# Geochemical Method Of Exploration For Hidden Complex Rare Metal Deposits Of Black-Shale Formations (Illustrated By Black Shales Of Western Uzbekistan)

**Akmal Khalilov, Bahtiyar Isakhodjaev, Bohodir Meliboev, Bekhzod Atabaev, Zulfiya Israilova**

**Abstract:** In the territory of Uzbekistan, deposits of rare earth elements have not been identified yet, but there are prerequisites for their detection. La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu and Y, Sc are today an unconventional type of raw materials for our country. Basically, increased concentrations of rare earth elements are associated with high-carbon geological formations. The analysis of the world market of rare-earth elements (REE) reveals that its consumption is growing by 3-4% every year. The growth in consumption is associated with the unique properties of REE - lightness, anticorrosion properties, heat resistance, etc. For numerous years, China has dominated the world export of rare earths, the United States is the major exporter; India, France, the CIS and Estonia also export them. The main world importers of rare earths are Japan, the USA and European countries.

**Index Terms**: black shales, formation, genesis, method of exploration, rare metal deposits, raw materials, Western Uzbekistan.

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## 1. INTRODUCTION

CURRENTLY, the world is familiar with about 70 of its own minerals (REE) and more than 280 minerals, where they are present in the form of impurities. The main ones, as follows: bastnasite, monazite, xenotime, parisite, churchite, rhabdophanite, euxenite, loparite, britholite, etc. The main scandium mineral is thortveitite. To date, there is no complete idea of the potential of Uzbekistan in REE and the criteria for the exploration for its industrial concentrations. In a number of publications on geology, mineralogy and technology, rare-earth mineralization accompanies uranium objects of the black shale type [4-11]. In the world, rare-earth elements are mined from endogenous, magmatogene-hydrothermal ores, products of their supergene crust transformation, ion-sorbing sediments, marine ones, alluvial ones and paleo-deposits. The bulk of the industrial reserves of endogenous rare-earth deposits in the world are contained in bastnasite ores (about 90%), monazite placers account for about 9%; about 1% falls on xenotime, apatite, gadolinit and other minerals.

In Uzbekistan, there are examples of industrial concentrations of Y-Ce elements of the rare-earth group in the phosphorite ores of Kyzylkum region, in siderites of the kaolin residual soil of the Angren brown coal deposit, in oil shales of various regions of the country. Within the development of carbon-siliceous shale formations in Bukantaus, Auminz-Beltaus, Tamdytaus and Northern Nuratau ore regions, numerous researchers found increased contents of U, Au, V, Mo, Re, elements of the Pt group, Sc, Y, and REE. Most likely, this is a separate type of deposits of the uranium-rare-metal-rare-earth formation localized in the black shale stratum and confined substantially for the carbon-silicon part of the section. In Western Uzbekistan, carbon-siliceous shales are quite widespread. In one or another volume, similar rocks are present in all Palaeozoic volcanic-sedimentary formations. However, the maximum ore saturation is confined only to Pre-Cambrian formations of the Kokpatass Formation (R2-3) and its analogues (Taskazgan, Suvliksai, etc.), whose geological bodies differ from their later analogues in significant thickness (up to 400 m or more), ore and superclark concentrations of V, U, Mo, Se, Sc, Y, Au, Ag, Cu, Zn, etc., exposing over an area of more than 1,500 km2 within the mountain structures of Bukantau, Tamdytau, Auminz-Beltau, Northern Nuratau and they are the main source of supply of mobile elements for Mesozoic and Cainozoic deposits sedimentary cover, enclosing a main volume of ore components, keeping them from loss. Among the various rare-metal concentrations developed within the Paleozoic uranium ore regions, two main groups (or categories) can be distinguished:

1. Relatively simple in composition and genesis monochronous deposits formed as a result of predominantly one-act occurrences of ore-forming processes (syngenetic ores or ores formed as a result of the initial stage of fissure water infiltration) [13].
2. Polychronic and polygenic deposits, complex in composition, history of development and origin, formed as a result of the occurence of several ore-forming processes, different in nature and substantially broken in time. Moreover, not only the redistribution of metals, but also often its additional contribution is associated with the processes superimposed on previously formed accumulations of ore concentrations. The resulting concentrations of ore elements of different ages and genesis have higher contents. In addition to the main, associated components, appear in them that increase the value of these complex deposits.

The marked groups (categories) of uranium deposits correspond to the endogenous, polygenic, and exogenous series. In Kyzylkum, the deposits of the exogenous series in the platform cover are of primary importance and much less are the polygenic accumulations of uranium ores in the black

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- *Akmal Khalilov, State Enterprise “Uranredmetgeologiya” of the State Committee for Geology and Mineral Resources of the Republic of Uzbekistan and National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan.*
- *Bahtiyar Isakhodjaev, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan.*
- *Bohodir Meliboev, National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan*
- *Bekhzod Atabaev, National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan*
- *Zulfiya Israilova, National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan*

shale thickness of the Palaeozoic basement. The polygenetic series includes a number of complex uranium (with vanadium, molybdenum, rhenium, REE and other ore elements) deposits, as follows: Djantuar, Koscheka, Rudnoe [6, 11], Djitym, Khojaahmet and others, and several dozen ore occurrences - Voskhod, Lozovoye, Novoe, Kaskyr, Boztau, Southeast Boztau and others, localized among the carbon-containing microquartzites of the Tazkasgan, Kokpatass, Suvliksai and upper parts of the Sarytau and Koksai suites. In addition, individual secondary occurrences of uranium mineralization are known in tectonic zones among the granitoids of the Altyntau and Auminzatau intrusive massifs. Among the ore clusters in the Auminzatau region, except for deposits represented in near-surface supergene conditions only by glist ores (uranium-vanadium, uranium-phosphate) - Rudnoye and Koscheka, deposits were established within which uranium glists developed in the oxidation zone are replaced by oxide ones (pitchblende) ores (Jantuar and others). In the Djitym deposit located under the Mesozoic-Cainozoic sediments of the platform cover, mineralization is represented by pitchblende and practically does not contain uranium glists. A series of uranium deposits and ore occurrences are known in the Bukantau region (Khojaakhmet, Lozovoe, etc.), which also occur among black shale strata, which are represented at depth by primary ores (pitchblende, uranium titanates in association with molybdenite and other sulphides) and are transformed in the upper parts by oxidation processes. It is noteworthy that in Auminzatau, Bukantau and in some other areas, many uranium deposits and ore occurrences of this type exhibit spatial and structural connection with suites composed of thick strata of carbon-siliceous and carbon phyllite shales [9, 14, 15, 16].

## 2 MATERIALS AND METHODS

### 2.1 Research Method

In the patterns of distribution of uranium deposits in the black shale stratum, block and linear redistribution are clearly occurred. Uranium-bearing tectonic blocks stand out, revealing an anomalous folded and domed structure and composed mainly of microquartzites. Large and long ore-controlling long-lived tectonic zones of deep faults have been identified, which, in combination with domes and arch elevations, determine the position of the main ore nodes, fields and deposits. There is no consensus on the genesis of uranium deposits in general and the age of mineralization among researchers who have been involved in their different studies. At the same time, various, often opposing points of view were expressed. In this paper, we consider these deposits to be polygenetic, and depending on the degree of erosion, their industrial value can be estimated in different ways [4, 6, 11]. Detailed studies that we carried out in 2010-2018 at deposits and ore occurrences in Bukantau (Boztau and Altyntau ore fields and others) [5, 6, 9, 11, 14, 15, 16] revealed that uranium-glist ores developed in the upper parts due to the Mesozoic residual soil and modern surface zone oxidation during fissure water infiltration are superimposed on primary oxide mineralization, which was supposedly formed in the Proterozoic (Riphean) - Early Paleozoic as a result of a metamorphism of carbon-siliceous shales primarily enriched in ore metals. Based on the analysis of research results in the formation of industrial mineralization of deposits in carbon-siliceous shales, we distinguish the following main milestones and stages:

1. The formation of carbon-containing siliceous silts in genesis of rifts zones, the origin of which is most likely dated to Riphean, dressed by various metals.

2. The formation of carbon-containing metasomatic microquartzites (quartzitolites), most likely at the end of the Caledonian era (S2-D1), which was also possibly accompanied by a redistribution of uranium and a number of chemical elements (V, Mo, Se, Cu, Ag, Au, Zn, TR, etc. .).

3. The formation of tectonic-magmatic structures at the orogenic stage of development at the end of the Late Hercynian era in the Late Palaeozoic (C3-P1), accompanied by the introduction of granitoids and the occurrence of various hydrothermal processes, including, possibly, the formation of primary hydrothermal oxide uranium mineralization with metal sulphides.

4. Development in the Mesozoic (mainly Early Cretaceous) of the residual soil, which led to the redistribution of mobile components and to erosion of already, formed primary deposits.

5. The occurrence of the Neogene-Quaternary stage of tectonic activation of the region, which was accompanied, inter alia, by hydrothermal activity, which caused metasomatic changes in the enclosing rocks, and, accordingly, additional redistribution of uranium.

6. Occurrence of Neogene-Quaternary exogenous processes of oxidation and redistribution of previously formed poor uranium ores with the formation of oxidation zones (uranium glists) and, possibly at a depth - zones of secondary concentration. Uranium and mobile foreign-metal impurities with variable valency migrated, which led to permeable sedimentary sediment cover.

An analysis of the patterns of distribution of uranium deposits in black carbon shales within the ore regions of Central Kyzylkum under consideration reveals their concentration in certain ore-bearing blocks and a tendency to tectonic knots. All uranium deposits are confined to specific folded-discontinuous structures and spatially gravitate to certain lithological-stratigraphic rock complexes, and are also often located within large geochemical anomalies and anomalous fields. Among the main local criteria that determine the conditions for the formation of uranium deposits (ore fields), there are distinguished structural, metamorphic, geochemical, mineralogical, lithological-stratigraphic, hydrogeological criteria reflecting the preservation of mineralization, landscape (erosion, morphological, etc.). In Western Uzbekistan, the main geological criteria that created favourable conditions for uranium ore formation on an industrial scale basis are considered based on materials from the Djantuar deposit, which is the most typical in terms of occurrence of various criteria and the largest, explored and studied in detail, including by us. To compare, supplement and summarize the data, as well as to confirm some conclusions, data on deposits and ore occurrences of the Altyntau ore field (Southeastern Bukantau), as well as ore occurrences Boztau (Bukantau) and Ustuk (Northern Nuratau) were used.

