ANNOTATION

PhD Dissertation in the field of study:

8D072 – «Manufacturing and Manufacturing Industries», educational program:

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Study of the influence of geodynamic processes on the accumulation of trace elements in the Mesozoic coal-bearing formations of Central Kazakhstan for the development of predictive criteria

Relevance of the dissertation. In today's world, coal should be considered not only as a traditional source of primary energy but also as an important mineral resource for the global economy, playing a significant role in the development of many countries, including the Republic of Kazakhstan. Despite the steady decline in coal's share in the global energy balance, its consumption remains strategically important in the medium and long term due to stable demand, developed infrastructure, and a high resource base.

Kazakhstan, as one of the largest greenhouse gas emitters in Central Asia, is consistently integrating into the global climate agenda. The ratification of the Paris Agreement in 2016, as well as the Strategy for Achieving Carbon Neutrality in the Republic of Kazakhstan by 2060 announced in 2020, have determined the need to transform the national energy sector. At the same time, the Green Kazakhstan National Project and documents regulating the development of the mineral resource complex emphasize the need for scientifically sound and integrated use of traditional raw materials, including coal, during the transition to low-carbon energy. Under these conditions, coal deposits are considered not only as an energy source but also as the subject of in-depth geological and geochemical studies aimed at identifying additional resource and prospecting opportunities.

In this regard, a comprehensive geochemical study of coal as a mineral resource is particularly relevant. This includes analysis of the distribution of trace elements and their mineral forms, which are key indicators of the formation conditions of coal-bearing formations. The content and geochemical specialization of rare earth and associated elements in coal reflect the characteristics of the source materials, the hydrogeochemical environment of peatlands, as well as the geodynamic conditions of sedimentation and the subsequent evolution of coal basins.

With the development of modern concepts in global geotectonics and coal formation theory, which view the formation of coal deposits as part of a unified process of lithospheric evolution, the importance of analyzing coal-bearing formations from the perspective of current geodynamic models is increasing. For the Mesozoic coal-bearing formations of Central Kazakhstan, formed within the Central Asian Fold Belt, inherited fault-block structures and post-collisional geodynamic processes were crucial,

controlling basin subsidence, facies differentiation of sediments, and the conditions for the accumulation of trace elements in coals.

Of particular scientific and practical interest are the rare earth elements in coals, which, on the one hand, serve as informative geochemical indicators of paleo-redox and hydrogeochemical conditions, and on the other, are considered a potential unconventional source of strategically significant mineral resources. In this regard, a pressing task is the development of scientifically sound predictive criteria for identifying coal-bearing formations with elevated trace element contents based on the integration of geochemical, mineralogical, and geodynamic data.

Investigating the influence of geodynamic processes on the accumulation of trace elements in Mesozoic coal-bearing formations in Central Kazakhstan is a pressing scientific and applied task of fundamental importance for the development of coal geology and geochemistry, as well as practical significance for forecasting, exploration, and evaluation work in the context of the transformation of the Republic of Kazakhstan's energy strategy.

The objective of this study is to establish geochemical and mineralogical patterns of accumulation and occurrence of trace elements in coals of Mesozoic coal-bearing formations in Central Kazakhstan to substantiate their relationship with the geodynamic conditions of coal basin formation and, based on this, to develop predictive criteria.

To achieve this goal, the study included the following objectives:

1. To analyze the current state of knowledge of the geochemistry and mineralogy of trace elements in coals, as well as existing understanding of the role of geodynamic factors in the formation of Mesozoic coal-bearing formations, taking into account the inherited fault-block structures of Central Kazakhstan.

2. To study the geochemical and mineralogical composition of coals from the studied formations and establish patterns of trace element distribution, determining mineral forms depending on the lithofacies conditions of formation and position in the section. 3. Based on statistical processing of geochemical data, establish stable associations of elements and factors controlling their accumulation (correlation, cluster, and factor analyses), and identify the relationship between the geochemical and mineralogical properties of coals and the geodynamic conditions of the formation and evolution of Mesozoic coal basins in Central Kazakhstan.

