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ИЗВЕСТИЯ

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РЕСПУБЛИКИ КАЗАХСТАН
Satbayev University

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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

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PROSPECTS FOR APPLICATION OF MULTI-SPECTRAL EARTH SENSING DATA IN FORECASTING AND SEARCHING FOR RESERVOIR-INFILTRATION URANIUM DEPOSITS

Abstract. Reservoir-infiltration uranium deposits («sandstone» type) today are the main active source of uranium mineral raw materials in the world and the only one in Kazakhstan. Their main advantage in the form of better environmental friendliness, productivity and minimum production costs creates prospects for their further detection in various parts of the world. It is important to simplify and improve multi-stage, expensive and difficult geological exploration works for the purpose of forecasting and searching them with affordable innovative solutions. The available multispectral satellite imagery has opened up new opportunities for the study of uranium ore provinces. Mapping of uranium ore provinces based on multispectral satellite imagery allows them to be compared with certain key ore-controlling data from geological and geophysical studies. The near-surface visible nature of geotectonic structures, climatic conditions and zonal anomalies are more easily and efficiently visualized using modern space technologies and computer solutions. The explanation of the derived correlations with the geotectonic and climatic conditions allows the use of multispectral images in order to simplify and improve the quality of forecasting, prospecting and exploration of reservoir-infiltration uranium deposits. More advanced aerial and space remote sensing methods make it possible to detect surface anomalies associated with this type of ore. The scientific explanation of the nature of these anomalies and their role in the geological and genetic model of ore formation creates a solid theoretical basis for improving the exploration methodology. The convergence of the results obtained, their theoretical explanation, simplicity and convincingness of the results make it possible to make new predictions of promising areas of reservoir-infiltration uranium regions for several of the key ore-controlling factors and use this methodology in conjunction with other data from regional and local studies at all stages of exploration.

Key words: Uranium ores, reservoir-infiltration deposits, geological exploration, prospecting, forecasting, multispectral sounding, satellite imagery.

Introduction. Reservoir-infiltration uranium deposits («sandstone» «roll-front» type by IAEA classification) have distinctive geotechnological parameters, due to which today they are among the most environmentally acceptable, productive and economically viable sources of natural uranium in the world [1]. The discovery of such deposits in the world is complicated by the relatively small thickness of ore bodies (usually 5-20 m) and their high depth of occurrence under a thick sedimentary cover (usually from 100 to 700 m and more). In terms of plan, uranium ores look by relatively narrow (several hundred meters) and extended (tens and hundreds of kilometers) intermittent and winding ribbon-like stripes, which also significantly complicates their search and forecasting at all stages of geological exploration [2, 3]. Forecasting and prospecting of such deposits in the main scope of work is carried out by exploratory drilling of geological exploration and hydrogeological wells with a set of related studies. When drilling wells, a complex of geophysical studies, core sampling, radiometric sampling, sampling from core and water for analytical studies and other work is performed. This search method proved to be the most successful and is used to this day. All previous regional and local geological exploration data, terrain maps and advanced research data are used to select the optimal drilling network and depth. The aim of this work is to improve and simplify the methodology for forecasting, prospecting and exploration of these types of mineralization by using a modern theoretical base, accumulated experience and innovative computer, air and space technologies, which will improve the possibility and profitability of expansion and replenishing the uranium mineral resource base of Kazakhstan and the world as a whole.

