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TECTONIC FACTORS OF IMPURITY ELEMENTS ACCUMULATION AT THE SHUBARKOL COAL DEPOSIT (KAZAKHSTAN)

Purpose. To study the features of the paleotectonic development of the area and to construct paleotectonic reconstruction of the deposit formation to establish the nature of impurity elements accumulation in the coals and enclosing rocks of the Shubarkol deposit, as well as to increase the mineral resource potential of coals.

Methodology. 25 samples of coal and mudstone from the Shubarkol deposit were analyzed. The samples were studied by instrumental neutron activation analysis (INAA) at the Nuclear Geochemical Laboratory of National Research Tomsk Polytechnic University.

Findings. An analysis of geological-structural and paleotectonic formation conditions of the Jurassic coal deposit was carried. The factors of formation of coal and carbon-containing rocks enriched with impurity elements and the conditions needed for its leaching and transportation to the coal seam were analyzed. It was found that the coals in individual samples have average concentrations of Ce, Ba, Sr, Sc, Zn that are higher than the Clarke, and Sm, Ce, U, Cr, Yb, Ba, Sr, Nd, As, Sc, Zn, Eu, La in the composition of mudstone have average values that are higher than in coals, and higher than the Clarke. It was established that one of the sources of rare-metal mineralization of coals (peat) in the Mesozoic and Cenozoic times were the rock massifs of the Kokchetau uplift in the north and northwest, the Kaptyadyr, Arganatinsk and Ulutau mountains in the west. They form the chain of the Kokchetau–North Tien Shan ancient folded structure and the Central Kazakhstan (Devonian) volcanic-plutonic belt in the east. They surround the sedimentation basin and serve as suppliers of clastic material during the coal-bearing strata formation due to tectonic processes of the Mesozoic–Cenozoic time.

Originality. The paleotectonic development of the Shubarkol deposit area during the coal-bearing formation has been reconstructed. It has been established that the Sarysu–Teniz uplift in the Permian–Triassic is separated into an independent block, to which the studied deposit is spatially and genetically related. It has been established that the distribution of elements in the coals of the Shubarkol deposit is determined by the peculiarities of metallogeny, geochemistry of the framing area and the mechanisms of the elements entering the coal seams.

Practical value. A purposeful analysis of materials for the peculiarities of high concentrations of impurity elements accumulation in coal in connection with deep fault zones at the Shubarkol deposit serves as an objective justification of the possibility of their integrated use, ensuring the development of the country's coal industry.

Keywords: *Shubarkol, geology, paleotectonics, paleogeography, coal, impurity elements*

Introduction. The world studies on geochemistry and mineralogy of trace elements in coal deposits and basins have made it possible to establish [1, 2] that coals are concentrators of many valuable metals including rare and scattered ones. At deposits of lignite and hard coal of almost any age and genetic type, more complete sets of elements are found [3, 4]. The main differences are conditioned by the tectonic position of the metallogenic province, peculiarities of the geochemical specialization of the framing rocks in which a coal basin or deposit was formed [1]. Kazakhstan deposits are no exception. Kazakhstan possesses large reserves of hard and brown coal. One of them is the Shubarkol deposit. The objectives of the research are to study the patterns of increased accumulations of metals in the coals of the Shubarkol deposit; the impact of the geological environment on the levels of their accumulation; conditions of concentration and forms of being in coals, which led to selecting the object of research. The composition of the Shubarkol deposit coal is diverse; it contains various impurity elements and rare metals. The studies showed [5] that the deposit contains significant contents of Ba, Sr, U, Th, Rb, Fe, Co, Ce, Zn and Sc.

The nature of the distribution of impurity elements and geochemical specialization of coals depend on the geological and structural position of the deposit, coal accumulation and the geotectonic setting of its formation [1–3]. Its role is deter-

mined by the impact of the whole complex of factors on accumulation of impurity elements in coal-bearing formations. Accumulation of metals in coal-forming peatlands or coal seams is a delicate geochemical process that is determined and regulated by many factors, the main of which is the composition of the recharge area of the coal accumulation basin, as well as the geotectonic factor – this fact needs to be paid special attention to.