### 2.2 Structural Criteria

One of the important structural criteria that led to the occurrence of ore-forming processes is the tectonic position of deposits in the structures of the ore area. The tectonic position of the largest deposits in the world is determined by their confinement to rather large tectonic knots [6], formed by a complex combination of heterogeneous structural elements. The Djantuar deposit is located in the southern marginal part of the orogenic arched uplift. This deposit and a series of ore occurrences that form the southern ore field are confined to the most mobile part of the Auminzin arched uplift with a large intrusion of the same name of the late Hercynian granitoids in the core part, elongated in the form of an oval in the sub-latitudinal direction and formed at the orogenic (Perm-Carbon) stage of development. At the same time, the field is located in a large horst structure, formed in the Alpine era of Neogene-Quaternary activation and largely inherited the Late Palaeozoic orogenic uplift. One of the most important structural features is the well-defined confinement of the field to the powerful, extended and long-lived sub-latitudinal South-Auminzatau-Beltau deep-seated tectonic zone, within which it gravitates to a complex site of joining and intersection of its steeply falling joints with longitudinal (subconcordant) (north-western and secant north-eastern) ones, as well as submeridional explosive faults. At the same time, the deposit is located in the southern exocontact of the Auminzin intrusive massif of late Hercynian granitoids and is localized among favourable rocks in the halo of contact metamorphism. It is noteworthy that the intrusive contact of granitoids, generally oriented along the zone, disturbed by tectonic discontinuities and accompanied by fracture zones, coincides in stretch and in general in dip with ore-bearing rocks. Moreover, within the ore-bearing section of the exocontact zone of granitoids, a complex branching belt of dikes of acidic, middle and damprophyric composition of sub-latitudinal and north-eastern directions is developed. The main ore-bearing structure of the deposit is a strongly constricted and deep synclinal, isoclinic fold, the core of which is made by a sequence of highly deformed carbon microquartzites of double thickness. The flatter wings (folds) are composed of the underlying sequence of deployed phyllites, often quartz and also containing horizons and strata of microquartzites. The folds are dissected by numerous and steeply falling, mainly small-amplitude discontinuous faults, both longitudinal (subconcordant) and secant - mostly sub-latitudinal, as well as less commonly north-eastern and submeridional. All the ore occurrences studied by us meet the considered criterion for mineralization localization. Ore-bearing black shale strata are characterized by distinct stratification and are represented by the alternation of carbon-bearing siliceous and phyllite rocks that are contrasting in lithological composition and physicomechanical properties, in which brittle deformations under the influence of tectonic stresses occurred in different ways. This led to the widespread development of interstratal and intraformational disturbances and breccias of various origins, creating increased permeability of rocks. In accordance with the favourable structural and structural-lithological conditions noted above, which determined the localization of uranium mineralization within such deformed zones and sections, the morphological features of ore deposits also occurred. Complex uranium deposits and ore occurrences of the Altyntau ore field in the southeastern part of Bukantau [7, 11-13] and the Boztau ore cluster of the central part of Bukantau occupy a somewhat different, but at the same time, largely similar tectonic position. The analysis of various geological materials and the results of personal field observations allow us to conclude that the Altyntau ore field is confined to a large, complex, long-lived ring-shaped dome structure dissected by a system of sub-wide and different-age faults (in the south); submeridional (in the west) and meridional (in the east) directions, as well as a series of low-amplitude faults of north-eastern stretch. The development of ring and semicircular disorders is also noted. In the central (core) part, the dome structure was interrupted by an intrusive (15 × 15km2) multiphase hypabyssal late Hercynian granitoids (C3-P1) of the orogenic stage of development. Their southern part, at least 10 km wide, is covered by a sedimentary cover. The alpine and modern structure of this ore cluster is a rather large horst-anticlinal structure, limited in the west and east by submeridional and meridional faults. As can be seen from the figures, all ore bodies are confined to the areas of development of thick plates of carbon-siliceous shales of Kokpatas suite. The vast majority of uranium deposits and ore occurrences are located within a large horst-anticlinal structure. Complex stratiform deposits and ore occurrences are localized in microquartzites of Kokpatas suite, located in a semicircle in the limb of folds and concentrated in certain structural clusters. In the north there is Khojaakhmet deposit, Chulkaratau ore occurence and others, and in the east - a series of ore occurrences Lozovoye, Djilandy and others, stretched in a chain along the meridional faults. A number of small ore occurrences of uranium are known among granitoids. In complex (multi-element) deposits localized in the black shale stratum of the folded basement, the primary pitchblende mineralization is controlled not only by lithological criteria (carbon microquartzites), but by steeply falling fractures of different directions in combination with layered stripping (Fig. 1-3).

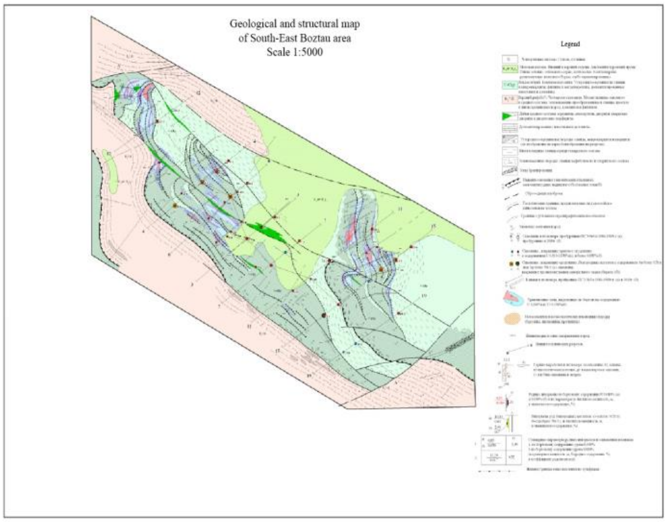

***Fig 1.*** *Geological and structural diagram of Boztau area.*

## 3 CRITERIA

Below are the main criteria for identifying black shale type deposits.

### 3.1 Lithological and Stratigraphic Criteria

These criteria are related to the confinement of industrial uranium mineralization to carbon-containing siliceous shales formed as a result of silicon metasomatism from terrigenous deposits of Taskazgan, Kokpatass, and Suvliksai suites.

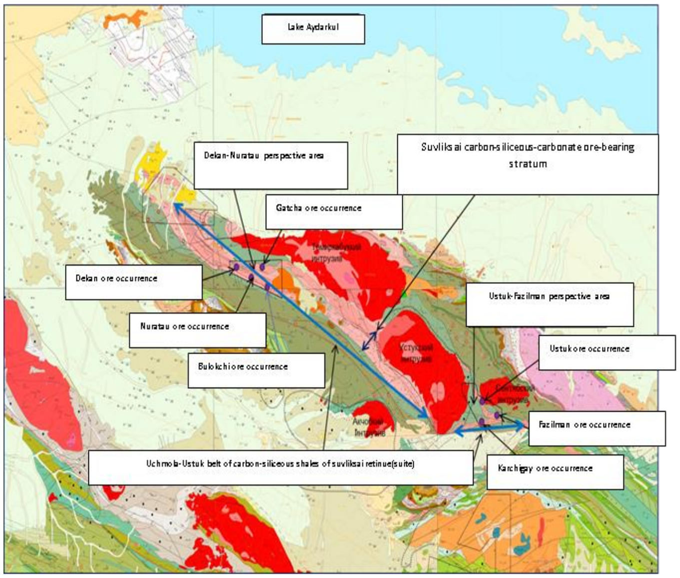

***Fig 2.** The geological and structural diagram of the ore occurrence of South-East Boztau.*

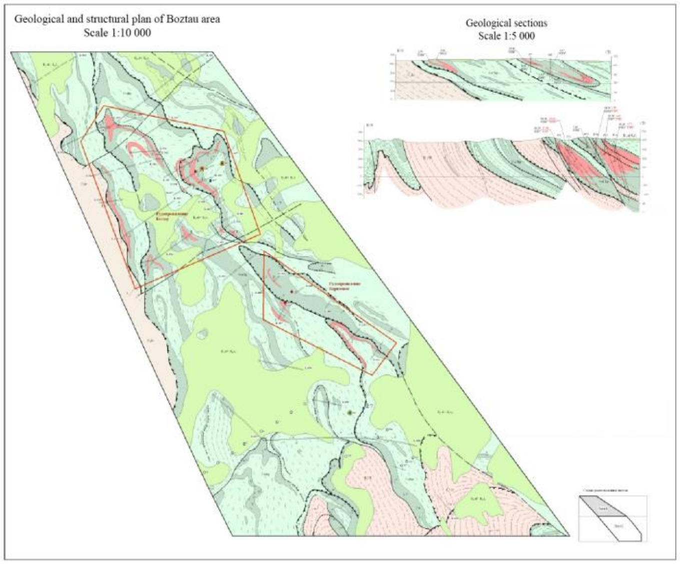

***Fig 3**. Overview geological map of the Nuratau uranium ore area.*

The primary composition and structure of this ore-bearing stratum had a significant impact on the development of silicon metasomatism. In the lower part of the section, primarily composed of alternating carbonate and silt-clay deposits, thick formations of carbon microquartzites are more localized, mainly near tectonic zones. Uranium deposits are confined to different parts of the section of Kokpatass, Taskazgan and Suvliksai suites. At the same time, a large scale of uranium mineralization has been established in the deposits of Auminzatau area, the Altyntau ore field and others, confined to the upper part of its section with a significant distribution of powerful carbon siliceous shales, which, with all other things being equal, are most favourable for ore localization. In our opinion, the influence of the lithological-stratigraphic criterion on the formation of uranium mineralization mainly affects this.

