PREDICTION OF FISSURE-KARST WATER INFLOWS INTO MINES BY SIMULATION

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ABSTRACT

The prediction of water inflows into mines was carried out at a deposit composed by Paleozoic karstic carbonate rocks. Water content of the deposit depends on the following natural factors typical of karst regions: a river runoff portion being absorbed by a karst rock mass; high water content of a fissure-karst aquiferous complex; horizontal and vertical variability in filtration properties of water-saturated rocks. All this was took into account in development and substantiation of an analog model of hydrogeological conditions of the studied area under natural environments, as well as in the process of their changing under mine-working impact.

A series of inverse and predicted problems was solved using the results of prospecting and developing works, observations of ground-water levels and regime of water inflows into the mine. Hydrogeological parameters of karst water-bearing complex and predicted water inflows into the mine being under different ways of its protection from ground-water infiltration were estimated. A series of hydroisohypse maps reflecting different stages of depression-cone formation, as well as maps of ground-water table amplitudes during large water inflows into the mine and river floods were used for these purposes.

The further development of the deposit to the depth of more than 500 m has confirmed reliability of the predictions made. The predicted perennial-, annual- and maximum monthly means (13,15 and 22 ths m^3/h relatively) were proved; the forecasting the drop of ground-water table by more than 100 m and the predicted assessment of forming suffosion-karst processes were substantiated as well. As a result of this a large collapse sink in overlying loose sediments was formed.

The changes in hydrogeological environment of the deposit and the region as a whole occurred under technogenous impact made, in their turn, the conditions of mine watering more complicated. Increase in the gradient of fissure-karst water flow triggers large water inflows into mine workings, particularly during floods at the near-located rivers. The long-term hydrogeological predictions grounded on analog or mathematical models of rather difficult conditions in karst regions are the basis for solving problems of management of water inflows into mines, drainage water resources and impact of deposit dewatering upon geoenvironment.

Description of the deposit

The prediction of inflows into mines was carried out at an ore deposit in an arid zone of Kazakhstan when the depth of mine workings there amounted to 300 m and was to be doubled in a few years. Water storage of the deposit occurring in piedmont is high as it is composed by Paleozoic carbonate karstic rocks associated with fissure-karst water-bearing complex. To the south of the deposit the Paleozoic water-bearing complex is submerged under a Mesocenozoic sandy-argillaceous rock mass with a confined Cretaceous-sandstone water-bearing complex at its basement.

High water content of carbonate rocks is provided for by an intensive recharge of fissure-karst water by infiltration in the mountain part of the region. The subsurface runoff of 10 m^3/s is formed by precipitation in the zone of formation of the depression cone around the mine. Near the mine it is followed by water infiltration (to 1-2 m^3/s) in the karst rock mass from two rivers with seasonal runoff (chiefly during spring flood). A characteristic feature in this case is that the direction and discharges of filtration fissure-karst water flow in the area of the deposit are variant and controlled by tectonic dislocation and rock karsting changing with depth (to 700-750 m), as well as by the formation of highly permeable steeply dipping karst zones widely spreading along tectonic-dislocation planes.

Pecularities of deposits in karst regions

The deposit under study is typical of hard mineral deposits located in karst regions. Deposits in these regions essentially differ in their hydrogeological conditions from those in other regions, which is due, above all, to hydrographical and hydrogeological pecularities common to areas of karst-forming. Such pecularities include, in the general case, intensive absorption of surface water and high water content of karstic rocks below ground-water table. This is attributed to high and, commonly, rather irregular rock permeability resulting from origination of surface and underground karst forms. Pecular combination and manifestation of the above-mentioned pecularities depend on geographical and geologic-structural conditions of pecular karst regions and deposits.

Surface-water absorption is observed in all areas of karstic rocks occurring over erosion entrenchments. In mining process this fact promotes watering of mine workings; contribution of surface water to water-inflow forming assumed to be rather essential here. Near large rivers 90% of water inflows into mine workings may be accounted for as river water.

Mine working below the local draining base level increases, in its turn, surface-water absorption which stimulates processes of suffosion and evacuation of the filler out of karst hollows into mine workings. Within period of deposit development these processes reach the earth surface. The quantity of surface karst forms increases by a factor of tens, numbering in some cases hundreds of funnels per 1 km^2. Commonly, these processes end ultimately with large surface-water inflows into mine workings.