Methods. A group of 25 samples was selected from Jurassic bituminous coals and mudstones at the Shubarkol deposit. The samples of the Central and Western sections were collected by the bulk method; the sampling interval was kept within 15–35 m. The rocks of the western wing of the Central section were sampled by the pinpoint and furrow methods. The rocks of the Eastern area were sampled by the core method, the sampling interval was kept within 5–20 m. The geochemical content of coals was determined by the method of instrumental neutron activation analysis (INAA) in the nuclear-geochemical laboratory of National Research Tomsk Polytechnic University (TPU) (analyst A. F. Sudyko).

Results. According to the results of INAA, the average contents of impurity elements in the samples taken at the Shubarkol deposit (see the Table) show that oxidized coals and mudstone samples have values that are higher than the Clarke, while the contents of unoxidized coals are lower than the Clarke values for bituminous coals. Based on the analysis of the published data [1, 2] and the materials of the authors of this work, the study on the features and factors of impurity ele-

ments including REEs in coals and clay layers of the Shubar-kol deposit, was carried out by developing a paleotectonic model of the development of the Sarysu-Tenz uplift, to which the studied deposit is genetically and spatially confined.

In order to understand metallogenic features of the Shubar-kol deposit coals, let us dwell on the main aspects of the Upper Paleozoic and Mesozoic paleogeography, as well as the history of the region tectonic development using the currently published data with additions and changes by the authors of this work.

Geological-tectonic characteristic of the Shubarkol deposit. The Shubarkol deposit of Jurassic coals is located in the Nura district of the Karaganda region. In the D grade coals from the Shubarkol deposit, accumulation of rare earth metals in concen-

trations close to industrial or industrial metals [5] took place. The thickness of the coal seams reaches 330 m, forming a sub-latitude syncline with gentle (5–10 and 5–15°) and steep (from 20–48 to 40–90°) wings. In the core of the syncline, the angles of incidence of rocks do not exceed 3–5°. The geology of the field is represented by terrigenous-carbonate rocks of the Upper Devonian and the Lower Carboniferous, terrigenous sediments of the Middle-Upper Carboniferous age and loose weathering products of the Mesozoic, as well as loose sediments of the Cenozoic.

The deposit is limited by peripheral faults (Fig. 1), in which the heat flow is slightly increased. With deposits up to a few hundred meters thick, coals are represented by long-flame varieties. Coals are transitional from brown to hard ones. The

Table

Average contents of elements in the samples determined by the INAA method at the deposit

| Rock/element | U | Eu | Ce | Th | Ba | Sc | Sr | Zn | La | Rb | Fe | Co | Sm | Cr | Yb | Nd | As |
|----------------------------------|--------------|-------------|--------------|-------------|---------------|--------------|---------------|------------|--------------|--------------|-------------|--------------|--------------|--------------|--------------|-------|--------------|
| Unoxidized coals | 0.32 | 0.13 | 9.40 | 0.77 | 100.2 | 1.38 | 33.8 | 27.6 | 2.67 | 3.15 | 0.22 | 6.32 | 0.61 | 3.53 | 0.57 | 3.67 | 1.69 |
| Oxidized coals | 129.9 | 13.8 | 163.5 | 7.23 | 976.01 | 21.22 | 642.68 | 13.88 | 54.81 | 27.87 | 1.16 | 51.64 | 32.20 | 46.54 | 60.66 | 93.06 | 12.72 |
| Clarke for hard coals [6] | 1.9 | 0.43 | 23 | 3.2 | 150 | 3.7 | 100 | 28 | 11 | 18 | 1 | 6 | 2.1 | 17 | 1 | 11 | 9 |
| Mudstone | 703 | 67.8 | 333 | 6.65 | 277.0 | 289.5 | 1355 | 508 | 69.44 | 17.18 | 3.60 | 11.44 | 103.2 | 338 | 274.4 | 191.9 | 114.9 |
| Clarke for sedimentary rocks [7] | 3.4 | 0.94 | 52 | 7.7 | 410 | 9.6 | 270 | 43 | 32 | 94 | 3.54 | 14 | 5.5 | 58 | 2.0 | 29 | 7.6 |
| Minimal commercial content | – | – | – | – | – | 10 | 400 | 400 | 150 | 35 | – | 20 | – | 1400 | 1.5 | – | – |