### 3.2 Mineralogical Criteria

Mineralogical criteria include a complex of multi-age and multi-type mineral associations formed at different epochs and stages of development of ore-bearing structures, which reflect the duration and multi-stage occurrence of various ore-forming processes within the deposits. The presence of mineral associations - pitchblende, vanadium oxides, various sulphates (barite, Celestine, alumstone, etc.), carbonates, kaolinite, zeolites usually with pyrite, copper pyrite and other sulphides indicates the occurrence of a multi-stage hydrothermal stage, which is associated with the deposition of primary uranium concentrations and the formation of primary uranium mineralization. All these mineral associations are direct indicators of the endogenous processes in different ages - Hercynian and Alpine, which can serve as mineralogical criteria. Mineralogical criteria are expressed in the formation of a distinct supergenic vertical mineralogical zonality occurred with different completeness and intensity in most uranium deposits of the province in question. According to our research, within the framework of various deposits, ore occurrences, and promising areas, two main zones are distinguished from top to bottom: uranium-micaceous (uranyl-vanadate and uranyl-phosphate mineral associations) and pitchblende-black with chalcosine, covelline, etc. The depth of its development reaches more than 200 m at the Djantuar uranium deposit, about 350 m at the Boztau ore occurrence, about 300 m at Ustuk and others. Below is a zone of primary pitchblende-black, less commonly, pitchblende-coffinite and pitchblende-brannerite mineralization with various sulphides (copper pyrite, mock ore, molybdenite, arsenic iron, etc.). However, as already noted, its formation is also most likely associated with the occurrence and development of surface oxidation processes. The formation of supergene mineralogical zonation is mainly due to the active infiltration and circulation of ground oxygen water through cracks as a result of tectonic activation of uranium ore areas in the Alpine Neogene-Quaternary stage of the region's development. This is indicated primarily by the correspondence between the depths of its distribution and the current level of groundwater (from 90 to 300 m) at most uranium deposits that reach the day surface (Djantuar, Rudnoe, Koscheka) and ore occurrences (Khojaakhmet, Lozovoye, Novoe, Boztau, Ustuk and etc.), as well as the complete absence of signs of it at uranium deposits blocked by the Mesozoic platform cover (Djitym) [104]. However, it is likely that earlier (Cretaceous) processes of chemical rocks rot took part in the formation of this supergene mineralogical zonality. The latter had a significant impact on the preliminary preparation of ore-bearing rocks for subsequent active groundwater infiltration and various chemical reactions.

### 3.3 Geochemical Criteria

These criteria primarily mean the general geochemical specialization of a certain type of rock (carbon siliceous shales) of the black shale stratum for uranium, vanadium, molybdenum, selenium, zinc, copper, silver, rare earth elements and others. Their increased concentrations in aggregate form geochemical anomalies of varying sizes and unequal in contents in the area of the ore cluster, deposits and individual promising areas, combined into anomalous fields and significantly distinguishing them from the adjacent non-ore-bearing areas of the ore areas. Depending on the scale of occurrence, these criteria can be both regional and local. In general, they reflect the uranium content of certain blocks - local sections. Under favourable conditions for the occurrence of uranium-bearing rocks, during the presence of a large proportion of the "mobile" form of uranium and the active (pressure) hydrodynamics of oxygen waters, these rocks could serve as an additional source of uranium and related metals. Based on geochemical studies [53, 55, 64, 105] within promising areas and ore occurrences, we came to the conclusion that all deposits are located in a complex polyelement geochemical field and are accompanied by halos of rare-earth elements of the yttrium group (in particular, yttrium), silver, lead, copper and zinc, barium, chromium, cobalt, molybdenum, scandium, sometimes selenium, vanadium. Moreover, deposits often spatially gravitate towards the peripheral parts of anomalies with reduced background uranium contents in the rocks. On this basis, we conclude that there are zones (sections) of the removal of this element around ore objects hidden at a depth. Our studies in the territory of the Altyntau, Boztau, Ustuk, Auminzatau districts did not indicate zones of significant removal of uranium and related elements from the host rocks around or adjacent to ore deposits, and this is due to the fact that all these objects were exposed to erosion, and we observe the upper parts of the ore sections where redistribution of uranium and associated ore elements occurs, therefore, their constant gain occurs. Therefore, in our opinion, this feature can be considered as a fairly obvious geochemical criterion for the formation of industrial mineralization at a depth. More precisely, the absence of uranium anomalies on the surface during the presence of abnormal concentrations of the above elements, the absence of radioactive anomalies cannot be a reason for refusing to study this area to a depth by drilling. Geochemical halos of elevated concentrations of uranium and related elements (Mo, Zn, Cd, Ag, TR, Se, Sc, etc.), which are clearly superimposed in the Altaintau field, as well as in the Boztau, SE-Boztau and Ustuk sections, are established different rocks of the black shale sequence. Such halos and anomalies developed within or around known uranium deposits and ore occurrences apparently reflect dispersion halos, which can be considered as geochemical criteria for the presence of mineralization exposed by erosion. Geochemical studies of vertical supergenic zoning in the ore occurrences of Boztau, Ustuk and some areas within the eastern part of the Altyntau ore field revealed certain differences in the behaviour of a number of related ore elements in it. So, we managed to find out that for each lateral type of uranium ores certain indicator elements are characteristic that form abnormal concentrations: for uranium-micaceous - molybdenum, REE, for pitchblende-black - selenium, lead, chromium, REE, for pitchblende-coffinite - zinc. At the same time, in all mineral associations of different types of ores, the presence of “through” elements-companions of uranium — cobalt, yttrium and scandium — has been established. The formation of vertical geochemical zoning is also associated mainly with exogenous processes. As noted earlier, when describing the relevant regional factors, chemical rotting processes within uranium deposits led to the removal of uranium and related elements from ore-bearing rocks and ores located in the upper-middle parts of the residual soil profile, and were concentrated in the lower parts of the ore-bearing rock strata of Kokpatask, Suvliksai and Taskazgan suites.

### 3.4 Hydrogeological Criteria

These criteria reflect the hydrogeological conditions of deposits and ore occurrences of known uranium ore areas lying among the black shale stratum of the folded base of the platform, which are mainly determined by the dynamics of infiltrated fractured underground oxygen-containing waters and the depth of their penetration from the surface through permeable structures and bedding rock. It is natural and logical to assume that these conditions varied in stages of development depending on the tectonic, geomorphological, landscape, and climatic conditions of the ore areas. The formation of geomorphological uplifts — the horst structures of Auminzatau, Beltau, Bukantau, Tamdytau, Northern Nuratau and others — led to an intensification of the dynamics of groundwater, an increase in the depth of their penetration, and the emergence of discharge centres along the periphery. The structural situation of this period was determined by the development of numerous heterogeneous violations, layer-by-layer breakdowns of rock brecciaing areas and zones, delamination and karst pore spaces, leaching pore spaces, caver and porosity of siliceous rocks, their fracturing, etc. The permeability of structures and host rocks has increased especially in connection with movements along faults at the Neogene-Quaternary and modern stages of Late Alpine activation. Repeated differentiated raises of the territory of ore fields and deposits at the last Neogene-Quaternary and modern stage of development caused significant changes in the level and hydrodynamics of underground fissure water in ore-bearing rocks. In turn, this led to the intensive development of the processes of transformation of uranium mineralization with the formation of the vertical supergenic mineralogical and geochemical zonality described above. On an individual basis, we observed this process in the southern part of the Altyntau ore field, when drilled airblast wells with depths of up to 70-80 m exposed ore sections and anomalies in black shales, and a couple of hundred meters on an adjacent profile located lower in the direction of groundwater movement, sample analysis revealed increased uranium content with a coefficient of radioactive equilibrium many times shifted towards uranium. Further, to the south uranium passed into the Lower Cretaceous sediments of sedimentary cover.

### 3.5 Safety Criteria for Uranium Mineralization

These criteria include the geological conditions for the existence of uranium deposits in their multi-stage post-ore development history and their transformation under the influence of endogenous processes. Their occurrence strongly depends on the degree of the post-ore erosion section, as well as on the penetration depth and intensity of supergenic transformations, which are very different for the uranium deposits and ore occurrences under consideration and are primarily due to the vertical amplitude of local raises formed in connection with differentiated tectonic movements within the ore areas. These criteria include the degree of erosion level, as well as the depth and intensity of the supergenic transformation of uranium mineralization in various deposits of the Central Kyzylkum province. We carried out the typification of uranium deposits localized in carbon-siliceous shales, according to the bedding conditions, the intensity of occurrences of different types of ore-generating processes and the depths of the erosion section. At the same time, several subtypes of uranium deposits are distinguished in the province, significantly differing in the level of the modern erosion section. Among them, the Djantuar deposit and the Voskhod, Boztau and Ustuk ore occurrences are characterized by a relatively minimal erosion section; Koscheka and Rudnoye are relatively deep; Khojaakhmet and Novoe are characterized by a very deep erosion section. However, not all uranium deposits known within the province were included in this typification. In particular, Djitym and other deposits and ore occurrences, those are blocked by a platform cover and are not affected by the processes of the post-Mesozoic destruction. In our opinion, most likely the depth of the erosion section in the territory of ore objects covered by a sedimentary cover is generally estimated to be insignificant. The depth and intensity of the development of crust formation processes reflects the criterion of supergenic transformation of uranium deposits, oxidation and transformation of metamorphogenic poor mineralization, which are due to the combined influence of most local exogenous criteria. In this regard, it should only be noted here that the uranium deposits of this province differ significantly by the degree of their supergenic transformation. Deposits of the Auminzatau ore field, which have a small vertical span (up to 150-200 m), are almost completely processed by the processes of supeergenesis and in their present form are mainly represented by uranium-micaceous ores. The uranium deposits of the Altyntau ore field (Khodjaakhmet, Lozovoye, Novoe, etc.) underwent much less supergene transformations, limited mainly by a depth of about 100 m, and below it, uranium-micaceous ores are replaced by primary mineral associations with pitchblende and uranophane. Deposits such as Dzhitym, overlapped by Mesozoic-Cenozoic sedimentary deposits with a thickness of more than 100 m, practically do not bear signs of supergenic transformation of ores. This is determined by the absence of secondary uranium-micaceous mineral associations and the almost complete absence of iron oxides, etc. Thus, it is concluded that the black shale type deposits of the Kyzylkum uranium ore province are characterized by a wide range of variations in the degree of mineralization preservation as a result of erosion and mineralization transformation from weak to very strong material-chemical processing of the ore composition.

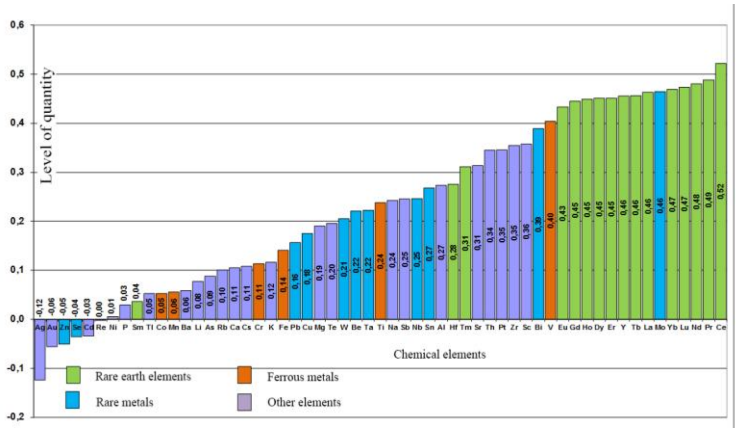

***Fig 4.*** *Histogram of the correlation of chemical elements with uranium.*

# 4 RESULTS AND DISCUSSION

## 4.1 Results of Application of Estimation Method

Geochemical Characteristics of Ores of Black-Shale Type.