4. Develop predictive geochemical and mineralogical criteria for identifying coal-bearing formations with elevated contents of trace elements.

The scientific novelty of this work lies in the following:

1. A pattern of spatial distribution of geochemical and mineralogical impurities in Mesozoic coals of the Central Kilogramme (CK) deposits is established, influenced

by structural and geodynamic factors. The coal composition is determined by paleoclimatic conditions.

2. Geochemical and mineralogical indicators of the formation conditions of rare and rare earth elements (REEs) under the influence of tectonic activation (zincite, cadmium sulfide) and additional enrichment of coals by hydrothermal and volcanic fluids are established.

3. A pattern of formation of trace elements and their genetic types is established under the influence of a tectonically active environment, which forms stable geochemical and mineralogical associations and determines the geochemical specialization of Jurassic coals of the CK deposits.

4. A set of geodynamic, geochemical and mineralogical features has been developed to predict zones of local accumulation of REE and associated elements in coal-bearing formations of the Mesozoic Central Asian region.

Scientific propositions submitted for defense:

1. Mesozoic coal formation in Central Kazakhstan was tectonically determined and controlled by the inherited fault-block structure of the Central Asian Fold Belt, which is reflected in the distribution of geochemical and mineralogical characteristics of coals. Under conditions of pulsating subsidence of post-collisional troughs, tectonic factors determined the geochemical specialization of coal-bearing formations, while climatic conditions had a subordinate, modifying effect.

2. It has been established that rare earth and associated elements in Mesozoic coals of Central Kazakhstan are localized predominantly in authigenic mineral phases (phosphate, clay, sulfide), and their accumulation is associated with tectonic activation and the influx of hydrothermal and volcanogenic fluids, as confirmed by mineral indicators and geochemical associations.

3. The chemical composition of coals from the Shubarkol deposit is characterized by stable geochemical and mineralogical associations of trace elements and their vertical and lateral zoning, caused by a combination of lithogenic, sorption-chemogenic, and epigenetic processes, as confirmed by the results of cluster and factor analysis.

4. A set of geodynamic, geochemical, and mineralogical criteria for identifying zones of local accumulation of rare earth and associated trace elements in Mesozoic coal-bearing formations of Central Kazakhstan has been developed and substantiated. The applicability of this set has been confirmed using the Shubarkol deposit and the Maikuben coal basin as examples. The geochemical specialization of Jurassic coals, including the distribution of rare earth elements and cerium and europium anomalies, reflects the influence of geodynamic and hydrogeochemical conditions of sedimentation and diagenesis.

The author defends:

1. The tectonically determined nature of Mesozoic coal formation in Central Kazakhstan, controlled by the inherited fault-block structure of the Central Asian folded belt, with the leading role of the tectonic factor in the formation of the geochemical specialization of coal-bearing formations under the subordinate influence of climatic conditions.

2. The predominant localization of rare earth and associated elements in the authigenic mineral phases of Mesozoic coals of Central Kazakhstan and their genetic relationship with the processes of tectonic activation, accompanied by the influx of hydrothermal and volcanic fluids.

3. Patterns of the geochemical and mineralogical organization of coals of the Shubarkol deposit, expressed in stable associations of trace elements and their vertical and lateral zonality, formed under the influence of lithogenic, sorption-chemogenic, and epigenetic processes.

4. A set of geodynamic, geochemical and mineralogical criteria for identifying zones of local accumulation of rare earth and associated elements in Mesozoic coal-bearing formations of Central Kazakhstan, confirmed by the example of the Shubarkol deposit and the Maikuben coal basin.

Factual material and personal contribution of the author. This work is based on materials obtained by the author during his doctoral studies, as well as as a result of research work within the framework of projects carried out at the Department of Geology and Exploration of Mineral Deposits of the NAO "Karaganda Technical University named after Abylkas Saginov", funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan as the contractor:

1. AP08052608, Contract No. 64-1 dated May 15, 2020 (2020-2022);
2. AP13067779, Contract No. 120-KMUZ dated May 20, 2022 (2022-2024);
3. AP26102801, contract No. 309/25-27, dated September 29, 2025 (2025-2027).