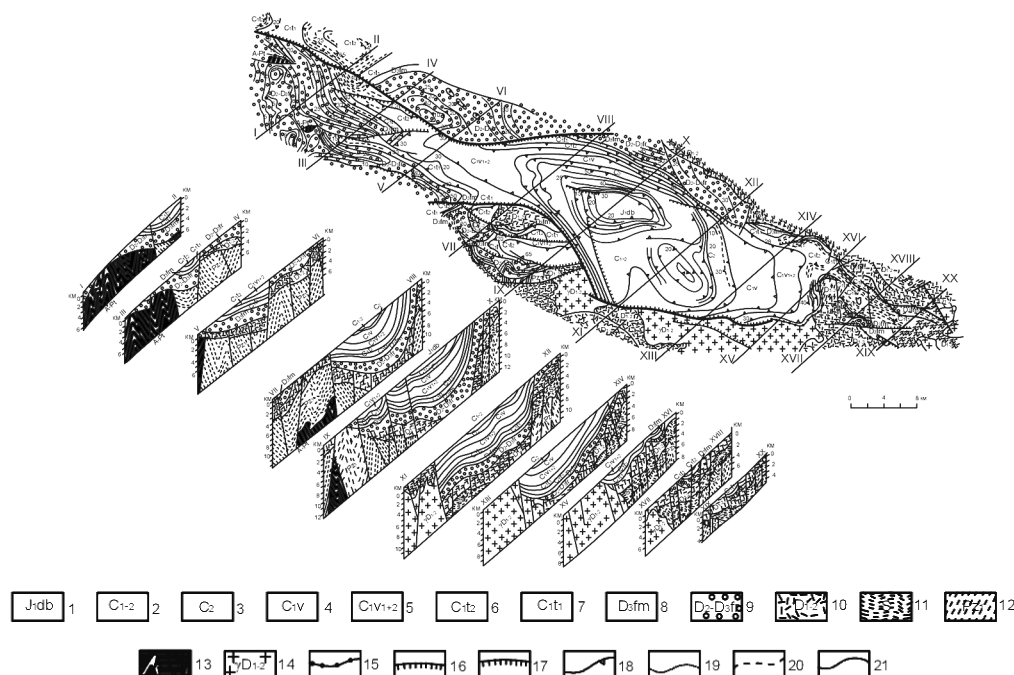


Fig. 1. Diagram of the Shubarkol graben-syncline structure (compiled by A. Ye. Mikhailov):

1 – lower Jurassic, Dubovskaya formation – red sandstones, siltstones and mudstones; 2–7 – Carboniferous system: 2 – upper part of the lower section and upper section – red-colored sandstones, siltstones and mudstones, lenses of conglomerates; 3 – upper part and lower part of the upper section – sandstones, conglomerates, siltstones and mudstones; 4 – Visean stage – limestones, sandstones, siltstones and mudstones; 5 – lower and middle substages of the Visean stage – pelitomorphic limestones, calcareous sandstones, siltstones and mudstones; 6 – Upper Turneian substage – organogenous limestones, silicified limestones, argillites, sandstones, organogenous and silicified limestones and marls; 8–10 – Devonian system: 8 – Famennian stage – pelitomorphic and organogenous limestones, sandstones and dolomites; 9 – upper part of the middle section and Frasnian stage – red-colored conglomerates, sandstones and siltstones, lenses of porphyrites; 10 – lower section – porphyrites, albitophyes, tuffs, volcanic sandstones; 11 – Silurian system – gray and green sandstones, siltstones and mudstones, limestone lenses; 12 – Lower Paleozoic – sandstones, conglomerates, limestones, volcanic rocks; 13 – Archean and Proterozoic groups – crystalline schists and gneisses; 14 – granitoids of the Lower-Middle Devonian; 15 – boundaries of regional disagreements; 16 – large breaks; 17 – small breaks; 18 – direction and angles of rock incidence; 19 – layers of sandstones and conglomerates; 20 – layers of limestone; 21 – beds of effusive rocks