High water content of karstic rocks manifests in forming watery aquifers. In this connection, deposits located in areas of water-bearing karstic rocks are generally highly flooded. At the same time, due to the intricate distribution of karstic fissures and karst hollows, as well as due to the variability of their shapes and sizes, the watering of mine workings is rather irregular. Water inflows into mine workings at either sites of the deposit may change from negligible to large water breakthroughs amounting to a few tens of thousands m^3/h.

Considerable inflows or even breakthroughs of ground water into mine workings occur as a consequence of the opening of large fissures and karst hollows under high hydrostatic heads of ground water, as is the case during developing deposits in karst regions. Water breakthroughs occur generally as a result of washout of a filler in colmatated fissures and hollows, some time after they are disturbed by a mine working. Hence evacuation of aqueous sandy and clayey material into mines may be a forecast of intensive water inflows.

Combination of the above-mentioned high water content of karstic rocks and absorption of surface water causes great seasonal and perennial fluctuations of water inflows into mine workings in accordance with hydrological and meteorological factors.

Distribution and amount of water inflows into mine workings depend mainly on filtration inhomogeneity of water-bearing karsting rocks in plane and section.

Studying a role of the plane inhomogeneity in forming water inflows into mine workings established the great influence (on them) of linear high-permeability zones in combination with chaotically inhomogeneous filtration properties of rocks which are due to irregular development of relatively small fissures and karst forms.

Formation of high-permeability zones is related to local karstification along large dislocated breaks, rock beddings, erosion area, etc. This results, under suitable conditions, in high anisotropy of filtration properties of karstic rocks. Ratio between permeabilities across and along rock bedding or linear zones reaches 1:100. Position and high filtration properties of the zones considered, filtration coefficients of which may be equal to a few hundreds of m/day, greatly influence on the structure of filtration flow of ground water. Their wide spreading, comparable to areas of disturbed filtration regime around mine workings, allows the sizes and configuration of these zones not to be ignored in studying the formation of water inflows by simulation.

Karstic rocks of deposits are characterized, besides inhomogeneity in plane, by changes in permeability in section (in vertical). General regularity of decrease in karstification and permeability with depth has at hard mineral deposits different manifestations. It shows, in general, an exponential dependence but at some deposits it is well approximated by a sloping line. Karsting and permeability of rocks in the upper zone of active weathering of carbonate sediments of the studied deposit increase firstly with depth, intensively decreasing after maximum values has been reached in the depth inteval 100-200 m. However in some local zones high permeability occur to a greater depth.

Decrease in permeability of karstic rocks with depth essentially affect formation of water inflows into mine workings. It reduces the rate of water inflows into deepening mine workings and increases the quantity of residual water columns over them, making safe dewatering of rock masses more difficult.

Results of simulation

The above typical features of deposits in karst regions, common to the studied deposit as well, were taken in simulating its hydrogeological conditions. Geologic-tectonic studies of the deposit under exploration, the results of drilling and mining works, the data on recharge and discharge of fissure-karst water and hydroisohypse maps of a water-bearing complex were the basis for the development of a planar analog model of the natural hydrogeological conditions of the region.

Substantiation of the model was carried out as a result of inverse problem solution on the network analog computer: the fissure-karst free and piezometric water surface (in the south of the deposit) was simulated through the refinement of transmissivity of the water-bearing complex.

At the further stage the planar model of a nonstationary filtration flow of fissure-karst ground water was developed using the results of perennial observations of ground-water regime and water inflows into the mine under the conditions of intensive withdrawal of water from the mine-working system (100 mln. m^3/yr. in average). The final substantiation of this model for a large region (4000 km^2) was carried out following the solution of a series of inverse problems, firstly - for the central perfectly studied part of the region, and secondly - for the region as a whole. Giving the known regime of water inflows into the mine and using for control the data on the regime of ground-water levels, the dynamics of filtration flow under the conditions of development of a deep and extended depression (tens of kilometers in radius) of fissure-karst water levels was simulated on the model.

The success of this simulation was predetermined by a preliminary integrated study of the information obtained during long-term exploration and production of the deposit. A great attention was payed to the determination of filtration inhomogeneity of the karstic rock mass in section and plane, systematization of perennial data on regimes of ground-water levels in close relationship with the nature and regime of water inflows into the mine, with mine works progress.

