Safety provision during development of the underground mine in water-bearing karsted rock mass

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Abstract. The present article describes issues of up-to-date methods and approaches to ensure safety during development of the underground mine in complex engineering-geological and hydrogeological environments. As a priority to ensure safety while constructing mine workings on the karsted territory is the decrease of water content of the rock massif due to construction of spot water intakes above ground. The efficiency of dewatering depends on quantity and capacity of dewatering wells. The same parameters influence on prime cost, so that in the suggested approach the maximum productivity is reached by selecting drilling sites by means of ground geophysics together with study of geological and hydrogeological conditions. In the presented paper, there is an example of successful drainage of karsted layer by constructing water intake consisting of two dewatering wells, which enabled to start developing the ore shoot, which was on suspension due to the complex environment.

1. Introduction
Occupational safety of development of mineral resources by an underground method directly depends on field hydrogeological environment and possibility to control water entry into mine workings. This issue is particularly critical during mine development related to karsted limestone massif with high water transmissibility, which increases probability of sudden entry of large amount of water into the mine. There are fairly large number of examples of mining in such conditions in the Ural region and they occupy the whole Urals from the northern to southern borders (Severouralsk bauxite mine, Vysokogorsky ore mining and processing works, Uchalinsky ore mining and processing works, etc.). Mainly they are connected with ore mining of natural resources [1-5].

2. Methods of study
One of the effective methods to reduce water content of mine workings, especially in case of mining at a depth of not exceeding 300 meters is deep well dewatering of the aquifer level confined to the roof of the ore body. However, establishing deep well dewatering on the perimeter of the deposit without taking into account structural features of the rock massif often does not solve a problem of water discharge and the majority of wells turned out to be unable to operate due to their low abundance of water.

The best results of drainage of the ore-bearing massif can be reached by a complex of analytic forecasting methods of water inflow into mine workings using current information of mineral exploration and practical application of geophysical methods for determining structural and tectonic
profiles of the rock massif and site selection of dewatering well staking [6-7]. It will allow reducing quantity of wells, which will result in significant reduction of expenses for dewatering and, consequently, in cost saving of ore mining.

One of the mines in the Southern Urals, where the described drainage approach was successfully tested with participation of authoring team, may serve as an example.

![Geologic cross section](image)

**Figure 1. Geologic cross section**

The essence of work was that one of the ore bodies of the successfully developed deposit, hosted at depth of a little over 200 m was found within underground water deposit in the karsted limestone massif (Fig. 1).

It was complicated by the fact that the karsted limestones overlaid directly in the roof of the ore body, which could lead to uncontrolled flooding of the mine goaf in case of its mining.

The goal of the research was to provide safe development of the ore body. The main purpose of the work was to reduce to minimum possible water inflows into the mine workings by arranging deep well dewatering with minimum expenses for its installation.

The volume of possible water inflow was difficult to predict, as while running deep well dewatering consisting of two wells (6 and 8), operating for the needs of the enterprise for drinking water supply, the decrease of the water level did not exceed 5 meter per a year though the total output was at the level of 160-180 m³/h. In addition, water wells were located within the area of possible deformation due to underground mining, which put in question their working efficiency at the beginning of underground mining works.

The degree of karst hazard with regard to emergency outburst in the mine workings is determined by static volume of underground water and limestone filtration properties, which define the response speed of static reserve and dynamic inflow [8-10]. At the current level of underground water in
limestones, which is about 100-120 m, the initial water flow from caverns can be within first thousand m$^3$/h, which presents serous risk for underground work.

Operation of static reserves with high filtration properties of rock and water inflow from the surrounding rock can last for a long time. This time period can be estimated approximately by operation of underground water intake from the wells no.6 and 8. At the average water flow rate from them, about 100 m$^3$/h, the annual decline of underground water table in its depression pit did not exceed 4-5 m.

Figure 2. Selection of drilling sites of dewatering wells by means of geophysics
In this regard, uncovering of karst structure can create a long emergency situation, which can take several years. A positive factor, which neutralizes this risk, can be the presence of the interbedded layer with thickness up to 70-80 m in the roof of the ore body, which can serve as a water-blocking layer excluding direct exit of the preparatory mine working in the karst hazard area.

3. Research results
The analysis of all survey information, monitoring wells, etc. enabled to define the direction of the main water inflow (north-west) and a complex of geophysical exploration enabled to choose the optimum drilling sites of dewatering wells (Fig. 2).

The first drilled exploration wells (points C1 and C2) showed full conformity with predicted open-cut and the output exceeding 100m³/h. As a result of drilling at the point C1 of the operation wells 15-B and at the beginning of its operation, the level in all wells started to fall (up to 5 m/month) which enabled to approximately determine the total volume of water entry [8,9].

Putting the well no.16-B into operation should have led to complete water catch in the catchman area, which was located further north than the ore body, providing volume control of the collected water and reducing the risk of ingress of the whole volume of water table into the mine. In addition, the wells no.6 and 8 were in the range of influence of mining works and their loss is a matter of time (Fig. 2).

Putting the well no.15-B into operation resulted in monthly depression of level in the wells no.6, 8 and 15-B within 1.5-2.2 meters, which placed in doubts further use of water intake for water supply.