studied area is characterized by a complex geological structure. To a large extent the composition of the structural-material complexes of the pre-Jurassic basement and the framing of the coal-bearing basin varies greatly. All this, alongside with the peculiarities of the paleofacial conditions of peat accumulation and the peculiarities of tectonic-magmatic processes, syn- and epigenetic coal formation determined the formation of the geochemical background of the coal deposit.

The Shubarkol deposit was formed in the inherited depression of folded areas formed on the Sarysu-Teniz uplift. The basin of the field developed over ancient sedimentary complexes that are part of the structural framework of the Caledonian accretionary-folded areas confined to the central part of the Sarysu-Teniz uplift or fault-shear zone [8], a large tectonic structure of the Western part of the Central Asian orogenic belt (CAOB).

The studied and analyzed paleogeographic [9, 10] and paleotectonic maps and diagrams [8, 11] depict the Sarysu-Teniz depression as a single basin before the Permian. At the end of the Lower Permian, one of the powerful tectonic movements of the Paleozoic occurs in the studied area, due to the collision of the Kazakhstan continent with Tarim and East-European continent. Huge continental masses, due to shear kinematics led to right-side large-amplitude displacements and shear formation in the Kazakhstan block of the composite continent, which in turn was accompanied by granitoid magmatism and mountain building representing the final stage of the Hercynian tectonic-magmatic cycle [11, 12].

According to paleomagnetic data, the East European continent reached its present position by the early Jurassic. This means that the manifestation of shear deformations that break the Kazakh Caledonides occurred during the Late Permian-Triassic [8, 13], at which time the collapse of strike-slip structures of the Central Asian orogenic belt was completed [14]. With these intense dislocations of the sub-latitude plan, the Teniz-Sarysu-Chuysky vast sedimentation basin was divided by the wide Sarysu-Teniz block uplift into two depressions: the northern, Teniz and the southern, Sarysu-Chuysky (Fig. 2), which in turn led to the formation of tectonic faults in the studied area.

The Sarysu-Teniz uplift is a large uplifted block 200 km wide and 250–300 km long. From the west it is bounded by the large

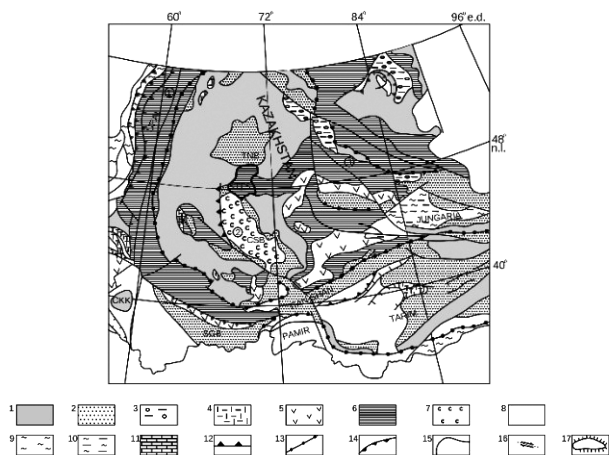


Fig. 2. Paleogeographic diagram of Central Eurasia, Early Permian according to [8] with additions by the authors:

Sedimentary basins: South Gissar (SGB), Chu-Sarysu (CSB), Teniz (TNB); blocks: Central Karakum (CKK); STFS – Sarysu-Teniz fault-strike slip zone; main faults (numbers in circles): Chelyabinsk (1), Main Karatau (2), Main Chingiz (3). Continental settings: 1 – lowlands; 2 – fluvial-lacustrine; 3 – coal-bearing; 4 – rift and orogenic volcanics; 5 – marginal-continental volcanic belts and mature island arcs; 6 – hills; 7 – evaporite basins; marine and oceanic settings: 8 – shelf; 9 – continental slope, bathyal; 10 – deep sea (black shale deposits); 11 – carbonate platforms; 12 – subduction zones; 13 – sutures; 14 – thrusts; 15 – facies boundaries; 16 – strike-slip faults; 17 – carbonate platforms

Karakengir fault, oriented in the meridional direction. Along this fault, the structures of the Sarysu-Teniz uplift are joined with the structures of the Kengir brachy-fold zone. The southern boundary of the Sarysu-Teniz uplift is the Zhezkazgan-Terekta fault. In the east, the uplift is bordered by the Atasu structures (Fig. 3). Here the largest structure can be considered the Kaindy immersion zone, which includes the Kaindy graben, Ulzhansk syncline, Tantal and Shubarkul graben synclines and horst anticlines. The zone has the northwest strike and is obliquely superimposed on the meridional structures of the Caledonian basement. The length of the zone is about 300 km, the width ranges from 20 to 40 km. To the northeast of it, faults and folded-block structures are characterized by northwest strikes, to the southwest of the zone; the superimposed structures are mainly elongated in sublatitudinal directions. Thus, the Kaindy zone is a junction of two tectonic directions. The boundary of the structure with the framing intrusive massifs (the Kokchetau-North-Tien-Shan chain of the ancient folded structure and the Central Kazakhstan (Devonian) volcano-plutonic belt) runs along shear-thrust faults. The basement of the basin consists of blocks composed of the Precambrian metamorphic rocks and volcanic rocks of the Lower and Middle Paleozoic.

The coal-bearing layers of the Shubarkol deposit were formed in the Jurassic time. Within this geological period,

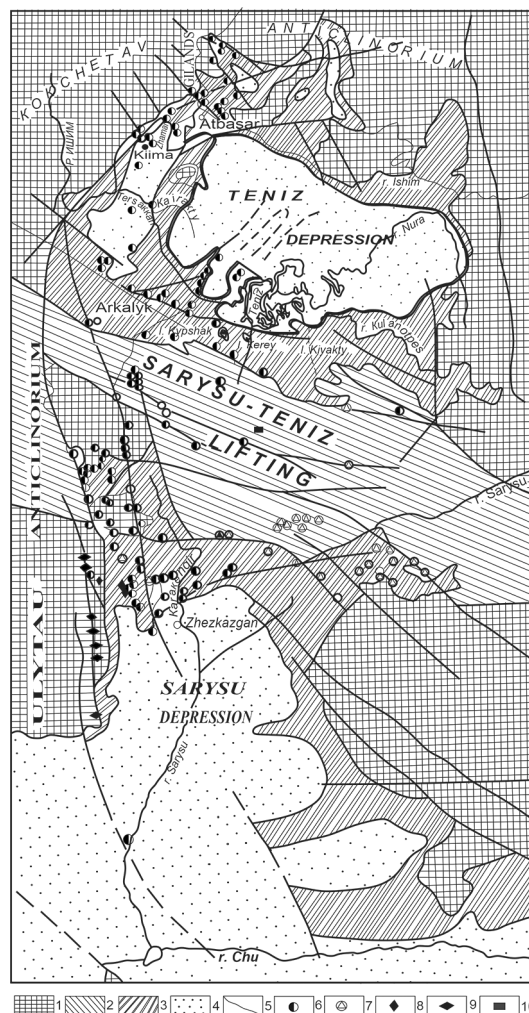


Fig. 3. Diagram of the tectonic structure and metallogeny of the western part of Central Kazakhstan according to (S. Sh. Seifullin):