The solution of the tasks was achieved, firstly, by creating a specific network for the selection of geochemical, channel and kernel samples from bedrock along the territory of the Altyntau (South-Eastern part of Bukantau) and Ustuks (Northern Nuratau) sites, as well as according to the assessment work in Boztau area (Bukantau). Their subsequent processing and analysis of samples in uniform measurement standards, and its subsequent statistical processing using computer software made it possible to create a complex of geochemical data. For the qualitative and quantitative characterization of mineralization, all lithochemical, channel, and kernel samples were analyzed by a modern highly-sensitive mass-spectrometer (ICP-MS) with inductively coupled plasma of AgilentTechnologies for 62 elements. Statistical processing of the results of the analysis of samples from the Ustuk site determined the correlation of chemical elements with uranium and a list of industrially valuable useful components present in the ore. Based on the results of statistical processing it follows that the maximum positive correlations with uranium are:

- Rare earth elements and especially ceric group;
- Of the rare ones - molybdenum, bismuth, algam, beryllium and tungsten;
- From black ones - vanadium and to a lesser extent titanium, iron, chromium (Fig. 6.1, 6.2).

Three geochemical associations of rare-earth elements with a maximum positive correlation between each other and approximately equally equal correlation with uranium were established (Fig. 4, 5). At the same time, two separate independent groups of elements Zn + Ni + Be and Cu + As + Sec were distinguished by sufficiently high correlation bonds with copper and between themselves and an extremely low value (0.2-0.24) with U + V + Mo associations [13]. It follows from the histogram and correlation scheme of the elements that uranium has a positive correlation with the rare-earth elements of both the cerium group (Ce, La, Pr, Nd, Sm) and the yttrium (Y, Er, Lu, Yb, Du, Ho, Tm) and terbium (Gd, Eu, Tb) groups [13].The table below shows the correlation of chemical elements with rare-earth elements (Table 1), which indicates the complex (uranium-rare-metal-rare-earth) nature of mineralization. In total, up to 30 types of useful elements with relatively high correlation bonds and fairly high contents (main REE, U, V, Mo and associated Hf, Pt, Sc, In, Cu, Zn, Ni, W, Ti, Be, Zr, Sr) were established. It should be noted that although there is no correlation between uranium and selenium on the surface, it increases with depth (according to the results of processing kern samples). Uranium in this case has a high bond with molybdenum, vanadium, selenium, molybdenum and rare earth metals. It follows from the table that “the rare-earth group of elements has a high level of correlation with vanadium (0.68), zirconium (0.65), scandium (0.6), bismuth (0.57), chromium (0.57) hafnium (0.52), uranium (0.52) and titanium (0.41), and with such metals as molybdenum, copper, zinc, nickel, beryllium and tellurium, the average (0.30-0.39) level of bonds."

***Table 1.*** *Correlation of chemical elements with rare earth elements.*

| Elements | | Ti | Li | Be | Na | Mg | Al | P | K | Ca | Sc | V | Cr | Mn | Fe | Co | Ni |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Cerium group | | 0.51 | 0.14 | 0.26 | 0.30 | 0.16 | 0.52 | 0.13 | 0.24 | 0.27 | 0.67 | 0.68 | 0.56 | 0.13 | 0.17 | 0.16 | 0.30 |
| Terbium group | | 0.39 | 0.07 | 0.26 | 0.21 | 0.15 | 0.40 | 0.08 | 0.13 | 0.32 | 0.58 | 0.69 | 0.60 | 0.18 | 0.14 | 0.11 | 0.33 |
| Yttric group | | 0.35 | 0.10 | 0.36 | 0.14 | 0.25 | 0.35 | 0.06 | 0.11 | 0.40 | 0.54 | 0.64 | 0.53 | 0.25 | 0.21 | 0.14 | 0.37 |
| ∑ REE | | 0.41 | 0.10 | 0.32 | 0.20 | 0.21 | 0.41 | 0.09 | 0.16 | 0.36 | 0.60 | 0.68 | 0.57 | 0.21 | 0.19 | 0.14 | 0.35 |
| | | | | | | | | | | | | | | | | | |
| Elements | | Cu | Zn | As | Se | Rb | Sr | Zr | Nb | Mo | Ag | Cd | Sn | Sb | Te | Cs | Ba |
| | | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 |
| Cerium group | | 0.38 | 0.30 | 0.29 | 0.07 | 0.19 | 0.36 | 0.72 | 0.55 | 0.35 | 0.07 | 0.00 | 0.30 | 0.22 | 0.38 | 0.22 | 0.42 |
| Terbium group | | 0.34 | 0.36 | 0.29 | 0.04 | 0.11 | 0.26 | 0.64 | 0.47 | 0.27 | -0.04 | 0.04 | 0.30 | 0.25 | 0.37 | 0.13 | 0.36 |
| Yttric group | | 0.32 | 0.36 | 0.30 | 0.06 | 0.11 | 0.23 | 0.59 | 0.48 | 0.30 | 0.07 | 0.07 | 0.37 | 0.22 | 0.39 | 0.14 | 0.28 |
| ∑ REE | | 0.35 | 0.35 | 0.30 | 0.06 | 0.13 | 0.28 | 0.65 | 0.51 | 0.31 | -0.06 | 0.05 | 0.34 | 0.23 | 0.39 | 0.16 | 0.34 |
| | | | | | | | | | | | | | | | | | |
| Elements | | Hf | Ta | W | Re | Pt | Au | Tl | Pb | Bi | Th | U | | | | | |
| | | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | | | | | |
| Cerium group | | 0.61 | 0.47 | 0.09 | 0.05 | 0.49 | -0.06 | 0.31 | 0.38 | 0.56 | 0.64 | 0.50 | | | | | |
| Terbium group | | 0.51 | 0.37 | 0.08 | 0.07 | 0.48 | -0.05 | 0.25 | 0.34 | 0.56 | 0.53 | 0.45 | | | | | |
| Yttrium group | | 0.46 | 0.34 | 0.14 | 0.07 | 0.48 | -0.01 | 0.20 | 0.26 | 0.56 | 0.48 | 0.62 | | | | | |
| ∑ REE | | 0.52 | 0.39 | 0.11 | 0.07 | 0.49 | -0.04 | 0.24 | 0.32 | 0.57 | 0.55 | 0.52 | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Correlation relationships | | | | | |
| | 0.22 | Weak (0.2-0.3) | 0.39 | Medium (0.3-0.4) | 0.51 | Strong (> 0.4) |

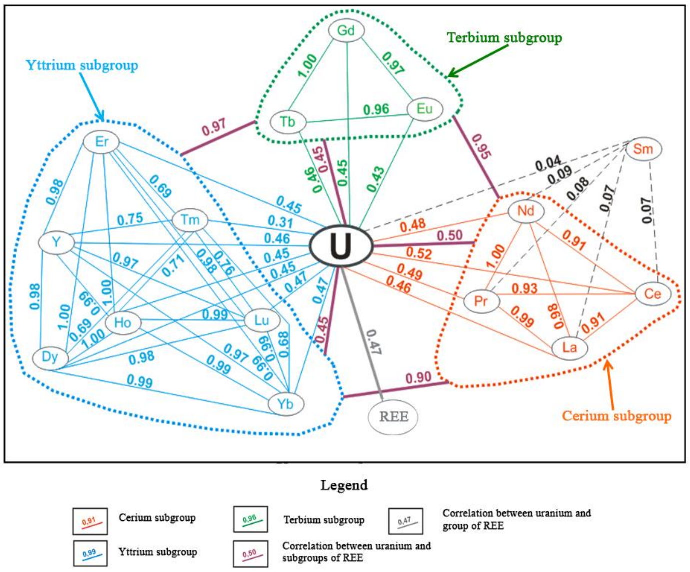

***Fig 5***. *Correlation between uranium and rare earth elements (Suvliksai Formation, Northern Nuratau).*

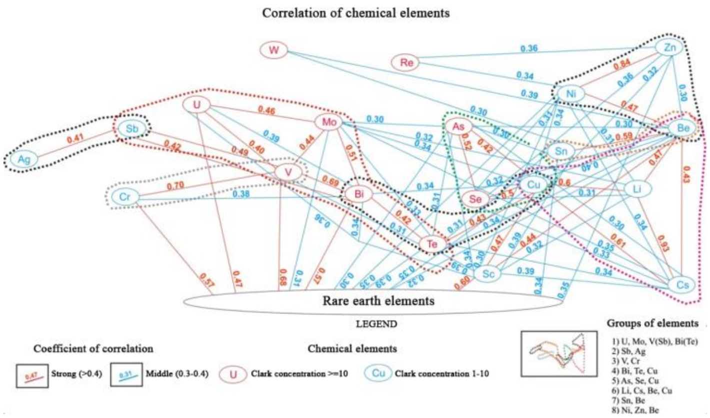

***Fig 6***. *Correlation of chemical elements.*

Elements such as tungsten, rhenium, silver, antimony and caesium are kept apart and have no correlation with rare earths and uranium. This is clearly seen in the following summary scheme of correlation bonds of chemical elements (Fig. 6). A particularly close positive correlation has been found between the contents of uranium and vanadium, titanium, molybdenum, bismuth, and rare-earth elements," both at the surface and at depth, where correlation increases with depth. "There is a weak positive correlation of uranium with metals such as scandium, hafnium, algam, niobium, beryllium, tungsten, copper and others [13]. Using the Surfer software, the geochemical halos of the chemical elements were delineated: U, V, Mo, Ti (Fig. 7) and Ni, Zn, W, Cu (Fig. 8) based on X-ray fluorescence analysis of samples by lithological and facial profiles.