A series of maps was compiled reflecting changes in the regime of ground-water levels at the sites of different rock permeability with seasonal increases and decreases in the levels by tens of metres, as well as with sharp decreases in the levels due to the development and drainage of the zones with high water storage yielding several thousands of m^3/h by mine workings.

Superimposition of maps enabled the delineation of the main linear karst zones accounting, to a considerable extent, for the direction and amount of inflows into the mine as their permeability was by 2-3 orders of magnitude higher than that of the surrounding rocks.

Predictions carried out on the model with allowance for the changes in rock permeability with depth and transference of ground-water drainage to the deep designed aquifers to the depth of 500 m allowed to determine future inflows and the area of formation of the cone of depression. In particular, its extention in piedmont amounted to more than 50 km.

Average values of water inflows into the mine for a few years amounted to 13 000 m^3/h, and the maximum annual average - to 15 000 m^3/h. The maximum monthly average inflows (22 000 m^3/h) were determined with allowance for the changes in annual precipitation in the area of piedmont and significant variations in water inflows into the mine with the seasons of the year.

Reliability of predictions

The prediction of inflows was entirely proved in the course of the further development of the deposit. Actual water inflows into the mine reached the predicted ones, but with no exceeding them.

A reliable simulation on the analog model of the hydrogeological conditions of the region and, in particular, filtration inhomogeneity of the karstic rock mass enabled an assessment of hydrodynamic efficiency of dewatering and waterproof measures. The model describes the influence upon water inflows into the mine: of drainage underground structures with different locations near the deposits, cementation of high-permeability zones, isolation of river beds. It was important for the mine protection from water inflows, as well as for solving problems of water supply as mine pumping-out was the only essential source of water supply in arid piedmont plain. Simultaneously with mine workings dewatering, water resources should be preserved as much as possible.

The prediction of development of depression cone was proved. According to the predicted estimates, the ground-water level in the central part of the depression cone decreased by more than 100 m with the further development of depression along piedmont. Fissure-karst water levels throughout vast territory in the south of the deposit dropped below the piezometric table of the Cretaceous water-bearing complex advanced here and throughout considerable area - below its bottom. This enabled water travel out of the Cretaceous sediments into the Paleozoic carbonate complex having formerly recharged the Cretaceous complex.

The prediction of existing the deep water zone of long-term curculation, determined by tracer studies, is believed to be proved. Anyhow, water-bearing fissures and karst hollows occur in mine workings to a considerable depth (about 700 m) and show, after washing-out of the clayey filler, significant water content. The southern trend of the depression indicates the ground-water leakage from Paleozoic strata underlying a thick Mesocenozoic rock mass of a piedmont plain penetrating to a depth of several hundred metres.

As it was supposed according to the establishment of high-permeability karst zones, suffosion-karst processes at the deposit progressed. They reached the day surface, resulting in formation of a large collapse sink. These events are associated with the highly karstic zone of tectonic disturbances in the area between the mine and the river valley. This zone was formerly characterized as a high-permeability one through which ground water in large amounts (thousands of m^3/h) moves to the mine.

In general the forecasted estimates of changes in hydrogeological conditions of the deposit with depth of mine works were proved within the predicted period. These processes go on progressing and require the further controlling.

CONCLUSIONS

Analysis of the conditions presently formed at the deposit enables an important conclusion concerning the development of new conditions of mine watering attributed to the hydrogeological environment changed under impact of mine workings, in particular concerning the complication of hydrogeological and mining-geological conditions of mine works. It results from periodical initiation of steep gradients of ground-water flow owing to great depths of mine workings and existence, near the mine, of rivers with seasonal runoff. Level differences amount to a few hundreds of metres presenting a risk of sudden inflows of fissure-karst water with large yield. The further measures of mine protection from ground- and surface water, dewatering, water supply, etc., are required to be continued. In this context, the combination of drainage systems constructed in the area of appoaching ground water to mine workings, isolation or removal of river beds and pumping-out of residual water inflows into mine workings is effective and economical for deposits in karst regions.

The long-term predictions of changes in hydrogeological conditions of vast territories using quantitative analysis of hydrogeological information on computers in combination with other methods are rather grounded and reliable. They represent the basis for solving problems of water resource management, development of measures to prevent water inflows into mine workings and to reduce a negative impact of deposit dewatering upon geoenvironment.

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