Some of the analytical studies were performed independently by the author, including chemical sample preparation procedures for coals and carbonaceous rocks using nitric, perchloric, and hydrofluoric acids, as well as elemental composition determination using ICP-OES and ICP-MS on a 7600 Duo spectrometer (Thermo Scientific Corporation, USA) and an Agilent 7700 ICP-MS spectrometer (Agilent Technologies, USA) with the assistance of analyst N.V. Zarubina at the Analytical Center of the Far Eastern Geological Institute, Far Eastern Branch of the Russian Academy of Sciences (Vladivostok).

A scientific internship was completed in Kazan, Russia, at the Institute of Geology and Petroleum Technologies of Kazan Federal University from May 23 to June 3, 2023. During the internship, consultations were received on the topic of the dissertation research from Professor R.Kh. Sungatullin, Doctor of Geological and

Mineralogical Sciences. A certificate of successful completion was received upon completion of the internship.

During the scientific internship, together with Professor R.Kh. Sungatullin, a foreign supervisor, cluster and factor analyses of geochemical data were performed and the results were interpreted. The joint work, based on the completed research, was published in a highly ranked scientific journal.

The validity of the dissertation's conclusions is ensured by the correct formulation of the objectives, the use of modern research methods, and the consistency of the obtained results with analytical data, including the results of analysis of 140 coal and coal-bearing rock samples obtained during field studies with strict stratigraphic reference, as well as the use of a range of modern, highly accurate, and complementary geochemical and mineralogical methods widely used in international scientific practice. The reliability of the analytical data is confirmed by the use of certified reference materials, intermethod comparison of results (ICP-OES, ICP-MS, INAA, SEM-EDS, XRD), parallel measurements, and statistical data processing using correlation, cluster, and factor analysis. The results are interpreted taking into account modern concepts of coal geology, geochemistry, and the geodynamic evolution of coal basins, ensuring the validity and reproducibility of the findings. The main provisions of the dissertation were published in scientific articles and abstracts of reports, and there is also a patent and certificates of state registration of rights to copyright objects.

All sections of the dissertation are presented in a methodological sequence and logically interconnected, ensuring the integrity of the research and the step-by-step solution of the scientific objectives, from the collection and analysis of factual material to the generalization of results and the formulation of scientifically sound conclusions. The structure of the work reflects the research concept, and the methods and approaches employed are adequate to the goals and objectives of the dissertation and correspond to the current level of development in coal geology and geochemistry.

The author's personal contribution includes the independent collection and systematization of factual material, the processing of geological data and laboratory results, sample preparation, and the determination of the elemental composition of coals using ICP-OES and ICP-MS methods using certified reference materials, as well as the preparation and interpretation of diagrams, charts, graphs, and cartographic materials using modern software (Microsoft Excel, CorelDRAW, AutoCAD, QGIS). The author also analyzed materials on the deep structure and geodynamic development of the region based on modern theoretical concepts, which allowed for the formulation of sound scientific conclusions and practical recommendations.

Thesis validation. The results of the dissertation research were validated and published in a series of scientific papers reflecting the main provisions and conclusions of this dissertation. Between 2021 and 2025, the author published 15 scientific articles,

including in peer-reviewed international and domestic journals indexed in Scopus and Web of Science.

Six of these articles were in international peer-reviewed scientific journals (Web of Science Core Collection, Scopus):

1) Blyalova G., Amangeldykyzy A., Kopobayeva A., Zhirkov V., Ryzhkov S. A Comprehensive Study of the Spatial Variations in the Distribution of Rare Earth Elements (REE) and Their Potential in the Coals of the Shubarkol Deposit, Kazakhstan //Minerals. – 2025. – Т. 15. – №. 2. – С. 170. https://doi.org/10.3390/min15020170

2) Копобаева А.Н., Блялова Г.Г., Амангелдікызы А., Сунгатуллин Р.Х., Оразбек Н. Геохимические особенности Майкубеньского угольного бассейна (Казахстан) // Горный информационно-аналитический бюллетень. – 2025. – № 9. – С. 135–150. DOI: 10.25018/0236_1493_2025_9_0_135.