1. Spatial combination of intense halos of chemical

elements representing uranium-rare-metal-rare-earth mineralization, with areas of development of scheelite-bearing skarns and skarnification zones developed along the Early Palaeozoic carbon-carbonate-siliceous shales (figures ...);

2. Vanadium and molybdenum have the broadest halo of distribution in scale and intensity; halos of all other elements are located in the outline of the anomalies of these two elements;
3. “Halo of abnormally high tungsten contents gravitate toward the zone of scheelite-bearing skarns; outside it, tungsten is occurred either by moderately low halos or by separate nest-like occurrences of medium and high contents”;
4. Anomalously high uranium contents in the bulk are combined with the zone of development of scheelite-bearing skarnoids and near-contact suture zones of intraformational faults (overthrusts), and, in general, over the entire outline development of the rocks of the Suvliksai suite. Low content halos generally form a relatively wide halo, remaining in the contours of the rocks of the Suvliksai suite;
5. Elements of the group of rare earths having a directly positive correlation with uranium form halos of almost identical in configuration to it:
6. The halos of vanadium and molybdenum are also combined with anomalies of uranium and rare earth metals;
7. Titanium forms intense halos localized mainly along the periphery of the outlines of uranium halos. The halos of copper and zinc have a certain offset from the outline of the halos of uranium, remaining within the limits of the development of rocks of the Suvliksai suite;
8. The halos of Bi, Sn, Nb, Ta, Be are mainly nest-like, isolated, low-stretched, and low-thick; they are controlled, most of all, by the areas of development of the scanning zones of carbon-siliceous shales.

Based on the high level of correlation of uranium with rare earth elements, vanadium and molybdenum, as well as rare earths with U, V, Mo, Sc, In, Cu, Zn, Ni, W, Ti, Be, Zr and Sr, with taking into account the presence of isolated dressed tungsten blocks in the outline of rare-earth ore bodies, the complex (uranium-rare-metal-rare-earth) mineralization character is established.

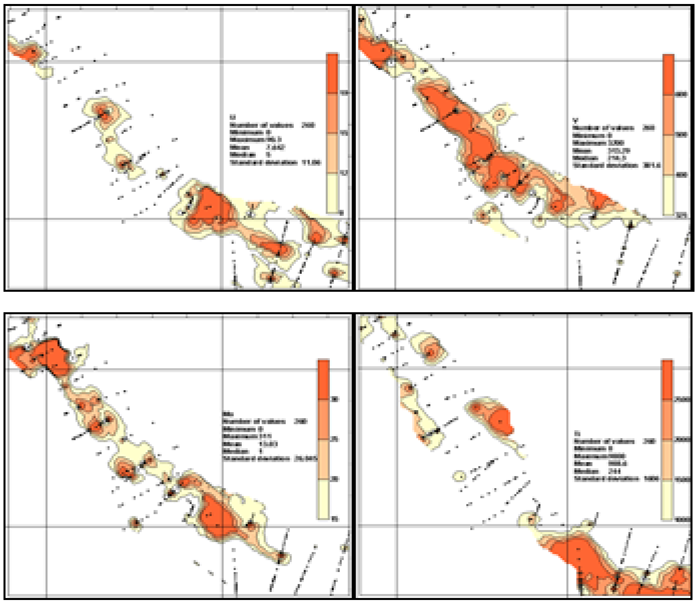

***Fig 7**. Geochemical halos of chemical elements: U, V, Mo, Ti.*

It should be noted that previous studies, using the example of Bukantau (Boztau site), established a high correlation of uranium with vanadium, molybdenum and yttrium in the aeration zone and with vanadium, selenium, molybdenum, yttrium, gold and silver below the groundwater level. Many researchers have also noted the relationship of uranium with gold and rare metals [11-14]. The East Altyntau section (an area of 40km2) is located in the position of the north-eastern and eastern end and exocontacts of the Altyntau intrusion (see Fig. 9). The site area is composed of three main rock complexes - granitoids and metamorphic rocks of the Kokpatass and Khojaakhmet suites.

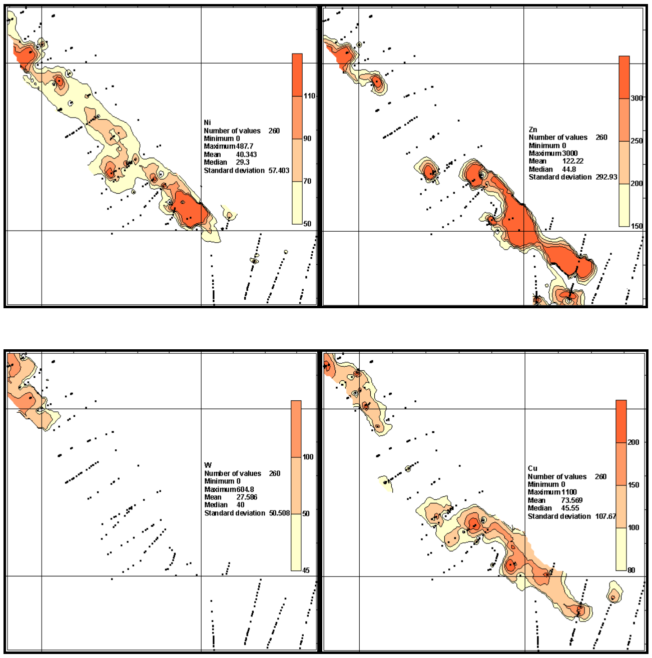

***Fig 8.** Geochemical halos of chemical elements: Ni, Zn, W, Cu.*

The site is characterized by the development of polygenic and polychronic mineralization of rare metals, uranium, anomalies of rare-earth elements, abnormal contents of Au, Pt, Bi, Rb, etc., as well as chalcophylic elements - Zn, Cu, Ag, Pb. We studied the intrusive formations of the Altyntau intrusion (C3-P1) [6-7, 12] in detail and they are represented by the following rocks:1) Biotite granites and gray adellites of the main phase; 2) Later pink mica granites; 3) Aplites and pegmatites in the intrusion and rocks of the bale. In granitoids and pegmatites from among rare-earth minerals, monazite and xenotime are established. The Kokpatass suite (R2-3) is composed of carbon phyllite-like quartz-fieldspar-micaceous, siliceous-micaceous and carbon-siliceous shales, quartzites with different contents of carbonaceous matter. The Khojaakhmet suite (V-Є1) is composed of interbedded metaterrigenous and siliceous rocks, which, when taking a sample, were diagnosed as phyllitic sericite, sericite-quartz, siliceous shale, and quartzites to various degrees dressed with carbon material. According to Z.M. Abduazimova, the terrigenous type of section is typical for the Khojaakhmet suite, and siliceous rocks can be tectonic blocks and lentils of rocks of the Kokpatas suite, therefore their belonging to the stratigraphic unit requires special studies. Based on the geological and geochemical data of S.M. Koloskova [12], complex anomalous of geochemical field of high contrast and intensity, and four types of geochemical associations that are promising for mineralization, were identified. It should be noted that the spatial combination of geochemical anomalies of rare-earth metals, vanadium, molybdenum, and uranium is confined to the outcrops of rocks of the Kokpatass suite, namely, plates of carbon-siliceous shales.

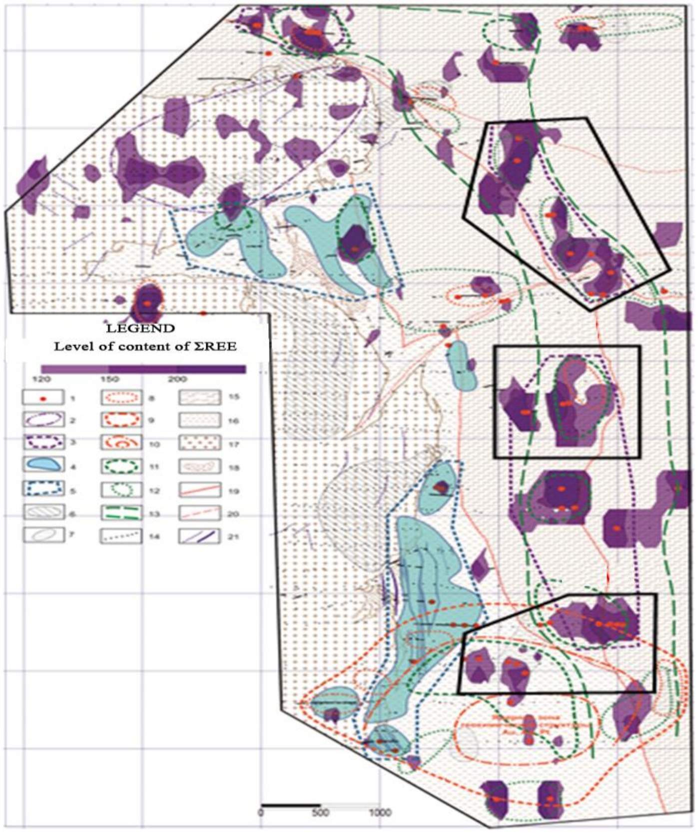

***Fig 9**. Schematic forecast-geochemical map of the Eastern Altyntau section (10,606 samples from primary geochemical halos). (Compiled by S.M. Koloskova).*

However, the absence of uranium anomalies on the surface should not serve as a negative criterion, and in this case, a negative assessment of the sites for setting up prospecting works is premature. Drilling of air blast wells in the areas of distribution of rocks of the Kokpat suite in East Altyntau revealed that during the absence of radioactive anomalies and mineralization points on the surface, gamma anomalies appear with depth. And the coefficient of radioactive equilibrium is shifted towards uranium, which indicates its removal from the surface and concentrations with depth. This provision is subject to the results of work carried out in the period from 2010 to 2012 in the areas of Boztau and Southeast Boztau [6, 9, 11, 14, 15, 16]. Rare-earth elements and yttrium: 1 - Abnormal geochemical points of the contents of the sum of REE + Y; 2 - Area of accessory mineralization of rare-earth metals in granitoids; 3 - Complex anomalous geochemical fields (CAGF) of high contrast intensity, promising for search of rare-earth mineralization. Rare metals (Be, W, Sn, Ta, Nb, Bi, Sb): 4 - CAGF fields of rare metals of high intensity; 5 - CAGF of high contrast and intensity, promising for search of rare-metal mineralization; 6 - CAGF of rare metals of low intensity - areas of diffuse mineralization; 7 - Halos of antimony. Precious metals (Au, Pt, Ag): 8 - Anomalous geochemical gold fields of increased contrast and intensity; 9 - CAGF of gold and satellite elements of high contrast and intensity, promising for the search for gold-platinum mineralization; 10 - Elements of the geochemical structure of gold anomalies - the boundaries of the nuclear and frontal zones of the ore-forming system. Radioactive and foreign-metal impurities (U, Th, Zn, V, Cu, Mo): 11 - CAGF of high-contrast and high-intensity that are promising for the search for mineralization of radioactive and related metals; 12 - CAGF of increased contrast and intensity of radioactive and foreign-metal impurities; 13 - Ore-bearing strip (zone) of development of the adjacent CAGFs of rare-earth, radioactive and non-ferrous metals, promising for the search for mineralization; 14 - Places of sampling for furrow, kern and geochemical samples. Elements of the geological structure: 15 - Deposits of the Kokpatass suite, R2-3; 16 - Deposits of the Khojaakhmet suite,V-Є1; 17 - Outline of granitoids of the main phase (gray granites), 18 - Outline of granitoids of the final phases (red granites). 19 - Inter- and intraformational sub-concordant faults; 20 - Intersecting faults; 21 -Quartz veins, pegmatitic bodies. PU is a prospective site for identifying complex uranium-rare-metal-rare-earth mineralization hidden at depth. We processed channel samples taken from surface mine workings (ditches) with different spatial localization of ores (from two siliceous plates No. 1 and No. 2) in order to study the mineralization characteristics in the aeration zone. Further, kern samples from wells that uncovered uranium mineralization below the level of underground fractured water were subjected to a similar treatment. At the same time, sampling was compiled for both the main productive stratum (carbonaceous siliceous and fillowite-like rocks of the Kokpatass suite) and for bodies of mouldy intrusive rocks containing uranium mineralization. Based on the statistical processing of channel samples, the following geochemical characteristics of ores were obtained from the analysis results (Table. 2, Fig. 10).

