HYDROGEOCHEMISTRY OF THE IRKUTSK BASIN AND QUALITY OF COAL

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ABSTRACT

The paper presents peculiarities in the chemical composition of ground waters in the Irkutsk coal basin in close relation to the tectonic regime of the territory. Analysis of the specific material have shown, that recent hydrogeochemical zonation is to a great extent (according to the prevailing development of individual zones) inherited one. The unizonal chlorid-sodium type of a hydrochemical section is proved to exist within the coal basin before Eopleistocene. A recent complex differentiated hydrogeochemical section was formed only in Pleistocene. Conditions for forming the main qualitative indices of coals - caking property and sulphur content - are analysed and their dependence on the chemical composition of ground waters, entering from Cambrian sediments during the Jurassic depression formation is revealed. The leading role of the organic matter is noted in the transformation of the chemical composition of ground waters at all the stages of the coal basin existence. The evidence is made of interrelations between the chemical composition of ground waters and quality of coals in different structural elements of the artesian basin. All these facts promote the directional search of water and coal of the presumed quality.

Irkutsk coal basin belongs to a platform lymnetic type. It is situated at the south-west of the Siberian platform and extends along the East Sayan and Primirsky Ridge as far as 500 km. Tectonically it is a piedmont trough of the Jurassic age. The basin has external and internal wings. The internal wing adjoins the piedmont and represents itself a linear extended aggregation of foredeep depressions with the thickness of Jurassic sediments up to 700 m. The external wing is more wide and sloping, but the thickness of coal-bearing sediments is less, it is about 40-100 m (Fig. 1).

Fresh-water coal-bearing series, composed of conglomerates, sandstones, aleurolites and coal rakes occurs on Paleozoic rocks mainly of Cambrian age. These rocks are some-

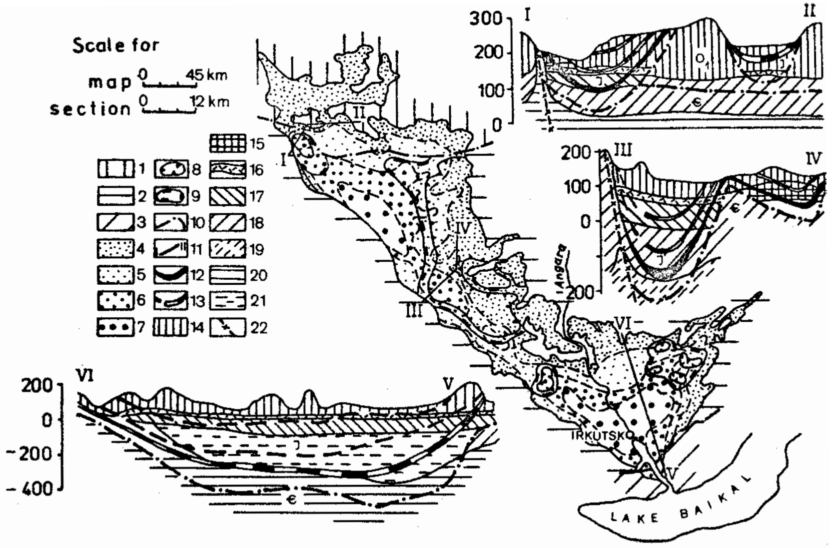

Fig.1 Distribution scheme of coal sediments and sulphur content in coals.

Rocks, underlying the Jurassic coal sediments: 1– Ordovician, sandy-clay; 2– Cambrian, terrigenous-carbonate, with gypsum; 3– pre-Cambrian, erupted. Thickness of coal-bearing sediments: 4– less than 100 m, 5- 100-200 m; 6- 200-400 m; 7– more than 400 m. Contour of workable coal seam distribution: 8– more than 4,5%; 9– 2,5%, 10– stratigraphic boundary; 11– section line, coal seams; 12– with high sulphur content (more than 2,5%); 13– with low sulphur content (less than 2,5%). Chemical composition of ground waters: 14– hydrocarbonate alkali-earth; 15– hydrocarbonate-sulphate, sulphate-hydrocarbonate alkali-earth, ferrous; 16– hydrocarbonate alkali-earth ferrous (glay); 17– hydrocarbonate-sodium; 18– sulphate calcium; 19– sulphate-sodium-calcium; 20– chloride, hydrogen-sulphur; 21– chlorid sulphateless, methane.

times heavily plustered. At the extreme north-west of the basin the pre-Jurassian bed is composed of Ordovician sandy-clay non-plustered deposits.