1 – lower and upper structural floors; 2 – Sarysu-Teniz zone of block folds; 3 – zones of marginal brachy-fold and linear structures; 4 – depressions (Tenizskaya and Sarysuiskaya) filled with Permian sediments; 5 – breaking violations. Minerals: 6 – copper; 7 – polymetals; 8 – iron; 9 – manganese; 10 – coal

geotectonic cycles of the Kimmerio-Alpine phase occur on the territory of the Central Asian orogenic belt, which led to insignificant displacements of rock blocks of newly laid faults and old tectonic seams (Fig. 4).

It is characterized by the predominant subsidence from the Middle Devonian to the Middle Carboniferous, and the general uplift accompanied by intrusion and intense ground volcanism in the Upper Carboniferous and Lower Permian.

The area of framing by terrigenous materials feeding the basin, which carried impurity elements and REEs, were the Kokchetau uplift in the north and northwest, the Kaptyadyr, Arganatinsk and Ulutau mountains in the west, which compose the chain of the Kokchetau-North Tien Shan fold system, and the Central Kazakhstan (Devonian) volcano-plutonic belt in the east, while metals entered the basin alongside with surface, groundwater. Igneous rocks are one of the main geological factors that can cause increasing the elemental content of coal, alteration of minerals, and the precipitation of authigenic minerals from magmatic hydrothermal fluids.

The impact of geochemical features of the provenance area on geochemical specialization of coals is emphasized by accumulation of elements in coals. The deposit is enriched in Zn, Ba and Sr, which is consistent with the presence of the Atasu type (Ba-Pb-Zn) deposits nearby. Coals also contain increased amounts of Hf, Ta, Nb and Sr, the elements which are characteristic of alkaline rocks and granitoids.

Due to the formation of the collage of strike-slip structures of the Central Asian orogenic belt in the studied area, deep faults appeared in the sedimentary basin of the Sarysu-Teniz uplift simultaneously with sedimentation processes accompanied by active ore formation with the emergence of a complex range of ore concentrations which then undergo complex transformations.

The ubiquitous development of horst-graben structures, composed of Cambrian and Ordovician rocks, overlain by effusive-sedimentary strata of the Lower-Middle Devonian and Carboniferous. The cores of positive structures are often complicated by acidic intrusions. Seven graben-synclines and eight horst-anticlines are distinguished in the territory (Fig. 5), which, in our opinion, are the main routes of movement, transportation and introduction of useful substances into the formation basin of the deposit due to leaching from the basement rocks and redeposition into the coal seam with participation of groundwater. For accumulation of high concentrations of impurity elements in coals, conditions are needed for the formation of enriched coal-bearing rocks and for their leaching and transportation into the coal seam. Such conditions are realized in modern bog systems of Western Siberia and could

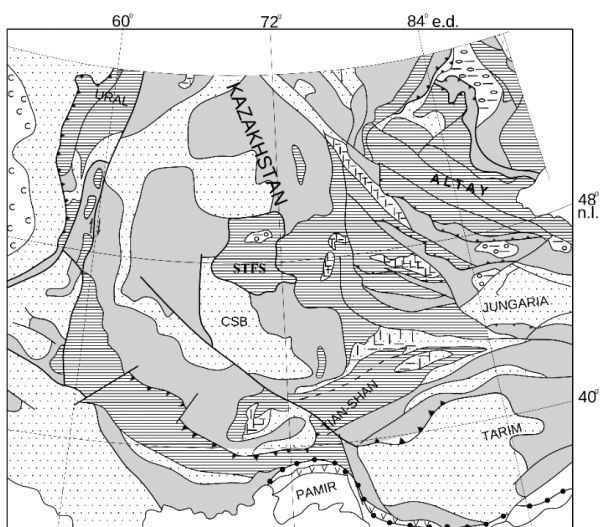


Fig. 4. Paleogeographic diagram of Central Eurasia, Jurassic according to [8] with additions by the authors (symbols in Fig. 2)