3) Kopobayeva A.N., Amangeldikyzy A., Blyalova G.G., Askarova N.S. Mineralogical and geochemical features of coals and clay layers of the Karaganda coal basin //Minerals. – 2024. – Т. 14. – №. 4. – С. 349. https://doi.org/10.3390/min14040349

4) Kopobayeva A.N., Amangeldikyzy A., Blyalova G.G., Askarova N.S. Features of rare earth elements geochemistry in coals of Central Kazakhstan. //Acta Geochimica – 2024. 43(5), 876-888. https://doi.org/10.1007/s11631-024-00677-3

5) Kopobayeva A.N., Blyalova G.G., Bakyt A., Portnov V.S., Amangeldikyzy A. The nature of rare earth elements accumulation in clay layers and coals of the Shubarkol deposit // News of the academy of sciences of the Republic of Kazakhstan. Series of geology and technical sciences. – 2022; № 2(452). – P. 117-130. https://doi.org/10.32014/2022.2518-170x.164

6) Amangeldykyzy A. Kopobayeva A.N., Bakyt A., Ozhigin D.S. Blyalova G.G., Mineralogy and geochemistry of the Shubarkol deposit Jurassic coals // News of the academy of sciences of the Republic of Kazakhstan. Series of geology and technical sciences. – 2021. – Т. 5. – С. 23-31. https://doi.org/10.32014/2021.2518-170X.94

4 articles in publications recommended by the authorized body:

1) Blyalova G.G., Kopobayeva A.N., Amangeldykyzy A., Askarova N.S., Ozhigin D.S. (2023). Ways of rare earth elements migration and transportation to the coals of the Shubarkol deposit. *Kompleksnoe Ispolzovanie Mineralnogo Syra= Complex use of mineral resources*, *324*(1), 24-33.

2) Amangeldikyzy A., Kopobayeva A.N., Blyalova G.G., Askarova, N.S. (2023). Geochemical speciation of coals in the Karaganda coal Basin. *Min. J. Kazakhstan*, *7*, 15-20.

3) Kopobayeva A.N., Baydauletova I.V., Amangeldikyzy A., Askarova N.S., Blyalova, G.G. (2025). Nature of ree accumulation in clayey interlayers and coals in Karaganda coal basin. *Kompleksnoe Ispolzovanie Mineralnogo Syra= Complex use of mineral resources*, *332*(1), 49-61.

4) Kopobayeva A., Amangeldikyzy A., Blyalova G., Askarova N. Study of the Distribution of Impurity Elements in Coals and Clay Layers of the Karaganda Coal

Basin // Труды университета. – 2023. №3 (92) – С. 151-156. DOI 10.52209/1609-1825_2023_3_151.

They were also presented in the form of reports at international scientific and practical conferences:

1) Kabyken A., Kopobayeva A., Amangeldikyzy A., Blyalova G., Askarova N. Ulgibayeva B. (2024, October). A Tool for Analyzing Geological Data Using the Grade Copilot Neural Network Within the Micromine Software. In *2024 IEEE 6th International Symposium on Logistics and Industrial Informatics (LINDI)* (pp. 000015-000018). IEEE.

2) Копобаева А.Н., Амангелдіқызы А., Блялова Г.Г. Особенности геохимии РЗЭ в углях Центрального Казахстана // Международная научно-практическая конференция «К.И. Сатпаев и науки о Земле», Алматы 2024. С. 174-178.

3) **Копобаева А.Н., Блялова Г.Г.** *Представление о геодинамических обстановках углеобразования месторождения Шубарколь.* Международная научно-практическая конференция **«Интеграция науки, образования и производства – основа реализации Плана нации»** (XIV Сагиновские чтения), 2022г., г. Караганда, Казахстан. С. 61–63. ISBN 978-601-320-725-4.