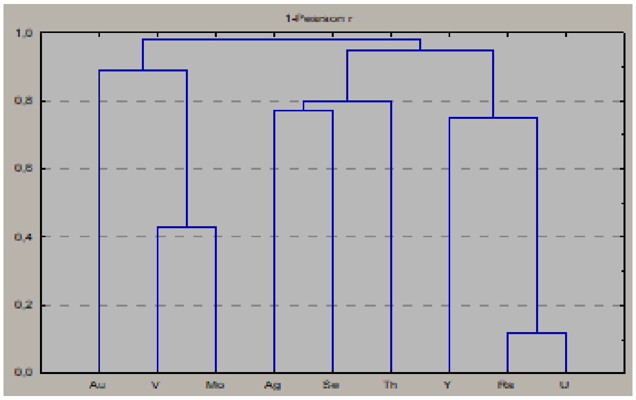

***Fig 10**. A layer of carbon-siliceous shales No. 1*

Dendrogram of links of elements in the aeration zone for sikes (According to quantitative analysis, 305 samples) Vanadium is associated with molybdenum, to a lesser extent with selenium and uranium. This is due to the fact that selenium and uranium migrated to the lower layers of the plate, vanadium remained in the area of the “vanadium” barrier” (see model), and molybdenum only began to migrate.

***Table 2**. A layer of carbon-siliceous shales No. 1*

Pair correlation coefficients of elements in the aeration zone according to the results of quantitative analysis (Sampling - 305 samples)

| | U | Th | Se | Y | Mo | Ra | Au | Ag | V |
|---|---|---|---|---|---|---|---|---|---|
| U | 1.00 | 0.08 | 0.26 | 0.25 | 0.02 | 0.88 | -0.03 | -0.06 | 0.16 |
| Th | 0.08 | 1.00 | 0.19 | -0.01 | 0.00 | -0.08 | -0.05 | 0.21 | 0.09 |
| Se | 0.26 | 0.19 | 1.00 | 0.21 | 0.00 | 0.18 | -0.06 | 0.23 | 0.22 |
| Y | 0.15 | -0.66 | 0.02 | 1.00 | -0.40 | 0.14 | -0.87 | -0.65 | 0.20 |
| Mo | 0.02 | 0.00 | 0.00 | 0.07 | 1.00 | -0.03 | 0.06 | -0.06 | 0.57 |
| Ra | 0.88 | -0.08 | 0.18 | 0.25 | -0.03 | 1.00 | -0.05 | -0.11 | 0.08 |
| Au | -0.03 | -0.05 | -0.06 | -0.08 | 0.06 | -0.05 | 1.00 | -0.06 | 0.16 |
| Ag | -0.06 | 0.21 | 0.23 | -0.01 | -0.06 | -0.11 | -0.06 | 1.00 | -0.01 |
| V | 0.16 | 0.09 | 0.22 | 0.14 | 0.57 | 0.08 | 0.16 | -0. | 1.00 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 01 | |
| | | | | | | | | | |
| Av. | 197.12 | 6.65 | 14.11 | 35.49 | 43.97 | 291.82 | 0.10 | 0.75 | 1,224.23 |
| Clark as per A.P. Vinogradov in shales | 3.2 | 11 | 0.6 | 30 | 2 | 3.2 | 0.003 | 0.1 | 130 |
| Clark of concentration | 62 | 0.6 | 24 | 1.2 | 22 | 91 | | 7.5 | 9 |
| Row of accumulations. | Ra91 U62 Se24 Mo22 V9 Ag7,5 Y1,2 | | | | | | | | |

***Table 3.** A layer of carbon-siliceous shales No. 2*

Pair correlation coefficients of elements in the aeration zone for sikes according to the results of quantitative analysis (Sample - 491 samples)

| | U | Th | Se | Y | Mo | Ra | Au | Ag | V |
|---|---|---|---|---|---|---|---|---|---|
| U | 1.00 | 0.20 | 0.01 | 0.05 | 0.12 | 0.79 | -0.02 | -0.04 | 0.17 |
| Th | 0.20 | 1.00 | 0.15 | -0.01 | 0.07 | -0.02 | 0.04 | -0.07 | 0.00 |
| Se | 0.01 | 0.15 | 1.00 | 0.04 | 0.21 | -0.02 | 0.03 | 0.04 | 0.23 |
| Y | 0.05 | -0.01 | 0.04 | 1.00 | 0.05 | 0.08 | -0.02 | -0.02 | 0.18 |
| Mo | 0.12 | 0.07 | 0.21 | 0.05 | 1.00 | 0.06 | 0.12 | 0.20 | 0.58 |
| Ra | 0.79 | -0.02 | -0.02 | 0.08 | 0.06 | 1.00 | -0.03 | -0.03 | 0.16 |
| Au | -0.02 | 0.04 | 0.03 | -0.02 | 0.12 | -0.03 | 1.00 | -0.02 | 0.04 |
| Ag | -0.04 | -0.07 | 0.04 | -0.02 | 0.20 | -0.03 | -0.02 | 1.00 | 0.07 |
| V | 0.17 | 0.00 | 0.23 | 0.18 | 0.58 | 0.16 | 0.04 | 0.07 | 1.00 |
| | | | | | | | | | |
| Average content | 214.94 | 6.55 | 16.74 | 57.49 | 49.40 | 260.65 | 0.09 | 1.04 | 1,190.99 |
| Clark as per A.P. Vinogradov in shales | 3.2 | 11 | 0.6 | 30 | 2 | 3.2 | 0.003 | 0.1 | 130 |
| Clark concentrations | 67 | 0.6 | 28 | 1.9 | 25 | 81 | | 10 | 9 |
| Row of accumulations. | Ra81 U67 Se28 Mo25 Ag10 V9 Y2 | | | | | | | | |

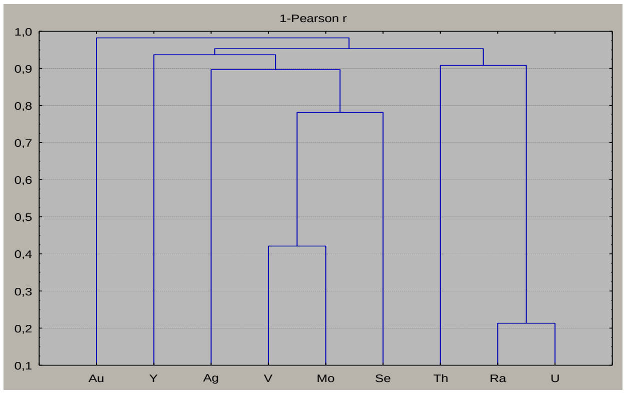

***Fig 11.*** *A layer of carbon-siliceous shales No. 2. Dendrogram of links of elements in the aeration zone for sikes (according to quantitative analysis, sampling - 491 samples)*

It is noteworthy that even in the zone of complete oxidation and removal, vanadium, molybdenum and selenium are interconnected and all three are with uranium. This is probably due to the formation of uranium - bog ore.

***Table 4.*** *A layer of carbon-siliceous shales No. 2. Pair correlation coefficients of elements in the zone of "ore formation" for wells according to the results of quantitative analysis (Sampling - 160 samples)*

| | U | Th | Se | Y | Mo | Ra | Au | Ag | V |
|---|---|---|---|---|---|---|---|---|---|
| **U** | 1.00 | 0.01 | 0.81 | 0.77 | 0.59 | 0.96 | 0.16 | 0.55 | 0.67 |
| **Th** | 0.01 | 1.00 | 0.26 | 0.28 | -0.02 | 0.00 | 0.35 | 0.21 | 0.05 |
| **Se** | 0.81 | 0.26 | 1.00 | 0.83 | 0.68 | 0.77 | 0.27 | 0.57 | 0.71 |
| **Y** | 0.77 | 0.28 | 0.83 | 1.00 | 0.63 | 0.77 | 0.26 | 0.55 | 0.70 |
| **Mo** | 0.59 | -0.02 | 0.68 | 0.63 | 1.00 | 0.57 | 0.11 | 0.40 | 0.41 |
| **Ra** | 0.96 | 0.00 | 0.77 | 0.77 | 0.57 | 1.00 | 0.18 | 0.56 | 0.71 |
| **Au** | 0.16 | 0.35 | 0.27 | 0.26 | 0.11 | 0.18 | 1.00 | 0.27 | 0.17 |
| **Ag** | 0.55 | 0.21 | 0.57 | 0.55 | 0.40 | 0.56 | 0.27 | 1.00 | 0.47 |
| **V** | 0.67 | 0.05 | 0.71 | 0.70 | 0.41 | 0.71 | 0.17 | 0.47 | 1.00 |
| | | | | | | | | | |
| **Av.** | **237.1** | **1.5** | **53.3** | **61.4** | **373.9** | **198.7** | **0.1** | **2.8** | **2,646.2** |
| Clark as per A.P. Vinogradov in shales | 3.2 | 11 | 0.6 | 30 | 2 | | 0.003 | 0.1 | 130 |
| Clark concentrations | 74 | 0.1 | 89 | 2 | 187 | 62 | | 28 | 20 |
| Row of accumulations. | Mo187 Se89 U74 Ra62 Ag28 V20 Y2 | | | | | | | | |