According to the availability of essential coal seams, Jurassian deposits are divided into three series: subcoal, coal and overcoal. Workable coal seams tend to the basement of the middle rock mass. In its remaining part the coaly substance is in abundance, but forms mainly thin layers and scattered material. The thickness of coal-bearing sediments and stratigraphic volume of suites is rather changeable. Moreover, overcoal and partially coal rock masses and the external wing of the basin are washed-off. Therefore, the workable coal seam occurs at the depth from 20 to 450 m.

Jurassic rocks are mainly outcrop, that stipulated the abundance of phreatic waters. With the growth of coal-bearing sediment thickness the number of aquifers increases up to 6-7. As a rule, they contain pressure waters with similar piezometric levels and only in the vicinity of the contact Y/€ the pressure in the subcoal rock mass increases by 20-30 m.

Irkutsk artesian basin, unlike the adjacent hydrogeological structures, has a peculiar hydrogeochemical outlook. First, it is characterized by the predominant development of chlorid saline waters in the considerable part of the basin and by the complex structure of the zone of hydrocarbon waters. It should be noted, that in the river valleys and in the zones of disjunctive and plicative dislocation chlorid waters reach the surface even if the thickness of Jyrassian rock mass is 400-500 m.

The presence of sulphate and chloride waters in the fresh-water sediments definitely indicates the paramount influence of the overflow from underlying Cambrian rocks. The development field of the Ordovician normal sea deposits in the Jurassic section consists, as a rule, only of hydrocarbon hydrogeochemical zone (see Fig. 1).

It is evident, that the existing type of hydrogeochemical zonation of Jurassic sediments is to a great degree inherited one. Its evolution is closely related to the tectonic regime of the territory. Regarding its main stages, we can affirm, that in the course of the Jurassic sediment accumulation the separation boundary of fresh and saline waters continuously migrated upwards. During this period the development of chlorid, rather than sulphate waters, prevailed. The zone of fresh hydrocarbon waters played a subordinate role and had low thickness. In the post-Jurassic period, up to the initial phase in the main stage of neotectonic movements, when the uplift was balanced by denudation, the hydrochemical section was practically unizonal, that is chlorid-sodium. In fact, this type of tectonic regime stipulates the vertical stability of hydrochemical boundaries (Shenkman, 1985).

The start of differentiation in the unizonal hydrochemical section coincided with the Eopleistocene stage of the relief formation. During this period the recent morphostructure of the Irkutsk amphitheatre was almost completely formed. As to the present-day hydrogeochemical structure of the basin, it was formed in Pleistocene. The morphostructure of the studied territory was formed during this period. Further development of the hydrogeochemical zonation was in parallel with the territory uplift and the deepening of the river-bed erosion. Due to this fact the hydrogeochemical boundaries moved downwards along the section. Accordingly, the upper zone thickness (hydrocarbon waters) was increasing and its structure was gradually becoming more complex. The subzone of soda waters, that was a buffer between fresh and saline waters, appeared.

Thus, in the historic development of the basin one can single out three stages, that differ in hydrogeochemical conditions. The length of these stages is considerably different. The shortest one is the recent period, during which the upper hydrodynamic and hydrogeochemical zones were formed. The coal-bearing seams within these zones are most completely studied. It was noted, that the specific features in the chemical composition of ground waters (Table 1), i.e. high concentration of the carbonic acid, ferrum and manganese, wide-spread occurence of the soda and glay waters, are to a great extent due to the previous hydrochemical conditions.

The overall view of these conditions is given above. One can definitely state, that with the deepening of the Jurassian depression, salination of chlorid waters increased. A very long period of time (Cretaceous period, Neogene, Paleogene) was evidently characterized by stable hydrochemical regime. Therefore, at the stage of the unizonal hydrochemical structure existence the period of the Jurassic depression formation is the most interesting one.