4) Копобаева А.Н., Блялова Г.Г. *Источники поступления элементов-примесей в угли Шубаркольского месторождения.* Международная научно-практическая конференция «Интеграция науки, образования и производства» (XV Сагиновские чтения), посвящённая 70-летию Карагандинского технического университета им. Абылкаса Сагинова, 2023 г., г. Караганда, Казахстан. С. 455–458. ISBN 978-601-320-906-7.

5) Копобаева А.Н., Блялова Г.Г. *Условия накопления угленосных отложений мезозоя Центрального Казахстана.* Труды Международной научно-практической конференции «XVI Сагиновские чтения. Интеграция образования, науки и производства», 2024 г., г. Караганда, Казахстан. Ч. 2, с. 518–520. ISBN 978-601-355-377-1.

The research results have been implemented at JSC Shubarkol Komir. An implementation certificate is available. The main provisions of the dissertation were tested during research internships and during research projects related to the study of the geochemical properties of coals from the Shubarkol and Maikuben coal basins.

Research Methodology. The methodological framework was developed taking into account current regulatory documents and modern international approaches adopted in coal geology and geochemistry. During the research and preparation of the dissertation, extensive use was made of published, archived materials, and the latest geological, geochemical, and mineralogical data on the methodology for conducting, processing, and interpreting analytical data using modern computer technologies at similar global and Kazakh coal deposits.

The study is interdisciplinary in nature, as it is based on the integration of geochemical methods, coal and coal-bearing rock mineralogy, coal deposit geology, and mathematical statistics. This allowed for a comprehensive assessment of the elemental composition of coals, the occurrence of chemical elements, and the conditions of their formation.

Field research included detailed channel sampling of coal seams and coal-bearing rocks, adhering to representativeness requirements and strict stratigraphic reference, ensuring the formation of a reliable and comparable sample. Laboratory studies utilized modern, high-precision analytical methods widely used in international geochemical practice. The primary methods for determining elemental composition were ICP-OES on an iCAP 7600 Duo spectrometer (Thermo Scientific, USA) and ICP-MS on an Agilent 7700x spectrometer (Agilent Technologies, Japan) at the FEGI FEB RAS analytical center. Quality control of analytical data was achieved using CLB-1 and SARM-19 coal reference standards (US Geological Survey), as well as by parallel measurements and comparison of results for key elements. Additionally, the elemental composition of samples was determined using instrumental neutron activation analysis (INAA), performed at the accredited nuclear geochemistry laboratory of Tomsk Polytechnic University using the IRT-T research nuclear reactor. This allowed for the determination of the contents of 28 elements, including rare earth and trace elements.

The mineralogical forms of trace elements were studied using a combination of modern mineralogical methods. This allowed us to establish the relationship between the distribution of elements and the organic and mineral components of coal at the microlevel and to identify mineral assemblages and microphases used as mineralogical indicators of sedimentation conditions and post-sedimentation transformations. The following methods and instrumentation were used in the study:

– powder X-ray diffractometry (XRD) on a DRON-3M diffractometer; diffraction patterns were recorded using the DIFRAC.Measurement software package; diffraction pattern interpretation and mineral phase identification were performed using EVA and TOPAS programs. The work was conducted at Tomsk Polytechnic University (Tomsk, Russia);

– Scanning electron microscopy (SEM-EDS) on a Hitachi S-3400N microscope equipped with a Bruker X@Flash 5010 energy-dispersive spectrometer for X-ray microanalysis; the studies were performed at Tomsk Polytechnic University (Tomsk, Russia);

– Analytical scanning electron microscopy (SEM-EDS) on a JEOL JSM-6490LV microscope with an INCA Energy X-Max EDS spectrometer, as well as on a Tescan Lyra 3 XMH dual-beam scanning electron microscope equipped with an AZtec X-Max 80 Standart EDS spectrometer; the studies were conducted in the Micro- and Nanoscience Laboratory of the Analytical Center of the Far Eastern Geological

Institute, Far Eastern Branch of the Russian Academy of Sciences (Vladivostok, Russia).

