Soviet Engineering Geology 1988 (1) S. 51-56

Plotnikov, I. I. (1988): Method of protecting mineral deposits in karst rocks from inundation. – Soviet Eng. Geol., 1:51–56, 1 Abb.

ISSN 0895-6324

METHOD OF PROTECTING MINERAL DEPOSITS IN KARST ROCKS FROM INUNDATION

I. I. Plotnikov

Inzhenernaya Geologiya, No. 1, pp. 59-65, 1988

UDC 624.131

Discussed are the conditions of application of various methods of protecting mines which reveal karst aquifer horizons from inundation by river discharge and ground water; a) organization of river runoff in water-impermeable channels; b) diversion of rivers beyond ore-enclosing karst rocks; c) use of underground water-impermeable screens to protect mines from inundation; d) use of drainage systems to protect mines from inundation. A flow chart has been developed for drainage systems of the cascade type which are based on filtration inhomogeneity and a decrease in rock permeability with depth. Determined are their effectiveness and the conditions and region of application in developing deep horizons of deposits in karst rocks.

The main factor complicating the development of ore fields in karst rocks (northern and southern Ural and northern Onega bauxites, Mirgalimsai and Gorevskii polymetals, Leningrad and Baltic schists, etc.) is their high degree of inundation. For example, in developing the Blinovo-Kamenskii and Kurgazak deposits (SUBR) the influx of water into the system of shafts exceed 7000 m^3/hr, in developing the Cheremukhovskii bauxite deposit (NUBR) it was 12-13 th. m^3/hr, and in shafts of the Mirgalimsai mines the maximal water influx reached 50 th. m^3/hr.

The main sources of inundation of mines are rivers feeding aquifer horizons, which form up to 90% of the volume of the drainage of the mines. Modeling and analytical calculations established that in developing northern Ural bauxites at a depth of 500-600 m without isolation of the Sos'va, Vagran, Kolonga, and Kal'ya Rivers, which are located at distances of 0.5-2 km from mines, the mean annual isolation of the rivers would be 18 th. m^3/hr. In developing the Novo-Toshemka and Perminskii bauxite deposits (Ivdel region) at a depth to 600 m the water influx into shafts without isolation of the Toshemka, Man-Tosem'ya, and Ivdel Rivers may reach 50 th. m^3/hr. Even more significant water influxes are expected upon development of the Gorevskii polymetal deposits located along the Angara R. Thus, the main problems of developing deep-seated deposits in karst rocks are related to the protection of the shafts from inundation due to river runoff.

There are four methods of isolating river water: 1) organization of river runoff in channels with a water-impermeable cover; 2) diversion of rivers beyond the karst aquifer horizon; 3) construction of water-impermeable screens in the karst aquifer horizon; 4) construction of drainage systems between source of inundation (rivers) and mine fields.

The first method is implemented in the SUBR (Kamenka R.) and the NUBR, where the runoff of the Vagran, Kolonga, Sarianaya, Kal'ya, and Cheremushka Rivers is carried in canals with a ferroconcrete cover for a total length of 49 km. After inauguration, hydraulic structures excluded total river runoff with a discharge of ~50 th. m^3/hr from the shaft water diversion. However, due to activation of undermining karst processes under the influence of the draining of the deposits there is destruction of the ferroconcrete casing of the canals, accompanied by catastrophic absorption of river water (up to 35 th. m^3/hr in the Vagran R.). The frequency of collapses of ferroconcrete casings depends on the size of the canals. During 20 years of use there were 30 collapses in canals to 40 m wide (9.2 collapses in 1 m), 1.1 in 1 km in those to 30 m wide, and 0.56 collapses in 1 km in those to 15 m wide. Collapses were not established in canals up to 8 m wide with a throughput capacity of up to 12 m^3sec. To eliminate hazardous situations in canals with a high water throughput capacity (more than 200 m^3/sec) regular reservoirs and standby canals were constructed on a rocky base, which greatly increased the capital expenditures for the construction of a water protection system.

Thus, the first method can be recommended for small rivers having a drainage basin area (F) of up to 250 km^2 or medium rivers (F to 2000 km^2) if they cut through karst ore-enclosing rocks for a limited distance.

