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GEOCHEMISTRY

The Hydrogeochemical Structure of Water Bodies in Flooded Openings of Coal Mines

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Removal and drainage of mine waters and their spontaneous flow from flooded openings of coal mines cause intense, mainly chemical pollution of the environment.

The hydrogeochemical characteristics of such water bodies are poorly studied, which prevents forecasting the consequences of spreading of mine waters and determination and realization of effective nature protection measures.

This paper describes investigation of important data on the presence of water of various compositions in coal mines liquidated by the “wet” method and on the heterogeneity of the hydrogeochemical structure of underground water bodies.

These data were obtained during the monitoring studies in Eastern Donbass, particularly in the single-layer flooded Komissarovskaya Mine. We registered the significantly contrasting nature of mineralization and composition of water in different areas of the mine system.

Thus, in 2011 the dry remnant of water flowing from holes 58 (depth 45 m) and 9083 (depth 163 m) located 2.9 km from each other was 3.2–3.4 and was 8.4–12.5 g/dm^3; the concentration of sulfate ions in the water is 1.3–1.7 and 6.9–8.3 g/dm^3; iron, 2–3 and 180–374 mg/dm^3. In 2010 the dry remnant was 3.1–3.4 and 8.4–14.8 g/dm^3; the concentration of sulfate ions in the water is 1.3–1.7 and 5.4–8.4 g/dm^3; iron, 2.1–5.3 and 215–534 mg/dm^3, respectively. Such a difference of indicators results from vertical heterogeneity of the water composition.

The correctness of such a conclusion is evident from the results of monitoring of the composition of water flowing from paired holes 8993 and 8994 (from April 2000 to July 2001, until liquidation of holes), the mouths of which are located 1.5 m from each other. These holes are located 0.2 km from Hole 58; they are vertical and have the same depth and construction and similar geological section and uncover the water body in flooded openings at the same depth (~200 m).

In the period when the level of mine flooding did not yet reach the surface, the water in Holes 8993 and 8994 was fresh. Self-flowing of holes started from a short release of fresh and then saline water. After 8–10 days, we registered a quite strong increase in the dry remnant (it exceeded a total of 15 g/dm^3) in the concentration of some components in the composition, in particular sulfate ions and iron. Such dynamics of the composition may be explained by the location of poorly mineralized water at the surface of mineralized water (Fig. 1) and uplift of their boundary in the course of mine flooding.

Periodical sampling of Holes 1862 (from 2001), 9092, 9093, 9118, and 9115 confirms the appearance and preservation of a “cap” of poorly mineralized water, the product of infiltration of meteoric and river waters. Analogous hydrogeochemical zonation is known in some other flooded mines.

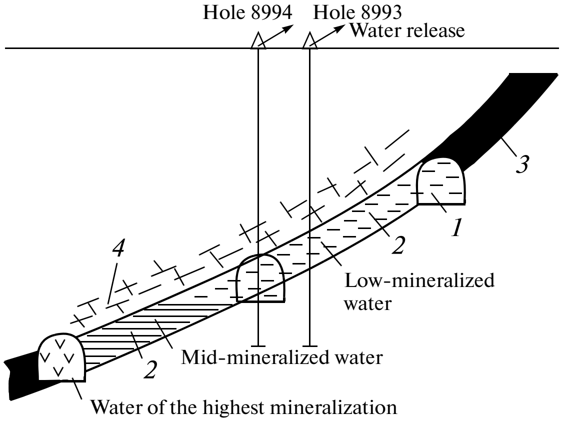

Fig. 1. Scheme of distribution of mine waters with different mineralization in the flooded Komissarovskaya Mine (in section) (April, 2000). (*1*) Main and development openings filled by the most mineralized water; (*2*) gob space filled by mid-mineralized water; (*3*) coal pillars; (*4*) water-transporting fractures.

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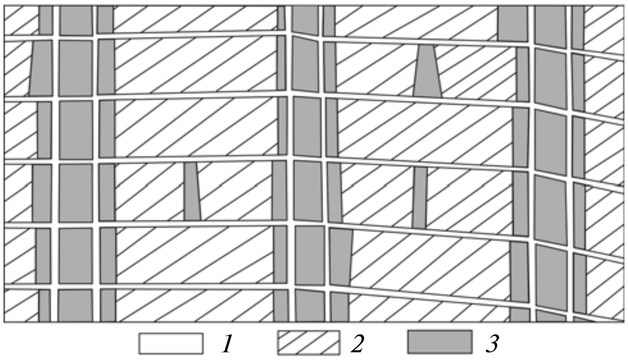

Fig. 2. Scheme of distribution of mine waters with different mineralization in the underground cavity space of the mine (in the layer projection). (*1*) Main and development openings filled by the most mineralized water; (*2*) gob space filled by mid-mineralized water; (*3*) coal pillars.

Sampling at different points of the considered water body allowed us to establish the presence of an areal hydrogeochemical heterogeneity as well.

The most contrasting was the composition of water flowing from Holes 8993 and 8994. Thus, the value of the dry remnant and the concentration of sulfate-ions and iron (almost entirely represented by the divalent form, g/dm^3) provided the following dynamical series: in water of Hole 8993 6.54, 4.42, and 0.3 (April 13, 2000), 1.1, 0.46, and 0.17 (March 14, 2000), 12.1, 7.3, and 0.07 (May 5, 2000); Hole 8994, 17.9, 10.4, and 0.21; Hole 8993, 14.4, 9.6, and 0.07 (November 23, 2000); Hole 8994, 17.1, 12.3, and 0.41; Hole 8993, 16.8, 10.2, and 0.25 (May 15, 2001); Hole 8994, 18.8, 10.5, and 0.41, respectively. The value of differences in the concentrations ranges from tens to hundreds of percents and provides evidence for a real contrast in the water composition. Note that the mineralization and sulfate and iron content in mine water are much higher than at the stage of mine exploitation.