The processing and interpretation of the results were carried out using correlation, cluster and factor analysis (STATISTICA 10), which ensured an objective interpretation of the results in the context of the geodynamic evolution of coal basins and made it possible to substantiate scientifically confirmed predictive criteria for the accumulation of impurity elements in coals.

The practical significance of this dissertation lies in the potential use of the obtained results in prospecting, exploration, and evaluation work in coal-bearing areas. The developed geochemical and mineralogical criteria, tested on coals in Central Kazakhstan, can be adapted for application to coal-bearing formations of various ages, taking into account their geological, structural, and lithofacies features. The research findings can be used in geological exploration, scientific research, and in the educational process for training geological specialists. The results of the research have been implemented in the production processes of Shubarkol Komir JSC.

Structure and Scope of the Dissertation. This dissertation consists of an introduction, six chapters, a conclusion, and a list of references. The total length of the dissertation is 166 typewritten pages, including 66 figures and 18 tables. The list of references includes 109 titles, including works by Russian and international authors.

Dissertation Summary.

This dissertation consists of an introduction, six chapters, a conclusion, a list of references, and an appendix.

Chapter one analyzes the current state of knowledge of coal-bearing formations in Central Kazakhstan, discusses the stratigraphic and lithofacies features of Mesozoic coal-bearing strata, and examines existing concepts of the region's geodynamic development. It is shown that the formation of coal basins is closely linked to post-collisional geodynamic processes and the inherited fault-block structure.

Chapter two presents the research methodology and analytical support for geochemical and mineralogical studies. It describes sample collection and preparation methods, analytical techniques for determining the elemental composition of coals and coal-bearing rocks, and statistical data processing methods that ensure the reliability and reproducibility of the results.

Chapter three examines the geodynamic evolution of Central Kazakhstan during the Mesozoic and its role in the formation of coal basins. The geotectonic setting, types of sedimentation basins, and stages of Mesozoic coal formation are characterized. A comparative analysis of the Shubarkol deposit and the Maikuben coal basin is provided.

Chapter four presents the results of geochemical studies of coals in Central Kazakhstan. Accumulation levels of trace elements and rare earth elements are determined, and patterns of their distribution and geochemical differentiation are revealed. Based on correlation, cluster, and factor analysis, stable element associations and the factors controlling their accumulation are identified.

Chapter 5 examines the mineralogical composition of coals and the occurrence of trace elements. The main mineral carriers of rare earth and associated elements are identified, the formation conditions of accessory and secondary minerals are characterized, and a genetic interpretation of mineral formation processes in coal-bearing formations is proposed.

Chapter 6 develops a system of exploration criteria for the accumulation of trace elements in Mesozoic coal-bearing formations of Central Kazakhstan. Geodynamic, geochemical, and mineralogical-geochemical criteria are substantiated, and the feasibility of their practical application in prospecting and exploration work is demonstrated.

Key findings and results of the dissertation:

Through the synthesis of extensive factual material and its thorough analysis, numerous conclusions of varying levels and significance were obtained. The most important findings are summarized in the dissertation abstract:

1. Analysis of domestic and international studies revealed that the coal basins of Central Kazakhstan, including the Maikuben Basin and the Shubarkol deposit, are characterized by a high degree of stratigraphic and structural-geological study, resulting from many years of regional and detailed geological exploration. Previous studies have established the lithofacies features of coal-bearing strata and revealed general patterns of their formation in Mesozoic intracontinental basins that inherited the Paleozoic tectonic structures of the Central Asian Fold Belt. 2. It has been shown that most existing coal accumulation models focus primarily on stratigraphic-tectonic and lithofacies analysis, which corresponds to the level of objectives and methodological capabilities at the time of their development. Geodynamic factors and their relationships with the geochemical characteristics of coals were typically considered fragmentarily and lacked a comprehensive justification. Early geochemical studies relied primarily on semi-quantitative analytical methods, limiting the ability to accurately interpret the scale and genetic nature of coal enrichment in rare, rare earth, and critical elements.