During this period rather heterogeneous geochemical conditions were evidently developed on the background of the uniform chemical type of ground waters. Different rate of the downwarping, reflected in the variable thickness of the coal-bearing sediments, indirectly proves that. But the most complete information on the paleogeochemical environment can be obtained from coal seams.

From this viewpoint the caking property of coal is the most valuable feature. According to the present-day views, it is acquired at the peat and lignite phases of coal formation. It should be noted, that the maximum caking property of coals is observed at the final stage of their formation. Beyond this stage it is not produced and can only be reduced. Decrease of caking property is either due to coal weathering, or occurs during the process of their metamorphism (Zabramny, 1959). The degree of caking capacity, in turn, depends on coal reduction, which is conditioned by the petrographic com-

Table 1. Hydrogeochemical zonation of the Irkutsk coal basin (averaged data).

	Chemical composition of water	pH/Eh	Salination	Content of mg-equ/l				Content of mg/l			
				HCO_3/CO_3	SO_4/Cl	Ca/Mg	Na	K/F	Mn/FeII	H_2S/NH_4	O_2/CO_2
Hydrocarbonate	alkali-earth (oxygenous)	7.0/+400	0.5	6/0	0.3/0.2	4/2	0.5	1/0	0/0	0/0	6/15
	alkali-earth (ferrous)	6.8/+80	0.6	7/0	0/0.1	4.5/2	1.0	1.5/0.5	0.2/12	0.5/0.3	0/50
	Sulphate alkali-earth (ferrous)	6.5/+120	1.6	10/0	13/0.2	14/7	2.0	2/1	0.3/20	0.5/0.5	0/150
	sodium	8.5/+20	0.7	9/0.3	0/0	0.3/0.2	8.5	1.5/2	0/0	0/1	0/0
Sulphate	calcium	7.0/+200	2.5	2/0	34/0.5	29/5	1.0	3/2	0.05/0.1	0/0	1/25
	sodium-calcium	7.0/+120	3.0	2/0	38/3	20/8	15	5/1.5	0.1/0.05	0/0	0/25
Chloride	sodium (sulphateless methane)	7.0/-50	5.0	0/0	0/50	0/0	50	3/2	0.5/1.0	0.3/3	0/15
	sodium (hydrogen sulphide)	6.7/-100	10.0	2/0	17/150	13/6	150	12/3	0.5/1.0	12/6	0/20

position, volatile matter outflow and total sulphur content. The higher coal vitrainization and the higher outflow of volatile matter, the better its reduction.

If in the sequal the acquired caking property were stable, one could follow the nature of geochemical conditions during the whole period of the coal-bearing seam formation. But actually the caking property of coal reduces. Neglecting the zone of coal weathering, its caking property, according to Hilt rule, decreases with the increase in the depth of coal seam occurrence. The loss of caking power and devolatilization depend on the degree of metamorphism. In other words, the outflow of volatile matter decreases with the increase of pressure and temperature. Thus, decrease in the outflow of volatile matter is accompanied by the increase of coalification degree.

In the Irkutsk coal basin the change of caking property with the depth does not correspond to Hilt rule. With the depth increase the degree of coalification (from C to A) also increases, and the outflow of volatile substance increases in parallel (Fig.2). The observed inversion, evidently, indicates, that the degree of coal metamorphism is rather low. Actually, the maximum thickness of Jurassian sediments does not exceed 1000 m, and rock temperature does not excede 30-40°C. Naturally, radical transformation of caking property in these conditions was impossible. Therefore, only the contrasts of the considered qualitative index were flattened. Contrasts of caking property during peat or lignite stages were, surely, much greater.

This suggests, that during the formation of a workable coal seam gradual degradation of high reduced conditions took place. Stress should be made on one peculiarity of spatial distribution of technological coal sorts for non-weathered coals. It consists in the fact that coalification is less notable than coal reduction. This is another proof of low coal metamorphism in the basin.

Sharply reducing conditions for coal formation were provided by the inflow of solutions, containing sulphates, that in turn provided the stability of relations between caking property and sulphur content. Increase in the outflow of volatile matter for non-oxidized coals goes in parallel with the growth of total sulphur content, but to some definite limits. The amount of sulphates, that provide sulphur content at the level below 2.5% was, evidently, sufficient for maintaining the required reducing conditions. Higher sulphur content (up to 8% and more) is due to epigenetic pyrite.