The composition of water in Hole 8993 and the number of holes uncovering the water body in other parts of the mine field below the "cap" of low-mineralized waters are in contrast as well.

The stability of the weight concentration of chloride ions in mine water at a low level is a sign of its formation from underground waters of shallow horizons.

Oxidation of sulfides in the mine mass is considered as the reason for the appearance of high-sulfate waters. Their formation in the Komissarovskaya Mine is favored by a high (up to 12%) concentration of pyrite sulfur in coal. Most likely an active role belongs to tionic bacteria, the presence of which was registered by the bacteriological analysis. These bacteria, as it is known, may provide a very high rate of transformation of elements composing sulfides into solution.

Water of Hole 9083 (depth 160 m; flow of water "captured" in openings from May to July 2001, with mineralization increasing to saline) had until 2011 inclusively and Hole 1862 (depth 230 m) had until the end of 2000 a dry remnant and the concentrations of sulfate-ions and iron comparable with water of Holes 8993 and 8994.

Note that the mouths of Holes 9083 and 1862 are located 2.9 and 3.6 km from Holes 8993 and 8994 and 0.7 km from each other.

Significant differences in the water composition are controlled by capture of adjacent hydraulic and hydrogeochemical water masses by these holes. One of them, filled by the most mineralized water is located in the system of unextinguished and partly extinguished development and main openings (uncovered by Holes 9083, 1862, and 8994), and the second one, in the gob of longwalls and minor water-transporting fractures (captured by Hole 8993).

Thus, the distribution of water accumulations with different characteristics is controlled by the peculiarities of the structure of the technogenous cavity created by mining and has a lattice–sectorial character in the layer projection (Fig. 2).

The reasons for the formation of such peculiarities of the hydrogeochemical structure of the water body are evident from the increase in the dry remnant and the concentration of sulfate ions and iron together with an increase in the debit of self-flow of Holes 8993 and 8994 up to 45 and 90 m^3/h, respectively.

As characteristics of the hydrodynamic environment, the debit of holes reflects the mobility of water flow in the drained object. As it is evident from the relationships between the debits of Holes 8993 and 8994, the most highly mineralized and, at the same time, high-sulfate and high-iron waters filled maximally permeable parts of the cavity space, exactly development and, for Hole 1862 main, openings. The contrasting character of the composition results from the strong differentiation of water exchange in different parts of the mine reflected in the rate of sulfide oxidation and washing out of inhibiting products of oxidation from the sulfide grain surface by water.

Water drainage provided or strengthened the hydrogeochemical individuality in these accumulations. This may also favor certain leveling of differences in the mine waters, for example, under the conditions of water inflow in the mine from several sources.

A direct relationship between mineralization and the velocity of transport of underground waters is not consistent with the known ideas on the inverse character of such a dependence. The deviations discovered are controlled by the appearance of favorable conditions for transformation of oxidation products into solution, as well as for their accumulation due to involvement of high pyrite contents in the formation of water composition and continuation of oxidation of mineral particles in the flow.

Radical weakening of the contrast in and stabilization of the water composition occurred by the end of the third month of flowing in Holes 8993 and 8994 against the background of convergence of flow debit. Stabilization (after 6 months of self-flow) was also registered for Hole 9083 (at the level of 14–15 g/dm^3); later the tendency toward a decrease in the mineralization (up to 9–12 g/dm^3) and concentration of the considered components in water was gradually developed.

These tendencies are signs of an increase in sulfide leaching in the path of water flow. Weakening of the contrasting water composition, as well as debit of Holes 8993 and 8994, also points to approvement of water exchange between two water accumulations in these holes and flowing in the gob space under the influence of rock suffusion. Its active development is evident from the significant concentration of suspended materials in the water.

The decrease in differences in the composition of water in holes points to the tendency of leveling of the composition of mine waters in the mine systems over large areas. We may assume that analogous mechanisms occur under the conditions of mining of less sulfurous coals.

More complex is the pattern of distribution of water indicators in multilayer mines, in which of special importance is the problem of water exchange between the parts of the water body. The different composition of water in mines in different layers (groups of layers) is typical. In addition, its homogenization may be developed, for example, under the influence of water removal.

This is observed even under the conditions of significant inflow of waters of anomalous composition, as this occurs in Glubokaya Mine, where chloride water with mineralization up to 75 g/dm^3 was coming in from rhyolite dykes during exploitation. After termination of intense removal of water from the mine, we should expect accumulation of highly mineralized chloride waters and the appearance of a clearly expressed layered hydrogeochemical structure, mainly in the lower layers.

The balance estimations for the Glubokaya and Komissarovskaya mines demonstrate a decrease in the portion of deep chloride waters in the total water inflow into the mine system in comparison with the period of exploitation, most likely as a result of afflux of their source by the water body.

Heterogeneity of the water composition in the flooded cavity space determines the variability of threats and risks by different directions from the mine during removal and spontaneous flow of mine waters.

The conclusions of this paper may be applied for prediction of the characteristics of mine waters, preparation of projects of mine liquidation, preservation of different objects, and hydrogeochemical monitoring in this relation.