3. Modern quantitative studies using ICP-MS, INAA, and SEM-EDS methods have confirmed the presence of elevated concentrations of REE, Ge, Sc, and associated elements in coals from the Shubarkol deposit and the Maikuben Basin. However, the

data obtained are local in nature and, in most cases, are analyzed outside of a unified stratigraphic-geodynamic and paleogeographic context.

4. Developing an integrated approach that compares the geochemical patterns of coals with lithofacies zonation, sources of terrigenous and volcanic material, and stages of the tectonic evolution of coal basins remains a pressing scientific challenge. The role of the organic and mineral components of coal in the concentration of rare earth and other critical elements and their relationship to sedimentation conditions, redox conditions, and postsedimentary transformations requires further study. It has been established that the formation of Mesozoic coal-bearing formations in Central Kazakhstan occurred under conditions of post-orogenic evolution of the region and was controlled by the inherited fault-block framework of the Central Asian Fold Belt, reactivated in the Mesozoic. Tectonic processes determined the geometry of sedimentary basins, the subsidence regime, and the spatial distribution of coal basins.

5. It has been established that the Shubarkol and Maikuben coal basins formed predominantly in graben-like intracontinental basins under conditions of prolonged tectonic-sedimentological development of the postorogenic Mesozoic plate, which contributed to the accumulation of thick Jurassic coal-bearing strata.

6. It has been determined that the spatial differentiation of coal basins and variations in the thickness of coal-bearing sections were determined by fault-block tectonics, with deep faults controlling the formation of local subsidence centers and alluvial-lacustrine-marsh sedimentation environments.

7. The geotectonic position of Central Kazakhstan between large cratons determined the region's mosaic structure, uneven vertical movements, and the formation of local depressions within which Jurassic coal accumulation was concentrated. The Sarysu-Teniz Uplift played a significant role in the structural organization of the coal basins, determining their segmentation, asymmetry, and differences in the thickness of the sections.

8. It has been established that coal formation during the Jurassic period occurred during alternating phases of subsidence and tectonic activation. Climatic conditions were relatively favorable and stable, but played a subordinate, modifying role relative to tectonic control.

9. It has been established that a comparison of the Shubarkol deposit and the Maikuben basin revealed that differences in the structure, thickness, and productivity of coal-bearing strata under similar paleoclimatic conditions are primarily due to geodynamic factors.

10. It has been established that the geodynamic evolution of the region determined not only the formation of coal basins but also the conditions for the accumulation of trace elements in coals, which is fundamental for predicting their geochemical specialization. 11. It has been established that the key patterns of

formation of Mesozoic coal-bearing deposits in Central Kazakhstan are associated with the Jurassic stage of geodynamic evolution. This period was characterized by the development of intracontinental extensional troughs, post-collisional structural reorganization, and the activation of deep faults, which determined sedimentation and the supply of material to the basins. During this period, coal-bearing deposits of the Shubarkol and Maikuben types formed, confined to fault-block structures.

12. It has been established that the sources of the Shubarkol coals correspond to acidic-intermediate igneous rocks and reworked crustal materials (based on the results of geochemical analysis: Zr/TiO_2 – Nb/Y, La/Th – Hf diagrams, Winchester & Floyd, 1977 [102]). The distribution of points reflects the influence of Jurassic geodynamic processes: activation of faults, the supply of finely dispersed volcanic material, and the reworking of crustal complexes under conditions of intracontinental extension. The geodynamic regime of the Jurassic determined not only the architecture of the sedimentary basin, but also the geochemical specialization of terrigenous material enriched in high-field strength elements (Zr, Nb, Y).

13. Transitional facies between bog and fluvial systems in coal basins have been identified, characterized by high variability in Ce/Ce* and LREE/HREE ratios, reflecting alternating oxidizing and reducing conditions. This creates promising zones for localized accumulation of rare earth elements due to a combination of organogenic and mineral fixation mechanisms. Block tectonics and differentiated depressions contributed to the formation of localized bog and lacustrine-bog conditions with reduced redox potential and a slightly acidic environment, favorable for uranium precipitation and REE concentration in organic matter and clay minerals.