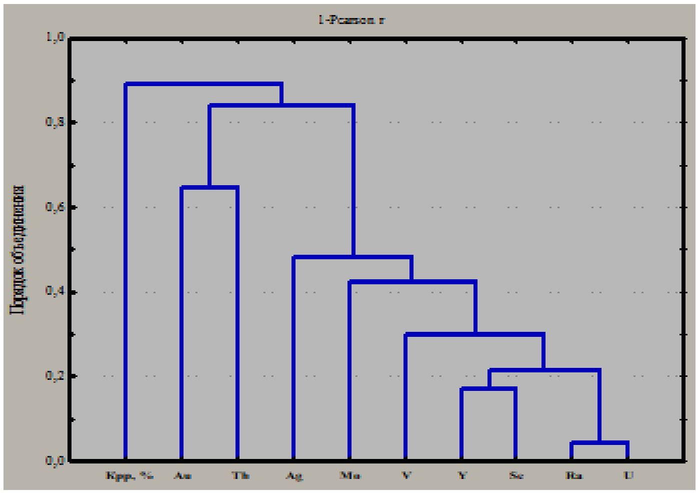

***Fig 12.*** *A layer of carbon-siliceous shales No. 2. Dendrogram of element bonds in the "ore formation" zone for wells (according to quantitative analysis of kern samples, 160 samples taken).*

It should be noted that uranium is associated (in order of decreasing correlation) with selenium, vanadium and molybdenum. Samples were taken below the aeration zone and mirrors of fractured-infiltration water saturated with oxygen. The nature of the relationship emphasizes the close migration relationship of these elements. A closer connection of uranium with selenium than with the other two elements leads to the fact that the wells fell into the subzone of uranium-selenium mineralization leaving the zone of the "vanadium barrier" [4-7], (see the geological-genetic model) and covered the halos of dispersion of vanadium and the beginning of the molybdenum ore subzone.

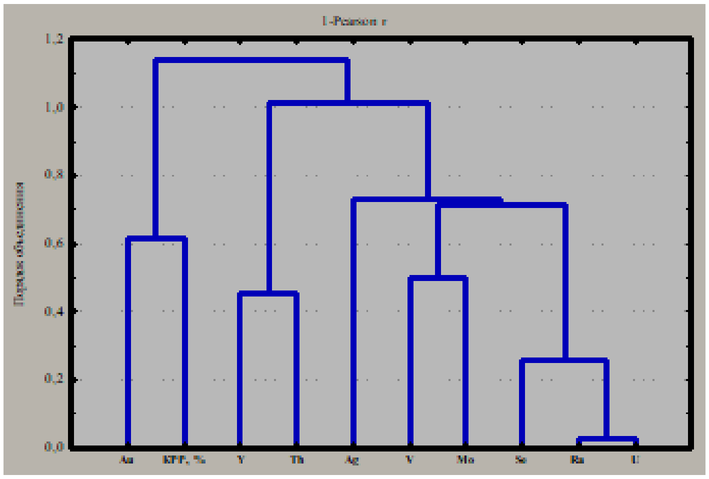

***Fig 13.*** *Dendrogram of bonds of elements in linear residual soils (aeration zone) data of quantitative analysis of kern samples (sampling - 90 samples).*

***Table 5.*** *Pair correlation coefficients of elements (aeration zone) in linear residual soils according to the results of quantitative analysis (90 samples)*

| | U | Th | Se | Y | Mo | Ra | Au | Ag | V |
|---|---|---|---|---|---|---|---|---|---|
| **U** | 1.00 | -0.07 | 0.73 | 0.09 | 0.23 | 0.97 | -0.14 | 0.20 | 0.34 |
| **Th** | -0.07 | 1.00 | - 0.16 | 0.55 | -0.14 | -0.07 | 0.29 | -0.13 | 0.21 |
| **Se** | 0.73 | - 0.16 | 1.00 | 0.04 | 0.36 | 0.75 | -0.10 | 0.36 | 0.31 |
| **Y** | 0.09 | 0.55 | 0.04 | 1.00 | -0.05 | 0.08 | -0.19 | -0.07 | 0.12 |
| **Mo** | 0.23 | -0.14 | 0.36 | -0.05 | 1.00 | 0.17 | -0.18 | 0.27 | 0.50 |
| **Ra** | 0.97 | -0.07 | 0.75 | 0.08 | 0.17 | 1.00 | -0.11 | 0.22 | 0.31 |
| **Au** | -0.14 | 0.29 | -0.10 | -0.19 | -0.18 | -0.11 | 1.00 | 0.17 | 0.27 |
| **Ag** | 0.20 | -0.13 | 0.36 | -0.07 | 0.27 | 0.22 | 0.17 | 1.00 | 0.28 |
| **V** | 0.34 | 0.21 | 0.31 | 0.12 | 0.50 | 0.31 | 0.27 | 0.28 | 1.00 |
| | | | | | | | | | |
| **Av.** | **130.3** | **20.9** | **13.5** | **81.5** | **57.4** | **131.8** | **0.2** | **1.5** | **1,177.3** |

The nature of the distribution and relationships underlines the free migration ability of Se, U, Mo, V - satellite elements in the stratum of carbon-siliceous shales. These elements (Fig. 13) were occluded by clay minerals of moulded lamprophyre dikes. The conditions of the radioactive equilibrium between uranium and radium were studied on the basis of channel samples from sikes and kern samples and from wells with uranium contents> 0.010. Samples were carried out according to the lithological feature (siliceous rocks and fillowite-like shales; dikes of intrusive rocks) and according to the values of the coefficient of radioactive equilibrium (equilibrium ores with Кpp = 90-110; addition ores with Кpp = 0-89; leached ores with Кpp> 110).

***Fig 14.*** *A plate of carbon-siliceous shales with anomalies of rare earths and uranium is promising for the discovery of hidden uranium-rare-metal-rare-earth mineralization. Bottom of the photo shows the banded coloration of black siliceous shales indicating oxidation processes (the carbonaceous substance is oxidized due to which light streaks are noted).*

Analysis of the samples reveals an extremely uneven state of the ores in the geological section. Only 21% of equilibrium ores were found in the aeration zone, and 68% of the ores are in leached state with an average equilibrium shift towards radium up to 155%. Below the level of underground fissure waters, with the emergence of dark-coloured carbonaceous rocks, the conditions of radioactive equilibrium sharply change to the opposite. Now, uranium becomes redundant over radium, and for 67% of ores Kpp takes an average value of 72%.Thus, in accordance with the above data, it can be stated that we have developed a system for predicting complex, multi-element uranium-rare-metal-rare-earth mineralization in black carbon-siliceous shales (microquartzites). The identification of promising territories (sites, areas) for revealing hidden uranium mineralization should be based on a complex of geological-geochemical, hydrogeological, mineralogical, lithological-stratigraphic and structural data. In the figure (Fig. 14) one of the plates of carbon-siliceous shales is shown on the occurrence of uranium-rare-metal-rare-earth mineralization revealed by us within the eastern part of the Eastern Altyntau section. The overprint of weak geochemical anomalies of uranium and rare-earth metals from the surface indicates the presence of hidden complex mineralization at a depth and leaching of a complex of paragenous foreign-metal impurities V, Mo, Se, TR, U, and others by groundwaters along surface cracks. The total forecast resources of various metals in the carbon-siliceous shales of Uzbekistan are huge. According to mass spectrometric analysis of samples from wells and surface mine openings in the Altyntau section, it was established that industrial mineralization of REE and Y, V, Se, Mo, Sc, Ag, U, etc. are developed in shales. There were identified industrial concentrations of the amount of REE. The metal content of the Vostochny Altyntau section is considered as an example, where the layers of carbon-siliceous and carbon-siliceous clay shales have a small thickness of up to 8.5 m and a length of 1,100 m. In spite of the low REE content, this type of mineralization should be considered in combination with other foreign-metal impurities. Within the development of carbon-siliceous strata of Western Uzbekistan, much higher industrial concentrations of rare-earth and rare metals are also noted. Currently, the issue of identifying complex mineralization within them has not been studied yet. In East Altyntau, we identified 10 ore zones with increased concentrations of the metal complex, with a total area of 6.3km2 and an average ore-bearing stratum thickness of 5.9 m.

The authors calculated the average content of useful components as a whole for the entire area of Eastern Altyntau site, as well as separately for the most promising sites. Estimated resources were calculated and an enlarged geological and economic valuation of the industrial mineralization of the black shale productive stratum of the REE site, rare, radioactive, noble and non-ferrous metals was carried out [14]. Since all metals contain directly the metals themselves (ICP-ms results), based on the atomic weight of each element, we recalculated the molecular weight of metal oxides. For example, the average TR content amount of 411.6 g / t is converted to $TR_2O_3$. The atomic weight from La is 138.91 and up to Lu-174.97, Y-89. The average atomic weight of 15 elements is 152.2 and the molecular weight of $TR_2O_3$ is 352.4. The average content of $TR_2O_3$ in carbon-siliceous and siliceous clay shales in this case will be 476.5 g / t. In the same way, the contents of other metals (V, Sc, W and U) were recalculated. The specific gravity of carbon-siliceous shales is taken equal to 2.6 t /m3. The calculation was carried out according to two options of cut-off grade for REE accepted as 0.02% and 0.03%. Ore mass with an average thickness of the productive bedding rock of 11.4 m (cut-off grade 0.03%) and 5.9 m (cut-off grade 0.03%) amounted to 45.6 million tons and 25.45 million tons of ore, respectively. The reliability coefficient of the forecast is taken equal to 0.8. At the same time, the resources of REE (metal) amounted to 10.33 thousand tons, and $TR_2O_3$ - 11.96 thousand tons. The calculation of the predicted resources of the associated useful components was carried out within the counting blocks for REEs based on the cut-off grade of their amount 0.04%.In addition to the number of predicted resources of certain valuable metals in the Altyntau area, their potential cost was calculated - the most probable, guaranteed amount of expected industrial reserves in case of development of the site and some other indicators. Considering the cost of oxides of rare and rare-earth metals on the world market, the total cost of the estimated forecast resources is more than 1.94 billion dollars. For instance, the USA is equivalent to the cost of an average gold mine with forecast resources of 51.2 tons and an average Au content of 2.0 g / t. With the conversion factor (Kf) of forecast resources to industrial reserves taken by us is equal to 0.6 and the extraction coefficient (Ec) taken is equal to 0.5 - the total cost of guaranteed extractable reserves of all useful components within the counting blocks is 819 million USD. In this article, we also tried to characterize the formations of carbon-siliceous shales as the most valuable source of scarce raw materials - various metals, and the source of such raw materials is located in favourable infrastructural conditions - in close proximity to industrial centers. The figures obtained for the valuation of these metals in only one search area reveal that Uzbekistan has enormous wealth located in the black carbon-siliceous shales of the mining regions of Central Kyzylkum, the development of which can become a significant source of foreign currency earnings.