Putting into operation the second well no.16 drilled at the point C2 allowed to drain the well no.8 for 10 days completely; and as bailing tests showed, it became possible to control the water level there by cutting off one or several wells (Fig. 3).

![Figure 3. Diagram of level variation in the wells](image)

Commissioning of the well no.16-B that was finished at the end of October 2016 led to drainage of the well no.8 to the depth of possible measurement with the level gauge. The task of ore body drainage considering the obtained results was solved in terms of minimizing the volume of static reserves of
underground water. In addition to it, it was decided to perform mining works for development of the ore body no.6 within the planned scope of work meeting safety requirements stated in the project.

At present, only one well no.6-B with the output of not more than 40 m³/h operates for dewatering and water consumption. The remaining wells are deactivated because of fall in level lower than the depth of the pumping equipment.

Based on these observations, the conclusion was as follows: complete development of static reserves up to the depth of about 130 m below the surface, dynamic influx of about 40-50 m³/h.

As the pumping equipment does not run deeper, karsted pockets where can be quite a large amount of static water remain in the ceiling between the ore body no.6 and the dynamic level in the wells.

One of such pockets (Fig.4) was uncovered during driving of the mine workings along the roof of the ore body with instant outflow of water with clay of about 3000 m³ volume.

![Figure 4. Uncovered karsted void](image)

The breakthrough occurred during blasting works; the fact was predetermined that there was no people in close proximity to the object, so that no one was injured. Later, the water inflow from the karsted void reduced to the level of 40-50 m³/h that corresponded to the dynamic influx observed at the water supply well.

According to the investigation results of the karsted void, its volume, danger calculations of sinkhole collapse at ground surface were done, which showed the absence of such danger. However, after further mining of the ore reserve there appeared high probability of integration of chamber and karst, which together represent danger of collapse. At the technical meeting with participation of
authoring team a decision was taken to eliminate the karsted void by filling. At present, the karsted void was completely filled and the water inflow was stopped.

Uncovering of the karsted void proved interrelation of aquifer pumped away by deep well dewatering with the rest of the massif buried above the ore body; and in future this will likely lead to complete drainage of wells and the remaining static volume and dynamic inflow will flow into underground mine workings. It does not present great danger for development of the ore body; repeated water outflow from the re-uncovered karst is possible, however, the main static water reserve was drained by deep well dewatering, and the built water intake facilities in the mine will cope with the task of water removal.

But water supply of the enterprise became an issue. And later an option of water supply from the deep well dewatering was worked out.

One of the option of the alternative source of water supply was accepted the option of draining the ore body no.1 by the method which had proved effective at the sixth ore body where pumped water was used for the needs of water supply of the enterprise. However, close proximity of borehole chosen by the authoring team to refuse heap did not allow to hope for high quality of water and to use it as drinking water.

An exploratory well at the indicated area was drilled and it showed high productivity but a small (about 10-15 meters) remaining layer of the aquifer. Observations for a short period showed gradual decrease of the water level and a complete chemical analysis confirmed bacterial pollution. Considering the absence of infrastructure in the direct proximity from the well (water duct and etc.) and a small water seam, it was decide not to drill an industrial well at this area. Moreover, a tendency for level decrease connected with both development of the first ore body and the influence of drainage of the sixth ore body showed decrease of risk of flooding during mining works at this area.

In this regard, a decision was taken to continue choosing alternative sources of water supply, which at present the authoring team keeps doing being a part of Department of Geomechanics at the Institute of Mining, the Ural Branch of the Russian Academy of Sciences together with geological and hydrogeological service.

Based on the performed investigations confirmed by practical implementation of the results at the Mining Works, it was possible to draw the following conclusions.

4. Conclusion

As a result of the performed work, there was an attempt to solve two tasks: on the one hand, the risk of mine flooding at the beginning of development of the ore body was brought down to a minimum and on the other hand, there was a possibility of deep well dewatering due to moving of water supply wells beyond the area of possible deformation of rock massif away from mining works.

However, as the results of implementation of the chosen approach showed, the task of water supply due to aquifer correlated with karsted limestone massif lying in the roof of the ore body was not simple. As the results of development of the ore body showed, despite moving water supply point beyond the area of possible influence of deformation processes, during mining works and water drainage into mine workings, karsted channels and voids allowed to flush the channels filled with clay, thus decreasing the water level in the wells lower than it is possible to sink the pump.

In addition, water intake from the well no.6 keeps operating but the level decreases gradually. The matter of water supply should be solved with the help of wells located outside the affected area of depression pit from mining works being performed at present, but it will lead to additional expenses for arrangement of water conducts and other infrastructure as well as for additional exploration works.

As far as the first task put before the present investigation is concerned, it was solved entirely. The main aquifer lying above the ore body was processed by four dewatering wells up to the level of dynamic inflows. At present, the full-fledged work is in progress to develop the reserve of the ore body with minimum risks of mine flooding due to which the ore body was on long suspension.

In conclusion, it should be noted that the competent comprehensive approach to the issues of drainage of mine workings, whether it is a mine or an open-cut mine, can significantly reduce capital
expenditures for arrangement of dewatering from the mine workings and increase safety of mine
development of natural resources and, if possible, use the pumped water for the enterprise needs up to
drinking water supply.

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