High sulphur content is mainly connected with the workable seams of the lowest stratigraphic position. Upwards the section sulphur content sharply falls up to 2.5, and further - up to 0.5%. This type of vertical sulphur distribution is observed everywhere in the subcoal layers whose thickness is less than 80 m. For a larger thickness the sul-

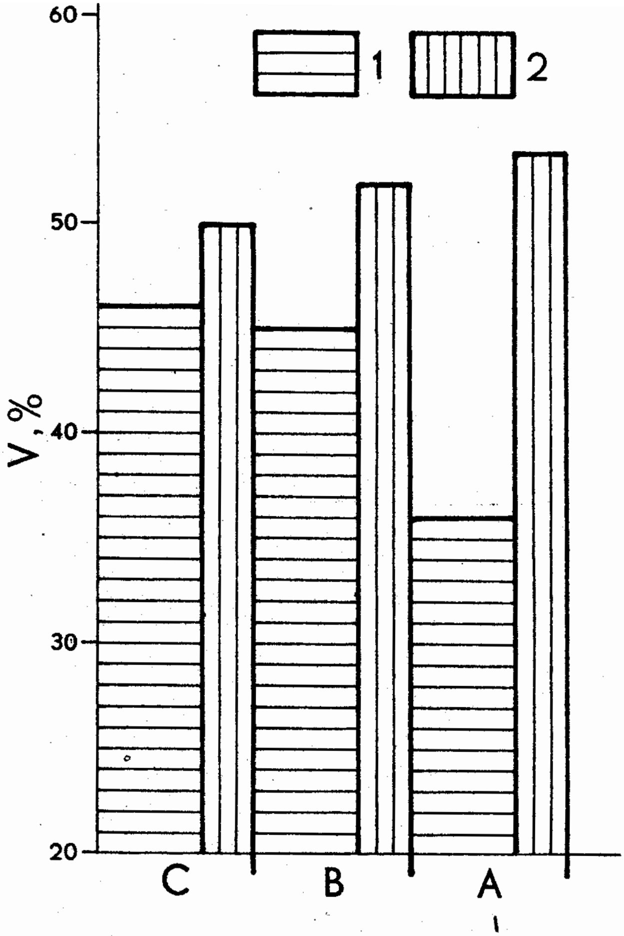

Fig. 2 OUTFLOW OF VOLATILE MATTER (V) AND TECHNOLOGICAL GRADES OF COAL.

1 – average value over the USSR basins; 2 – Irkutsk basins; A – fat coal; B – gas coal; C – candle coal.

phur content does not exceed 2.5%. It is evident, that peculiarities in the behaviour of total sulphur content and caking property are rather close. This similarity is due to the fact, that growth in the sediment thickness enhanced the isolation of peat layers of higher stratigraphic levels from the sulphate source. This conclusion is valid for all the stages of sulphur formation (Fig. 3).

The generalized graph presents two maximum stratigraphic levels, above which the coal with high sulphur content is absent. These levels are extremely low and hardly reach 70 and 40 m. In the former case subcoal sediments are presented by sandstones and conglomerates, in the latter case - mainly by clay and clay breccia. The character of the cumulative frequency curve deserves special attention. Highly screened rocks are characterized by the prevalence of coals with low sulphur content, and weakly screened rocks - by prevalence of coals with high sulphur content. Both cumulative frequency curves affirm the decisive role of the subcoal mass penetrability.

It is evident, that some samples of coals with low and high sulphur content show high and low content of total sulphur, respectively. On the whole, this fact relates to the horizontal filtering heterogeneity, stipulated by the facial variability of rocks. At the same time there are through vertical zones with high penetrability. According to salination (up to 10-15 g/l) and chemical composition of the water (sulphate-chloride), waters of deep horizons enter the surface through a 400-500 m thickness of coal-bearing sediments.

During circulation hydrogen-sulphide is produced, whose concentration at Eh=-170 mv reaches 40 mg/l. This suggests, that at present there also exist favourable conditions for sulphitization.