Methods and solutions. For the study, materials were initially collected on the main sources of mined natural uranium in the world in the person of the Shu-Sarysu and Syrdarya reservoir-infiltration uranium ore provinces located in the southern part of the Republic of Kazakhstan. Numerous materials have been accumulated due to previous direct participation in various types of geological exploration, cameral and research work in these uranium ore provinces for 13 years in the organization of Volkovgeology JSC and one year in the Institute of High Technologies LLP of NAC Kazatomprom JSC. The historical materials of the previous geological exploration works of the Volkovskaya and Krasnokholmskaya expeditions were mainly used, with the addition of previous fund and public regional and geophysical studies, as well as data from modern geological exploration and research. Based on the materials of many years of experience, collected and literature data, the main ore-controlling factors on a regional scale were investigated and their mapping was analyzed. Cartographic information was analyzed from 40 to 50 parallel of North latitude and from 60 to 78 meridian of East longitude, as well as adjacent territories. Further, using various modern computer solutions and multispectral space sensing data, maps of these uranium ore provinces were compiled and combined in formats associated with ore-controlling factors. For the set goals and objectives, a satellite map of the terrain was chosen in combination with a satellite map of visible RGB light, which displayed the near-surface geotectonic and climatic conditions precisely at the level of detail that is closely related to ore-controlling factors. When creating a terrain map, a number of different methods were tried on the basis of publicly available data such as ALOS AW3D, SRTM, etc., which were easily visualized in software solutions such as Global Mapper, Surfer and the like, but there were difficulties in choosing the optimal color system for displaying the elevation level , which took a significant amount of time. To significantly simplify this task and obtain a sufficient level of quality, a ready-made solution World Relief Map was used in the catalog of ArcGIS online maps, which was freely exported at a resolution of 5000x5000 pixels, which is quite enough for a small-scale regional study. When choosing data for satellite maps of visible RGB color, materials of numerous Internet services with space images such as Google, Bing, Yahoo, Nokia, Yandex, ArcGIS and others were examined. After a detailed comparison, publicly available ArcGIS Imagery and Google imagery were selected, which had readily available, more recent, better quality and already processed data for the surveyed area. When combined with a terrain map, the color gamut of Google maps more clearly matched the satellite terrain map, and therefore chose the data on Google images. SASPlanet software was used to create high-resolution satellite maps with coordinate reference, which made it possible to download and seamlessly paste several thousand satellite images of these services in a matter of minutes [4]. The created satellite maps were combined with 50% layer-by-layer transparency in the Mapinfo Professional program and supplemented with thematic data, as well as compared with thematic maps on the data of uranium ore provinces (figure 3). Based on the compared data, a detailed analysis was carried out for the convergence of the results with ready-made thematic maps and ore-controlling factors, their quality, and detail (figures 1, 2, 3). After a detailed comparison, a theoretical explanation of the relationship between the uranium-ore zoning and the obtained mapped data was proposed, which also explains the studied local anomalies by other methods of remote sensing by other authors.

Results and discussions. According to the infiltration model of ore formation, the hydrodynamic conditions of the region, the climatic conditions of the ore formation epoch and the geochemical type of ore-hosting rocks are identified as the main factors necessary for the formation of uranium deposits [5, 7]. For the formation of a favorable reservoir-infiltration system, it is necessary to lay down permeable deposits between impermeable strata, the formation exit to the area of surface water recharge and the area of its unloading, which allows the infiltration process to take place for a long time. The formation of such layers is primarily determined by the geotectonic regime of the area. The uplift of the earth's crust above sea level leads to its destruction by natural phenomena and the transfer of newly formed loose sediments. Sedimentation occurs in stages and is characterized by different facies in conditions of activation [6] and calm, as well as climatic and other changes. The formed formations are universally characterized by the alternation of various lithological-facies zones with different filtration and geochemical features. The sedimentation process in many cases leads to the formation of strata of the syneclisous type, and the violation of this structure, as a rule, creates other areas of aquifer recharge and unloading. For this reason, continental mountainous areas, which are well observed on satellite images, almost always form infiltration artesian basins in the immediate vicinity, and their scale largely depends on their type. The humid climate is favorable for the formation of organic sorbents and uranium reducing agents, but thereby prevents its migration in the waters, and the arid climate is favorable for the penetration of formation waters carrying uranium over long distances and depths, but not favorable for the formation of a powerful reducing barrier that allows the formation of a rich and contrasting deposits [7]. Zonal and periodic