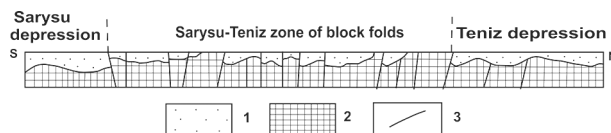


Fig. 5. Section of the Sarysu-Teniz zone of block uplifts (according to Yu. A. Zaitsev):

1 – upper structural level; 2 – lower structural level; 3 – faults

be realized in ancient basins of peat (coal) accumulation [3].

The northernmost structure of this zone of block uplifts is the Kireyskaya horst-anticline, to the south of it there are alternating the following structures: the Kagyl graben-syncline, the Kaptyadyr horst-anticline, the Tantal graben-syncline, the Bolumbayzhal horst-syncline grab, the Shubenark horst anticline, the Algabas graben syncline, the Ayrzhal graben syncline, the Karamendin horst anticline and the Terekta horst anticline, which is the southern extreme structure of the Sarysu-Teniz uplift. During the uplift of the Sarysu-Teniz structure, land areas arose that underwent denudation, weathering and other transformations with the development of hypergene processes. Here, infiltration ground and pressure hydrodynamic systems of atmospheric supply were formed, with the activity of which the formation of various weathering crusts was associated. The depth of penetration of infiltration waters of atmospheric supply was determined by the position of regional bases of erosion (drainage): that was about 100 m. The processes of migration of groundwater in the sedimentary basin of the deposit took place during the tectonic processes of the Cimmerian epoch, which were described above, as well as during the introduction of magmatic bodies into the cover of the basin, when the collage of strike-slip structures of the Central Asian orogenic belt was completed. In zones of large faults, atmospheric water penetrated to the depth of 1–1.5 km forming linear weathering crusts. As a result of the intrusions impact, the temperature of groundwater near them increased sharply. There arose complex-constructed hydrothermal hydrodynamic systems that could be fed by exogenous waters of the earth's crust (infiltrogenic, sedimentogenic), as well as fluids released from cooling magmatic bodies.

One of the sources of rare-metal mineralization of coals (peats) was the rock massifs of the Kokchetau-North-Tien Shan ancient folded structure, which surrounds the sedimentation basin and serves as a supplier of clastic material during the formation of coal-bearing strata due to tectonic processes of the Mesozoic-Cenozoic time. They were activated in response to collisional events, with active Late Cenozoic tectonic phases associated with the Indo-Eurasian collision. As a consequence of those events, there was a large-scale stimulation of the Central Asian buried belt, which led to the intensification of sediment transport into the formation basin of the field. High and abnormally high concentrations of the elements accumulation were caused by the intense (or prolonged) input of metals into the peat bog or into the coal seam.

Such a picture of metallogeny of coals of the substantially syngenetic nature could be caused by the increased content of the complex of elements at the deposits (the Atasu ore region, deposits of the Zhezkazgan group, etc.) in the erosion area, its close proximity to the sedimentation basin, and well-developed weathering crust.

Conclusions.

It has been established that in the Permian-Triassic the Teniz-Sarysu-Chuysky vast sedimentation basin is divided by the wide Sarysu-Teniz block uplift, to which the studied field is spatially and genetically related, into two depressions: the northern one, Teniz and the southern one, Sarysu-Chuysky due to collision of the Kazakhstan continent with Tarim and the East-European continent. In connection with this, the collage of strike-slip structures of the Central Asian orogenic belt was completed, which in turn led to the formation of a large number

of tectonic faults in the studied area. Impurity elements entered the coals through the formed faults from the basement rocks due to the removal and redeposition with participation of syn- and epigenetic processes of migration of groundwater.