Occurrence of the sulphate-reduction process mainly at low stratigraphic levels resulted in the considerable transformation of the initial sulphate-chloride waters. Chloride waters with low sulphate concentration and noteworthy hydrogen sulphide content (Table 1) occur, as a rule, within the coal series, where sulphate-reduction is almost completed. Therefore, in the coal series there are mainly chloride sulphateless waters saturated by methane, with small amount of hydrogen suphide and Eh=+20 mv.

Methane accumulation indicates, first of all, that the sulphate-reduction is gradually damping upwards. Actually, final metabolism products of sulphate-reducing bacteria are the initial substratum for methane-producers (Borzenkov, 1980). During methane production the solution alkalization (unlike the sulphate-reduction) takes place, and, as a consequence, $CaCO_3$ precipitates. It may be concluded, that predominant development of the secondary carbon-bearing cement above the workable coal seams is due mainly to this process.

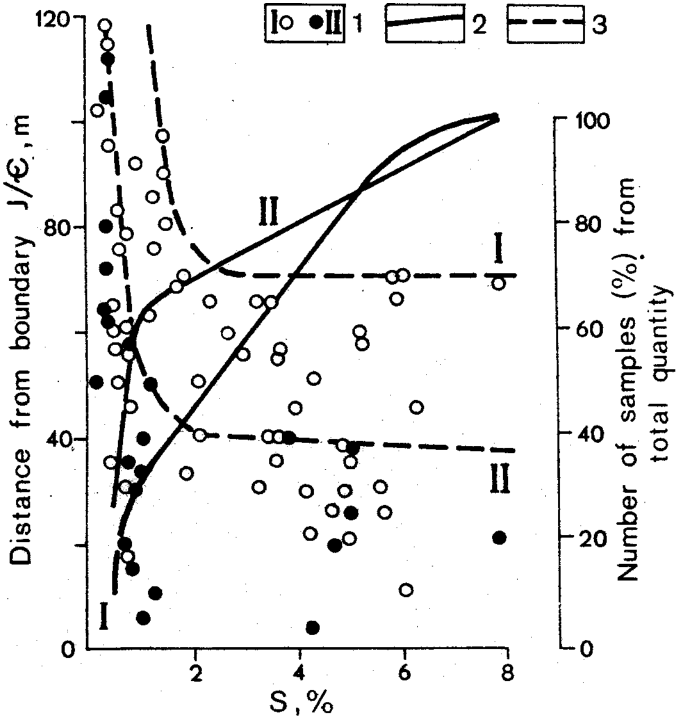

Fig.3 SULPHUR CONTENT OF COALS AT DIFFERENT POSITION OF A COAL SEAM OVER THE ROOF OF PALEOZOIC ROCKS

1-vertical position of control points; 2-cumulative frequency curve of sulphur content; 3-an envelope curve of the area of sulphur existenee;
Province of the subcoal sediment development:
I-fluvial fraction (sandstones, conglomerates); II-weathering crust (clay, breccia).

It is not an accidental fact, that this part of the hydrogeological section is low watery and has a distinct upper hydrogeochemical boundary.

When thickness of the coal-bearing sediment is more then 150 m, soda waters occur on the sulphate and especially chlorid waters. Their position in the hydrogeochemical section is quite definite. During existence of the mono-zonal type of a hydrochemical section the absorbed continental complex was substituted by the sea one. With the start of neotectonic movements the absorbed complex was newly rearranged. The process of soda production was stimulated by humic acids, incoming from weathering zones, that extracted calcium from the solution in the form of humates. As to hydrodynamics, soda waters occur at the border of zones with active and slow water exchange. Their reserves are rather large, but their resources are limited. Discharge of these waters in the valleys of large rivers is traced only on the weak piezominima. The subzone of soda waters is one of the most typical elements in the hydrogeochemical section of coal-bearing sediments.