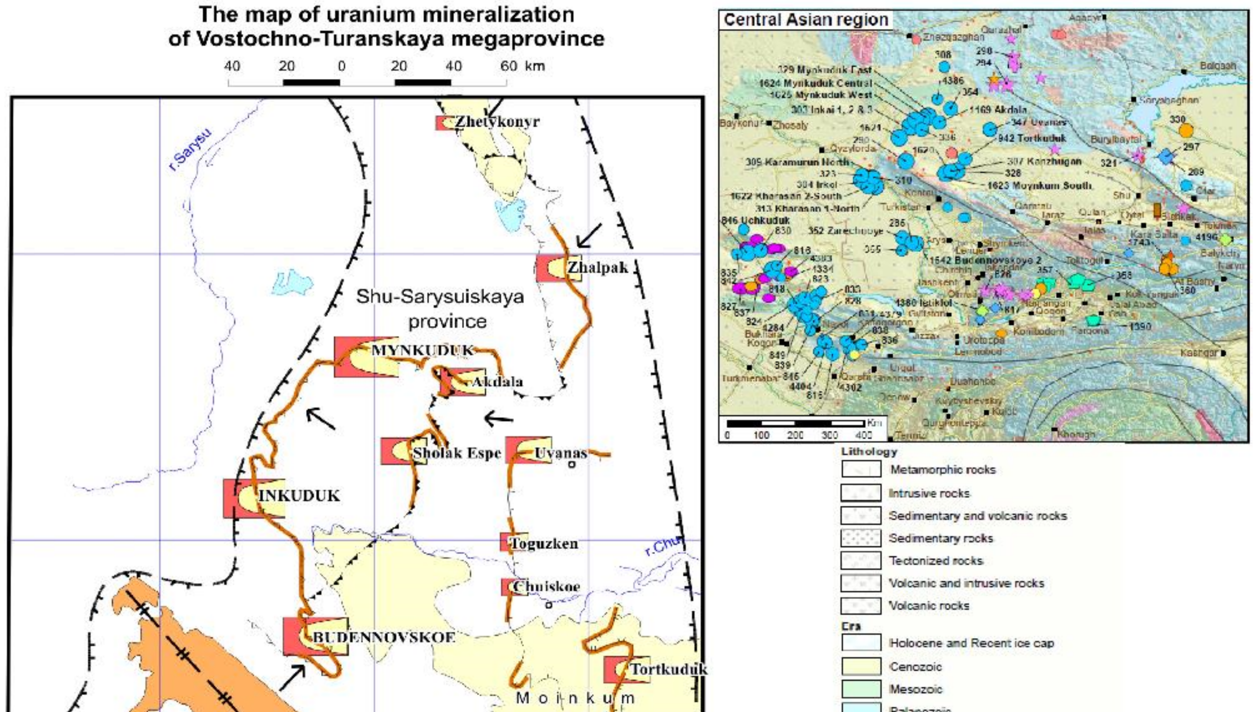

Figure 1 – Uranium mineralization of the East Turan province

climate changes from arid to humid and vice versa create geochemical boundaries with different oxide-tion-reduction potentials of sedimentary deposits favorable for the formation of uranium mineralization. But the formation of uranium mineralization is possible only during periods of a sufficiently long arid and subarid climates allowing uranium-dissolving surface waters to penetrate with a rich oxidizer over long distances and depths to transfer a significant amount of reservoir-infiltration ores to the reduction barrier [5]. Therefore, at the current time, the most promising for predicting potential reservoir-infiltration uranium provinces are desert and semi-desert zones in the vicinity of continental mountain ranges and uplifts, as well as adjacent areas. In such systems, extended zones of formation oxidation have formed, the fronts of pinching out which are the main ore-controlling factor in deposits of this type. The Shu-Sarysu and Syrdarya uranium ore provinces together represent the East Turan uranium ore megaprovince divided by the relatively young Karatau uplift. In a schematic form, the mineralization of these provinces according to the published data of Volkovgeology JSC and the IAEA [8] shown in figure 1. A more detailed display of them based on the data of deep geological mapping at a scale of 1: 1,000,000 [based on the base http://wms.vsegei.ru/] and the results of geological exploration for uranium are shown in figure 2. Near-surface geotectonic and climatic conditions are the most important factors necessary for the forma-tion of a uranium ore province and its main ore-controlling factor. The creation of a combined satellite elevation map and the visible spectrum of colors with the overlay of thematic data allowed us to compare the convergence of the results (figure 3). The result surpassed all expectations, the resulting map, based on multispectral satellite images, perfectly displayed the near-surface geotectonic environment of the area, absolutely similar to the data of deep geological mapping at a scale of 1: 1,000,000, and displayed the