The second method, the diversion of rivers beyond a karst aquifer horizon which inundate an ore field, is partially implemented in the NUBR and is discussed in planning the development of the Gorevskii lead-zinc deposit. It excludes the possibility of destruction of hydraulic structures under the influence of undermining processes, but its realization involves significant material expenditures. For example, the cost of diverting the Sos'va and Shegul'tan Rivers from the northern Ural baxuite deposits exceeds 500 million rubles, and the implementation of the project extends for four decades. Expenditures for diverting the runoff of the Ivdel and Ai Rivers (SUBR) are comparable with the previous estimate. Thus, this method ensures more reliable water protection, but may be realized only under favorable geomorphological conditions.

The third method, creation of subsurface water-impermeable barriers, is proposed for protecting the Cheremukhovskii and Sos'va bauxite deposits (NUBR) from inundation by the runoff of the Sos'va and Shegul'tan Rivers. Its essence amounts to the artificial break in the continuity of the aquifer horizon with the aid of plugging aquifer fracture and karst systems by cement or clay-cememt solutions. Water-impermeable barriers are placed between the shafts and sources of their inundation. Most favorable for their construction are linear geological structures of limited width, thickness, and homogeneous water conductivity. In karst aquifer horizons plugging was applied in construction of the bores of shafts and foundations of hydraulic structures [1,2,6], where the effectiveness of the method was determined by the density of the network of plugging boreholes which ensure completeness of exposure of the aquifer systems.

The effectiveness of application of the method in the NUBR in karst aquifer horizons, which have a significant width (more than 2-3 km), thickness (more than 300-400 m), high and inhomogeneous water conductivity (more than 3000-5000 m^2/day), depends on successful solution of the following problems.

1. The aquifer horizon is penetrated by karst channels filled by loam and clay material; their volume reaches 60% of the total karst of the rocks. Karst forms filled by clay material are inaccessible for plugging solutions. After construction of a water-impermeable barrier the continuity of the aquifer horizon is destroyed, and the difference in the pressure head of the ground water in its upper and lower reaches may be 300 m, which leads to intensification of karst undermining processes in the body of the dam. Investigations established that the eroding rate of lithological varieties of the filler of karst cavities ranges from 0.3 to 0.5 m/sec. Decompacted easily eroded material in which the undermining process begins at gradients of more than 0.05 fills the karst forms located in the upper part of the geological structures (to a depth of 90 m) adjacent to river valleys. Far from river arteries and at a depth of more than 90 m the filler of karst forms is represented by compacted clay material in which undermining begins at gradients exceeding 0.2. At gradients higher than 3.2 the filler acquires quicksand properties and instantaneously penetrates mines or open karst cavities. These processes are accompanied by an increase in the permeability of the aquifer by 5-10 times. To prevent undermining a water-impermeable barrier about 1500 m thick is necessary; when it is less than 94 m thick it is possible for the filler to flow instantaneously from karst cavities with the formation of open channels in the barrier itself. We should remember that in the upper area of karst aquifer horizons to a depth of 60-90 m the porosity of the rocks exceeds 10-20%, whereas in the depth interval of 100-300 m it averages about 2%. Under these conditions the expenditures for plugging solutions for the construction of one barrier may exceed 1.0 billion rubles, which is hardly acceptable in terms of economic considerations. The solution of this problem is seen in the development of methods of consolidation of the filler of karst systems.

2. The karst massif is penetrated by open karst channels which are the main conductors of ground water. The total volume of such channels in the depth interval of 100-300 m does not exceed 0.4%, but the throughput capacity of one channel with a pressure head of 300 m reaches 30-40 th. m^3/hr. In constructing water-impermeable subsurface barriers we must reveal each karst channel by a plugging borehole. This problem can be solved by increasing the density of the network of plugging boreholes to 0.5 × 0.5. The recommended network has been tested in plugging rocks in the Kal'inskii karst zone of the NUBR during the cutting of the Yuzhnyi ventilation bore of the Cheremukhovskii mine, but its application in construction of a water-impermeable barrier with dimensions of 300 × 1500 × 400 m will lead to unacceptable expenditures (more than 7 billion rubles). To solve the eco-

nomic problems which arise we must develop cheap, reliable methods of discovering open karst channels in an aquifer horizon at a depth to 400-500 m with the subsequent plugging through directional boreholes. Only in this case do there appear prospects for lowering the density of the network of plugging boreholes by a factor of 70-80. However, existing methods (seismoacoustic, Gregor radiotest, etc.) have not been tested under the discussed conditions. Thus the application of water-impermeable barriers in karst aquifer horizons to protect mines from inundation by subsurface and river runoff is held back by factors of a technical and economic nature. Only after development of cheap reliable methods of detecting karst channels at a depth of 400-500 m and decreasing the cost of plugging solutions by 10-15 times (2-3 rubles/m^3) may water-impermeable barriers find wide application in protecting mines developed in karst rocks from inundation.