14. It was established that the studied coals are characterized by positive europium anomalies (Eu = 1.1-2.3), confirming the hydrogenic mechanism of metal accumulation from formation waters. 15. It has been established that the mineralogy and petrographic composition of coals from the Shubarkol deposit, including kaolinite, anatase, and zircon, reflects the influx of weathering products and volcanic material, the influence of fluid flows in fault zones, and the formation of authigenic and diagenetic minerals—carriers of REE, Zr, Nb, Y, and U. The occurrence of trace elements is determined by the interaction of organic matter with mineral-forming processes controlled by Jurassic tectonic activation.

16. It has been revealed that stable associations of petrogenic components and trace elements are formed in the coal-bearing strata, reflecting various sources of matter and features of geochemical processes, identified through cluster and factor analysis. The obtained patterns serve as the basis for developing predictive criteria for identifying coal deposits with elevated contents of rare earth and associated trace elements. 17. Mineralogical studies of coals and coal-bearing rocks in Central Kazakhstan have revealed a multistage mineral formation process involving diagenetic, epigenetic, and

locally hydrothermal processes. The main concentrations of trace elements and REEs are confined to diagenetic and epigenetic phases localized in the organic matter of coals and zones of its contact with the mineral matrix. Coals in the Maikuben Basin are characterized by spatial and genetic differentiation of mineral phases, which predicts the geochemical specialization of the basin, including the accumulation of Fe, S, and associated trace and rare earth elements.

18. It has been established that the combination of authigenic kaolinite, anatase, and the zircon-baddeleyite association, together with signs of tectonic activation (palygorskite), can be considered a reliable mineralogical criterion for identifying zones of coal enrichment in rare and rare earth elements.

19. It has been established that Ti is strongly bound to the aluminosilicate phase (r=0.93 with Al2O3), entering the kaolinite structure in the form of submicron inclusions of anatase.

20. It has been established that the mineral component of the coals is represented predominantly by quartz and kaolinite. This indicates a high degree of maturity of the original terrigenous material and intensive chemical weathering in the feeding areas of the paleobasins. Genetic heterogeneity of quartz and clay minerals: both clastogenic (alien – originating from outside) and authigenic (newly formed) quartz have been identified in the Shubarkol coals. Kaolinite in the form of well-crystallized vermicules and spherulites indicates active processes of early diagenetic kaolinization in an acidic environment under the influence of fluids.

21. It has been revealed that the main carriers of high-field strength elements (Zr, Hf, Nb, Ta) are zircon and baddeleyite (ZrO2), which is rare for coals. The presence of baddeleyite and anatase (TiO2) serves as an indicator of secondary mineralization and the possible influence of volcanic material or deep fluids.

22. It has been established that the leading mineral form of rare earth element fixation is phosphates: monazite (a concentrator of light rare earth elements – La, Ce, Nd) and xenotime (a concentrator of heavy rare earth elements – Yb, Lu, and yttrium). Their presence in the form of authigenic films and crusts confirms the redistribution of rare earth elements from organic matter to the mineral phase during coalification.

23. A system of exploration features and an integrated analysis of geodynamic, lithofacies, geochemical, and mineralogical-geochemical parameters has been developed, which allows:

to assess the prospects of coal basins in the early stages of exploration;

to identify zones of increased concentrations of trace elements, including rare earth elements;

- predict the geochemical composition of coals in promising basins and local anomalies;

- optimize the planning of exploration and appraisal work and further research, including the study of igneous and volcanogenic material, as well as epigenetic and hydrothermal processes.

The application of the developed criteria allows for the development of scientifically sound recommendations for exploration and appraisal work, minimizing costs, and increasing the efficiency of coal basin exploration. Furthermore, these features can be used to predict the geochemical composition of coals in promising basins and to identify new local anomalies, opening up opportunities for further fundamental and applied research in coal geochemistry and mineralogy.