In the zone of intensive water exchange, where the main volume of subsurface drainage is concentrated, fresh and subsaline (up to 3 g/l) hydrocarbon, hydrocarbon-sulphate and sulphate-hydrocarbon alkali earth waters are developed. Within the drainage influence of small catchment areas (up to 1000 km^2) the presence of hydrocarbon (0.5 g/l) oxygenous waters with low content of carbonic acid is observed. Fluorine, ferrum, manganese and ammonium form of nitrogen are absent. In this part of the section extreme oxidizing conditiond predominate. At the same time the oxidation process of the organic matter is rather intensive. Therefore, at the depth of 50 m oxygen concentrations fall to a zero. Oxidability (permanganate and bichromate ones) also grows with the notable vertical shift and at the basement of the layer CO_2 content is rather high. Carbonic acid accumulation indicates, that the process of organic matter oxidation reached the stage of the partial decomposition of humic acids. Thus, coal oxidation in the subzone of hydrocarbon oxygenous waters reached the phase of humic acid extraction.

In the expansion field of coals with low sulphur content under hydrocarbon oxygenous waters, hydrocarbon waters also occur, but with high concentration of bivalent ferrum, manganese and carbonic acid. Fluorine appears, oxidability slightly reduces. Geochemically they are typically glay waters. The reducing conditions prevail in the aquifer owing to the fact that oxygen is absent and potential-setting elements are presented mainly by ferrum and manganese. Glay waters are developed throughout the area of Jurassic sediments, except for the regions, bounded by an isoline of coal with sulphur content of 2.5%. The aquifer thickness does not, evidently, exceed 20-30 m, but it has contrasted upper and lower hydrogeochemical bounds.

In the areas, where coals with high sulphur content (more than 2.5%) occur in the oxydation zone, the subzone of

Table 2. Hydrogeochemical zonation and coal quality.

ROCK		Thickness of coal-bearing sediments, m	150			150-350			350			
		Depth of workable coal seams, m	100			100-250			250			
		Total sulphur content, %	1.0 - 6.0 and more						6.0-1.0 and less			
		Coal grade	L	C	B6	C	B6	B13	B6	B13	B17	A
WATER	Hydrocarbone	alkali-earth, oxygenous	+	+	+	-	-	-	-	-	-	-
		alkali-earth, ferrous	+	+	+	-	-	-	-	-	-	-
		sulphate, ferrous	-	+	+							
		sodium				+	+	-	+	+	-	-
	Sulphate	calcium		+	+	+	+	+				
		sodium-calcium				-	+	+				
	Chloride	sodium, sulphateless							+	+	+	+
		sodium							+	+	+	+

A - fat coal; B - gas coal, C - candle coal; L - brown coal. The number at "B" denotes a height of coke button.

hydrocarbonate oxygenous waters is either suppressed, or disappears. It is substituted by mixed sulphate-carbonate waters with salination of up to 2.5 g/l. Unlike the hydrocarbonate-gypsum waters the presence of FeII (up to 100 mg/l), Mn (up to 2 mg/l), carbonic acid (up to 450 mg/l) and a lot of magnesium is traced. Oxygen is absolutely absent, a small amount of H_2S appears. On the whole, as compared to the "soft" humic acids, the subzone is characterized by deep reprocessing of coal-bearing sediments by H_2SO_4. It should be noted, that despite high sulphur content, caking coals are absent here.

The thickness of this subzone may reach almost 100 m. As a rule, it occurs immediately on the subsaline sulphate waters.

On the whole the Irkutsk coal basin is characterized by binary zonation of the hydrogeochemical section: either HCO_3-Cl, or HCO_3 - SO_4, with the prevalence of the former type. Both types reflect the lytofacial heterogeneity of the pre-Jurassic bed.

Study of the Irkutsk coal basin confirmed the existence of different hydrogeochemical conditions, each having workable coal seams. Relations in the water/rock system from the geochemical viewpoint are rather peculiar. Therefore, there is a rather good spatial conjunction between the chemical composition of water, coal quality and its sulphur content (Table 2).

Sign "+" in the table denotes the conjunction of coal quality and chemical composition of water; "-" denotes the absence of the corresponding coal quality; an empty square means, that the hydrogeochemical zone is not developed.

Interrelations between the chemical composition of ground waters and coal quality in different structural elements of the artesian basin is evident. Such conjunction has high forecasting potential for the directed search of water and coal of presumed quality, especially in the insufficiently studied areas of the coal basin.

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