The fourth method, protection of deposits from flooding by special drainage points situated between the sources of inundation and ore fields, has been tested in the development of bauxite deposits in Hungary and in the northern Urals region. Drainage points consist of water-lowering boreholes equipped with immersible pumps. Five drainage points operate in the northern Urals bauxite fields, including 100 water-lowering boreholes with a working diameter of 500 mm and a depth to 400 m, equipped with ETsV-16-175K and ETsV-14-210-300 pumps [4]. Investigations have established that the effectiveness of this method of water protection is determined by the distance of the fields from the sources of inundation, depth of mines, magnitude of water conductivity, and filtration inhomogeneity of the aquifer horizon. In general, in deposits bedded in inhomogeneously karsted ore-enclosing rocks with a mean water conductivity of 800-5000 m^2/day at a depth of more than 300 m, the optimal conditions for the application of the method arise when the ore fields are located more than 5 km from rivers with practically unlimited water resources. However, in protecting mines at a depth greater than 500 m from influxes of water, which reach 30-40 th. m^3/hr, expenditures for constructing drainage points of the conventional type may exceed 80-90 million rubles, and exploitation expenditures may reach 10-15 million rubles a year. Therefore, to increase the effectiveness of protecting deep-seated deposits from inundation by river and subsurface runoff under the discussed conditions it is advisable to apply drainage systems of the cascade type.

In planning drainage systems of the cascade type we use data which characterize the decrease in karst, fracturing, and water conductivity of the water-enclosing rocks with depth. Therefore, in exploring mineral deposits we must establish not only qualitative, but also quantitative variations in the permeablility (fracturing, karst) of rocks with respect to depth with substantiation of the general principles of the conditions of variability of hydrogeological parameters. For the conditions of the Gorevskii deposit Ponomarenko established that the decrease in the permeability of rocks with depth is approximated by an exponential dependence [5].

In detailed exploration and industrial development of bauxite deposits of the Urals it was established that the decrease in karst (K_k) with depth (H) is approximated by regressive equations of five types: 1) $K_k = aH + B$; 2) $K_k = a\lg H + B$; 3) $1\lg K_k = aH + B$; 4) $\lg K_{kl} = a\lg H + B$; 5) $K_k = a + bH + cH^2$, where a, b, and c are the parameters of the regressive equations. Different types of variability of karst and permeability with depth determine the difference (by a factor of 5-10) in the regimes of the decrease in water conductivity, and water yield of the aquifer horizon in the process of draining it.

The effect of a decrease in the influence of karst on the dynamics of the ground water is strengthened by the inhomogeneous distribution of karst aquifer systems in map view. The coefficients of variation (C_v) which characterize the filtration inhomogeneity of the aquifer horizon increase with a decrease in water conductivity (KM), width (B), and increase in length (L) of the aquifer horizon (band-bed type). This relationship is approximated by regressive equations of the logarithmic type:

$$\lg C_v = 1,8798 - 0,4784 \lg KM, \quad r = -0,78;$$
$$\lg C_v = 0,8477 - 0,3176 \lg L, \quad r = +0,77;$$
$$\lg C_v = 0,7894 - 0,3842 \lg B, \quad r = -0,76.$$

It is established that the filtration inhomogeneity of karst rocks increases with the increase in their bedding depth. The variability of the parameter of the aquifer horizon is the reason for the development of increased filtration resistances in it, which appear at different hypsometric levels in the form of weakly permeable rock units which influence the distribution of the actual velocity of the ground water with respect to the depth of the aquifer horizon. In drainage of rocks before the crest of such natural