It has been determined that the sediments removal into the formation basin of the field from the massifs framing the studied area, i.e. the rock massifs of the Kokchetau uplift in the north and north-west, the Kaptyadyr, Arganatinsk and Ulutau mountains in the west, which compose the Kokchetau-North-Tien-Shan ancient folded chain structures and the Central Kazakhstan (Devonian) volcano-plutonic belt in the east occurred due to tectonic processes in the Mesozoic-Cenozoic time. They were periodically activated in response to collisional events, with active Late Cenozoic tectonic phases associated with the Indo-Eurasian collision. These structures are one of the sources of high concentrations of impurity elements in coals in the areas of the Shubarkol deposit, where the concentrations of individual elements (U, Th, Ba) or elements of the siderophilous group (Ce, Sc, Zn and Sr) determined by the INAA method.

It has been established that distribution of elements in the coals of the Shubarkol deposit is determined by the peculiarities of metallogeny and geochemistry of the surrounding area of the deposit and the mechanisms of the elements entry into coal seams.

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Тектонічні особливості накопичення елементів-домішок у вугільному родовищі Шубарколь (Казахстан)

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Мета. Визначення особливостей палеотектонічного розвитку району й побудови палеотектонічної реконструкції формування родовища для встановлення природи накопичення елементів-домішок у вугіллі та вміщуючих породах родовища Шубарколь, а також для підвищення мінерально-сировинного потенціалу вугілля.

Методика. Проаналізовані 25 проб вугілля та аргіліту родовища Шубарколь. Проби вивчалися методом інструментального нейтронно-активаційного аналізу (ІНАА) в ядерно-геохімічній лабораторії Національного дослідницького Томського політехнічного університету.

Результати. Виконано аналіз геолого-структурних і палеотектонічних умов формування родовища Юрського вугілля. Проаналізовані фактори формування збагачених елементами-домішками вугілля та вуглевміщуючих порід і умови, що необхідні для його вилуговування та транспортування до вугільного пласта. Встановлено, що вугілля в окремих пробах мають середній вміст Се, Ва, Sr, Sc, Zn вище кларкового, а Sm, Се, U, Cr, Yb, Ва, Sr, Nd, As, Sc, Zn, Eu, La у складі аргіліту мають середні значення вище, ніж у вугіллі, а також мають значення вище кларкових. Встановлено, що одним із джерел рідкіснометалевої мінералізації вугілля (торфів) у мезозойський і кайнозойський час були масиви гірських порід Кокчетавського підняття на півночі й північному заході, Каптиадирські, Арганатинські та Улутауські гори на Заході, що складають ланцюг Кокчетав-Північно-Тянь-Шаньської древньої складчастої споруди та Центрально-Казахстанського (девонського) вулканно-плутонічного поясу на сході, які оточують басейн седиментації та служать постачальниками кластичного матеріалу при формуванні вугленосної товщі за рахунок тектонічних процесів мезозой-кайнозойського часу.

Наукова новизна. Реконструйовано палеотектонічний розвиток району родовища Шубарколь при формуванні вугленосної формації. Встановлено, що Сарису-Тінзиське підняття в Пермь-тріасі виділяється в самостійний блок, з яким просторово і генетично пов'язане досліджуване родовище. Встановлено, що розподіл елементів у вугіллі родовища Шубарколь визначається особливостями металогенії, геохімії обрамлення району родовища й механізмами надходження елементів у вугільні пласти.

Практична значимість. Цілеспрямований аналіз матеріалів за особливостями накопичення у вугіллі високих концентрацій елементів-домішок, у зв'язку із зонами глибинних розломів на родовищі Шубарколь, служить об'єктивним обґрунтуванням можливості комплексного їх використання, що забезпечує розвиток вугільної галузі країни.

Ключові слова: Шубарколь, геологія, палеотектоніка, палеогеографія, вугілля, елементи-домішки

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