develops in the sloping bottom of the room and rock in the hanging wall grows exponentially as mining depth increases, and on this basis, it is possible to minimize the fracturing area and displace rock in the hanging wall in the direction of the stoping area;
   - increasing the depth of mining operations and reducing the distance from the room in the direction of the hanging wall leads to growth of the stress concentration coefficient in the ore body, which changes according to an exponential dependency that justifies the width of the room at its point of contact with surrounding weak rock in the hanging wall.
2. The dependencies of rock pressure manifestation in the rock mass near the rooms have been determined. They make it possible to improve the technique of calculating parameters of the stoping space thanks to the correction of coefficient $K_{KH}$ for rooms situated in the hanging wall of the deposit in direct with weak rock.
3. Mining system parameters in the impact zones of weak surrounding rock have been rationalized. Accounting for the influence of these factors makes it possible to preserve the accepted parameters of footwall rooms and indicates the necessity of reducing the parameters of rooms situated in the deposit's hanging wall.
4. Improved technology for mining of rooms of the hanging wall in weak rock has been proposed, based on reducing the volume of preparatory works, secondary break-up, repair and restoration work, and raising production quality.

References