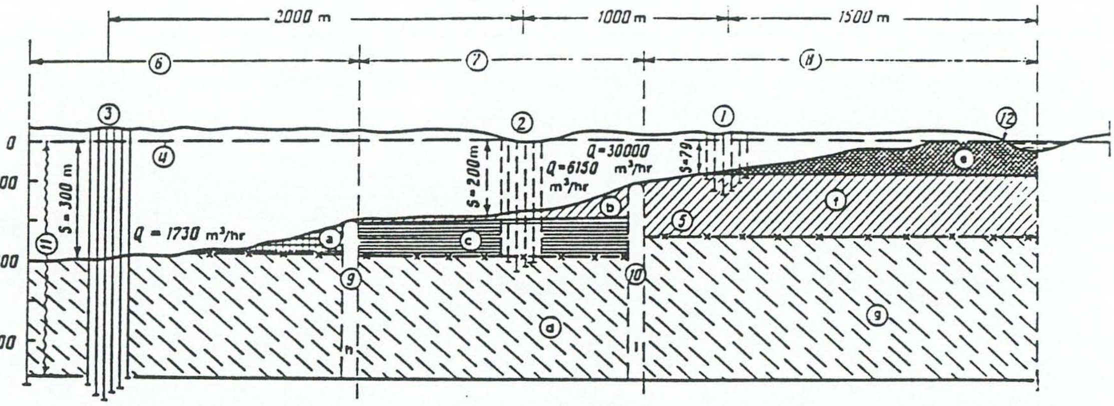

Fig. 1. Diagram of drainage system of cascade type in northern area of NUBR: 1) head drainage point; 2) central drainage point; 3) lower drainage point; 4) static level; 5) boundary of subzone of interrelated karst; 6) southern filtration block; 7) central filtration block; 8) northern filtration block; 9 and 10) weakly permeable barriers; 11) boundary of mineralization area; 12) valleys of Sos'va and Shegul'tan Rivers; 13) parameters of variation of water conductivity (KM) with respect to depth: a) KM = 5400 m^2/day; b) KM = 825 m^2/day; c) KM = 425 m^2/day; d) KM = 203 m^2/day; e) KM = 6620 m^2/day; f) KM = 1992 m^2/day; g) KM = 825 m^2/day; h) KM = 160 m^2/day; i) 250 m^2/day; Q = 30,000 m^3/hr is the productivity of drainage points of the drainage system.

subsurface dams in which the karst level is ≤0.18%, there are breaks in the continuity of the aquifer horizon, accompanied by the stabilization of the water influxes into systems of mines [3]. However, such breaks coincide with the boundaries of geological tectonic structures, but they are established within them as well when the water-enclosing rocks have a high filtration inhomogeneity (C_v > 150%). In this case, the amplitudes of the breaks in the levels exceed 300 m. This is a reason why under conditions of the NUBR up to 80% of the productivity of karst aquifer horizons is related to them by the upper part of the water; it is pumped out by drainage points from a mean depth of 196 m with mines 700-1400 m deep and karst rocks more than 1800-2000 m in total thickness.

The established principles are used to substantiate the method of protecting mines from inundation by river and subsurface runoff by drainage systems of the cascade type, which consist of 2-3 drainage points (head, central, and lower) located in sequence between the source of inundation and the protected mines. The drainage points, which consist of water-lowering boreholes or drainage shafts, are usually positioned in front of barriers of weakly permeable rocks. Prospecting criteria for the latter may consist of high values of the coefficients of variation which characterize the filtration inhomogeneity of lithologically homogeneous rocks (C_v < 150%), decreased values of their karst content (≤0.18%) and water yield (<0.04), calculated by intervals for different transverse cross sections of the aquifer horizon. However, in placing drainage points we must consider critical values of the ground water gradients, at which there is an increase in the water conductivity of rocks under the influence of undermining processes in the aquifer horizon. In particular, in the area of the aquifer horizon adjacent to the source of inundation (between the river and the head drainage point), the projected gradients should not exceed 0.05, and within the central and lower drainage points they should be lower than 0.2. Consequently, in cascade water decreases in steps of up to 100 m the distance between the head drainage point and the river should be more than 2000 m, and between the head and central drainage points it should be at least 500 m. In this case, the depth of the water-lowering boreholes (drainage shafts) and water decreases will be determined by the hypsometric position of the crest of weakly permeable barriers. The water decrease should be anticipated before the crest, but the drainage work must be extended below the crest by the value of ΔH, within which the revealed aquifer systems provide total discharge of the water by means of the pumping equipment installed in the borehole (shaft). In karst rocks ΔH usually does not exceed 100 m.

In the presence of three or more barriers with different hypsometric positions of their crests in the aquifer horizon the optimal placement of drainage points is based on economic calculations, in which the main parameters are the cost of constructing drainage points (capital expenditures), which depend on the depth and productivity of the water evacuation. It is advisable to use modeling to evaluate the productivity of the drainage at a given depth of water lowering at the boundary of the shaft field for different versions of positioning of drainage points.