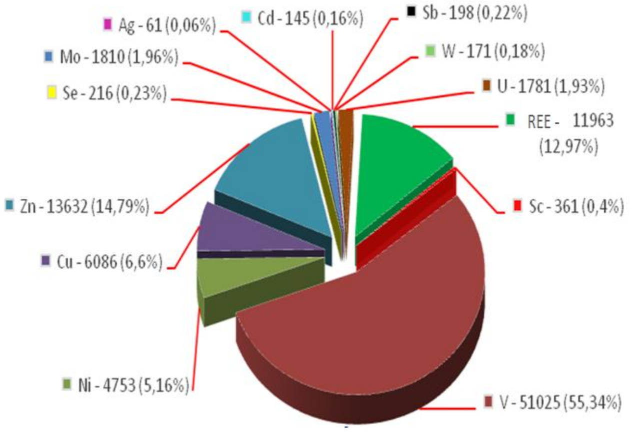

**Fig 15.** *The structure of the forecast resources of carbon-siliceous and carbon-siliceous clay shales of the Altyntau section (in standard units).*

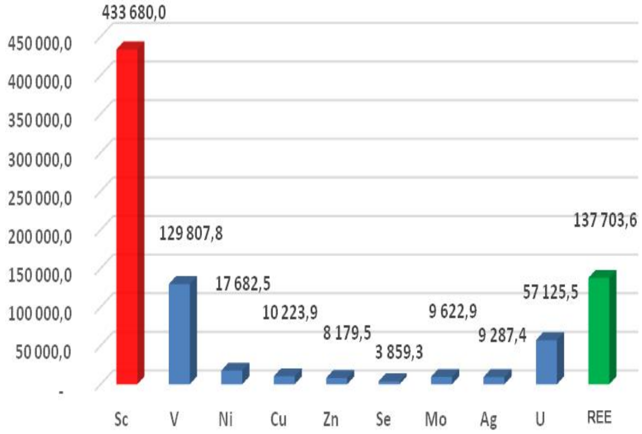

***Fig 16.*** *The structure of the forecast resources of carbon-siliceous and carbon-siliceous clay shales of the Altyntau section without consideration of V (in standard units).*

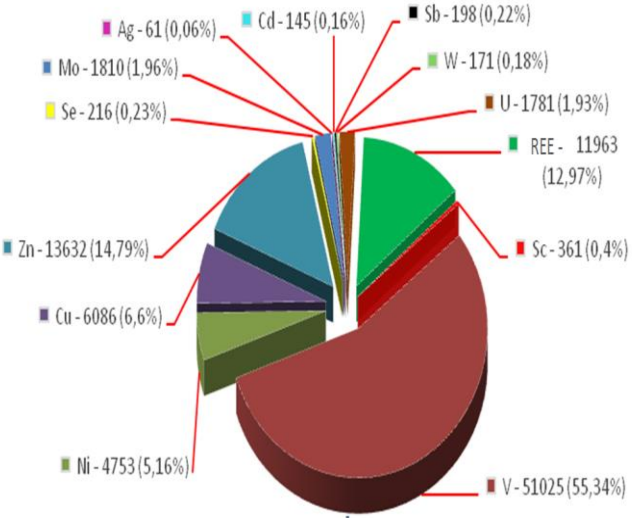

***Fig 17**. The structure of potential market value (in USD amount) of reserves of productive geological positions of carbon-siliceous, siliceous-clay shales of the Altyntau section, excluding small elements - Cd, Sb, W, Re.*

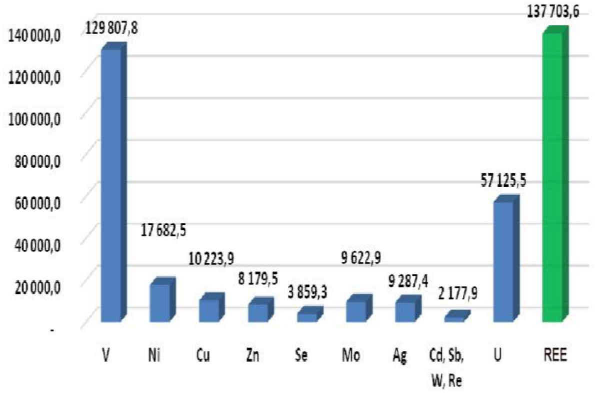

*Fig 18. Percentage distribution of useful components in the structure of potential market value of reserves of productive geological positions of carbon-siliceous shales of the Altyntau section, excluding small elements - Cd, Sb, W, Re.*

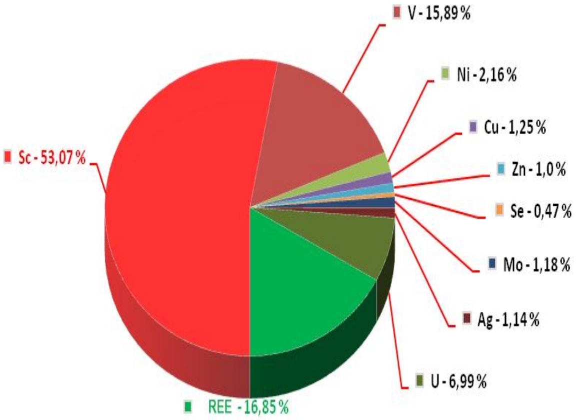

***Fig 19.*** *The structure of potential market value (in USD) of reserves of productive geological positions of carbon-siliceous shales in the Altyntau section, excluding Sc.*

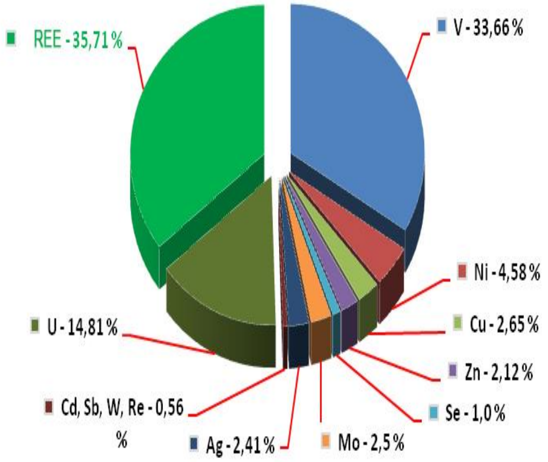

***Fig 20.*** *Percentage distribution of useful components in the structure of potential market value of reserves of productive geological positions of carbon-siliceous shales of the Altyntau section, excluding Sc.*

## 5 CONCLUSIONS

1. Thus, among the criteria noted above, structural,

lithological-stratigraphic, hydrogeological, mineralogical, geochemical, and preservation criteria for uranium mineralization associated with the conversion processes and their products are clearly distinguished. The interpretation of the latter is very ambiguous and apparently depends on the genetic representations of the authors, evidence and their interpretation.

2. An analysis of the role of the identified criteria in the formation of uranium deposits of the crystalline basement of the province reveals the combined occurrence of various processes and their relationships at all stages of the formation and transformation of ores. For each of the identified main stages of development and formation of uranium deposits in the black shale strata - preparatory, ore-forming and transforming, the prevailing influence of the above local criteria for surface oxidation (for industrial mineralization) is a feature. Thus, in other words, the determining stage in the formation of an industrial facility is the last one, associated with the processes of supergene surface oxidation by fractured oxygen underground waters, which leach the ore component from the eroded parts of poor primary deposits and its subsequent migration through weakened zones and accumulation.
3. The preparatory stage determines favourable conditions for the formation of uranium deposits; most likely, the process of metamorphism and hydrothermal transformation under which the formation of high-carbon microquartzites appears to be dominant. The greatest importance among them was the regional metamorphic process itself, which caused the formation of siliceous shales, which are the main ore-hosting formation.
4. The final transforming stage is determined by the occurrence of various complex processes at various depths and surface processes with their paramount importance for the formation of industrial secondary uranium-rare-metal-rare-earth ores. In close combination with the tectonic factor, surface processes of mineralization oxidation and transformation determined the degree of erosion section of the considered type of deposits and the conditions of their conservation under sedimentary formation of a young platform cover.
5. Local processes played a large role in the post-ore transformation of black shale deposits. Most of them were dominated by subsequent surface oxidation processes, as evidenced by the intensive development of supergene processes, which often led to their complete processing and the formation of industrial uranium complex mineralization with new mineral types of uranium-micaceous ores.
6. To reveal the hidden complex rare-metal-rare-earth mineralization, it is necessary to conduct a geochemical survey within the plate of carbon-siliceous rocks, which is the leg of the synclinal or anticlinal fold of the Proterozoic complexes of the Taskazgan, Kokpatas or Suvliksai suites, and to build an erosion model of the alleged mineralization with the definition of ore deposits and correlation relation of chemical elements. A favourable geochemical sign of the presence of a hidden complex deposit is a high correlation between the clarke or superclarke concentrations of uranium and REE on the surface even during the absence of radioactive anomalies. During the absence of anomalies, it is premature to draw negative conclusions.
7. Uzbekistan has a chance to become a global producer of REE. Geological exploration of rare-earth mineralization in Uzbekistan has begun in the last 5 years. Modern analytical methods make it possible now to state with full confidence that uranium-vanadium facilities in black carbon-siliceous shales are complex uranium-rare-metal-rare-earth, often with noble metal specificity and high contents of non-ferrous and other metals [4, 6, 7, 11, 13-15].
8. Modern forecasting methods based on geological and genetic, geological and mathematical modelling of complex mineralization in carbon-siliceous shales, allow already at the exploration stage to identify promising positions for verification drilling of wells based on knowledge of the migration ability of various metals in a variety of geological, hydrogeological environments and ideas about the proposed position in the ore section of rare-earth mineralization and its vertical scope.
9. It would be advisable to reconsider the “black shale” type uranium-vanadium deposits to identify industrial concentrations of rare-earth mineralization, and given the current market conditions for REE it is economically feasible to put them into operation. First of all, such works should be carried out at facilities where increased REE concentrations of up to 2-3% have already been noted in the wells — black-shale type uranium-vanadium deposits.
10. The developed methodology can be applied in other territories where carbon-siliceous strata are widely spread.

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