A drainage system of the cascade type is recommended for protection of the northern part of the northern Ural bauxite basin from inundation by runoff of the Sos'va and Shegul'tan Rivers, which are 4.5 km from the boundaries of the bauxite deposits (Fig. 1). Research has established that an aquifer horizon of the band-bed type, adjacent on the north to a mineralization area, breaks down into three structural hydrogeological subdivisions, which are characterized by high water conductivity (KM) and a decline in the permeability (K) with depth: the southern rocks (KM = 5400 m^2/day, K declines from 26 m/day to 9.6 m/day at a depth of 300 m), central block (KM = 3900 m^2/day, K declines from 81.0 m/day to 2.75 m/day at a depth of 275 m), and northern block (KM = 8697 m^2/day, K declines from 87.1 m/day to 3.9 m/day at a depth of 200 m). In this case an increase in the filtration inhomogeneity of rocks with depth is established. The coefficients of variation of rock permeability for 10 transverse cross sections of the aquifer horizon were C_v = = 0.76 in the interval of 0-100 m, C_v = 1.90 in the interval of 100-200 m, and C_v = 2.42 in the interval of 200-300 m. Established in depth intervals with increased values of C_v are weakly permeable barriers in the southern and central filtration blocks, which are characterized by water permeability of KM = 160 m^2/day and KM = 250 m^2/day, whose crests are located respectively at depths of 170 and 130 m (Fig. 1).

Modeling established that if the drainage point is located in the southern block near the boundary of the mines, the water influx into the drainage system is about 36 th. m^3/hr from a depth of 300 m. The capital expenditures for construction of the drainage system may reach 100 million rubles, and exploitation expenditures exceed 12 million rubles a year. If a drainage system of the conventional type is created in conjunction with diversion of the rivers and construction of water-impermeable channels, the residual influx of water is about 18 th. m^3/hr. In this case, according to the estimates of the All-Union Planning, Surveying, and Scientific Research Institute and the VIOGEM the capital expenditures exceed 500 million rubles, and the actual periods of implementation of water-protection measures are about 40 years.

In implementing a drainage system of the cascade type the drainage is distributed among the points in the following manner: head 30 th. m^3/hr from a depth to 100 m; middle 6000 m^3/hr from a depth to 180 m; lower 2500 m^3/hr from a depth to 300 m. The effectiveness of a drainage system of the cascade type is much higher than conventional due to the decrease in the method of depth of drainage, which ensures a decrease of not only exploitation expenditures for drainage (from 12 million rubles to 3.5-4 million rubles), but also capital expenditures for construction of drainage points (from 100 million to 25-30 million rubles) due to the decrease in the depth of the drainage work, simplification of the design of the water-lowering boreholes, etc.

Drainage systems of the cascade type may find application in protection of deep-seated mineral deposits from inundation, which are confined to karst rocks (Boksitovyi deposits of the Urals, Mirgalimsai and Gorevskii polymetal deposits, Bererznyakovskii and Solikamsk potassium salt deposits, etc.). Thus, with optimization of methods for protecting deep-seated mineral deposits in karst rocks from inundation we must consider not only the boundary conditions of the aquifer horizons, but also their structural features: filtration inhomogeneity and variation of permeability with depth. In the presence of medium and large rivers near mines, flowing for a significant distance through karst ore-enclosing rocks, the most reliable and effective method of protecting mines from inundation is the combination of drainage systems of the cascade type with the diversion of rivers or organization of river runoff in canals with a water-impermeable covering. In this case, under the discussed conditions the problem of isolating the river runoff is its removal from the boundary of the industrial mineralization to a distance at which in the process of water-lowering we prevent the development of ground water gradients which intensify undermining processes causing an increase in the water conductivity of the aquifer horizon.

REFERENCES

1. G. I. Man'kovskii, "Battling karst water in mining construction," Shakht. Str-vo, no. 1, 1959.
2. G. I. Man'kovskii, Special Methods of Construction of Mine Bores [in Russian], Nauka, Mosocw, 1965.
3. I. I. Plotnikov, "Features of the development and drainage of mineral deposits in carbonate karst massifs," Gorn. Zhurn., vol. 7, pp. 10-13, 1974.
4. I. I. Plotnikov, E. S. Gorev, and N. M. Gulemin, "Principles and methods of protecting mines from indundation," Ibid., no. 2, pp. 12-16, 1984.
5. Yu. V. Ponomarenko and N. A. Gogoleva, "Features of hydrogeological calculations of drainage devices in fractured rocks," in: Materials of Methodological Conference [in Russian], Belgorod, 1968.
6. M. V. Rats, Imhomogeneity of Rocks and Their Physical Properties [in Russian], Nedra, Moscow, 1968.

30 September 1986

Northern Urals Geological Exploration Expedition