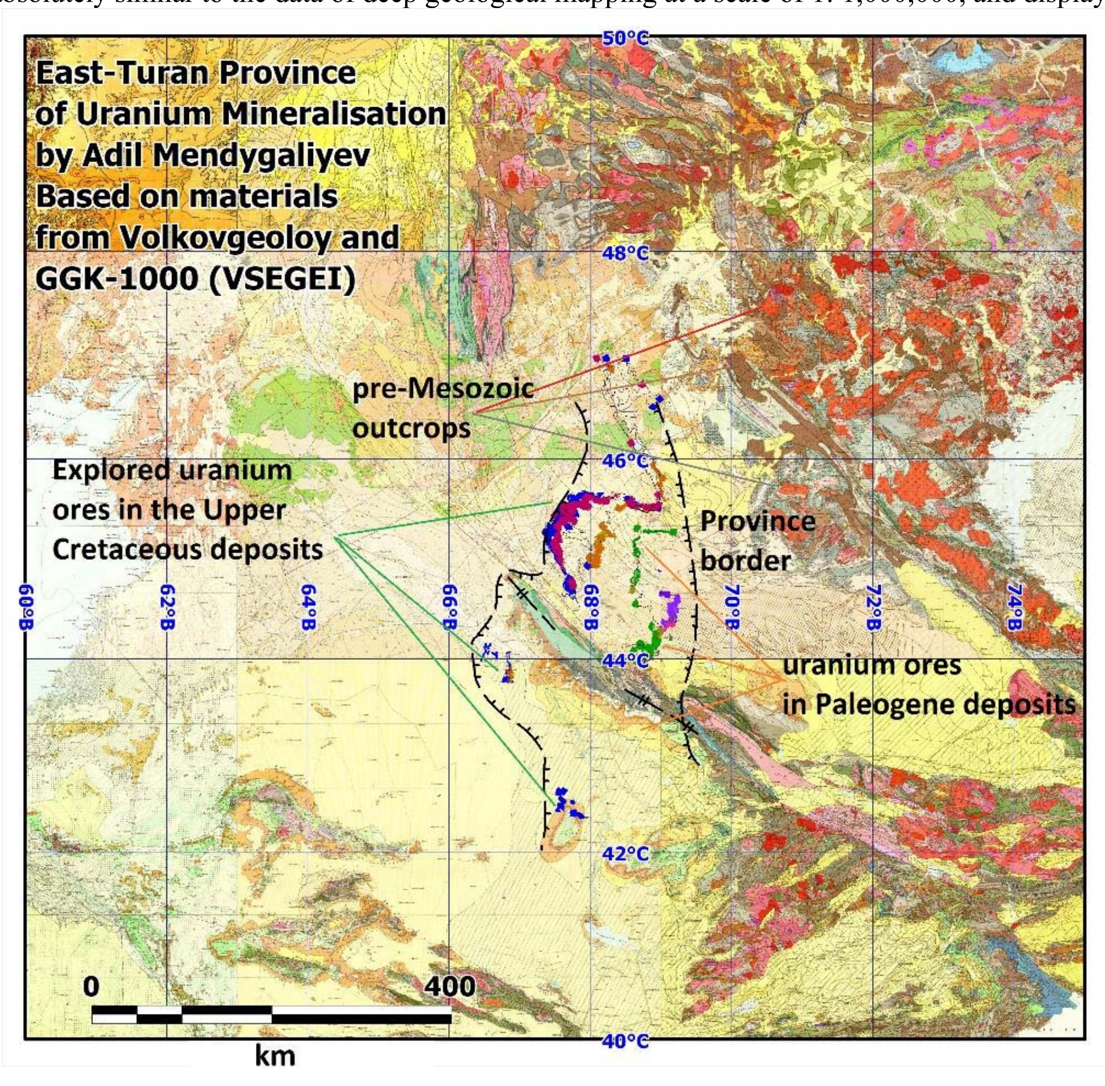

Figure 2 – East Turan uranium mineralization on map of deep geological mapping

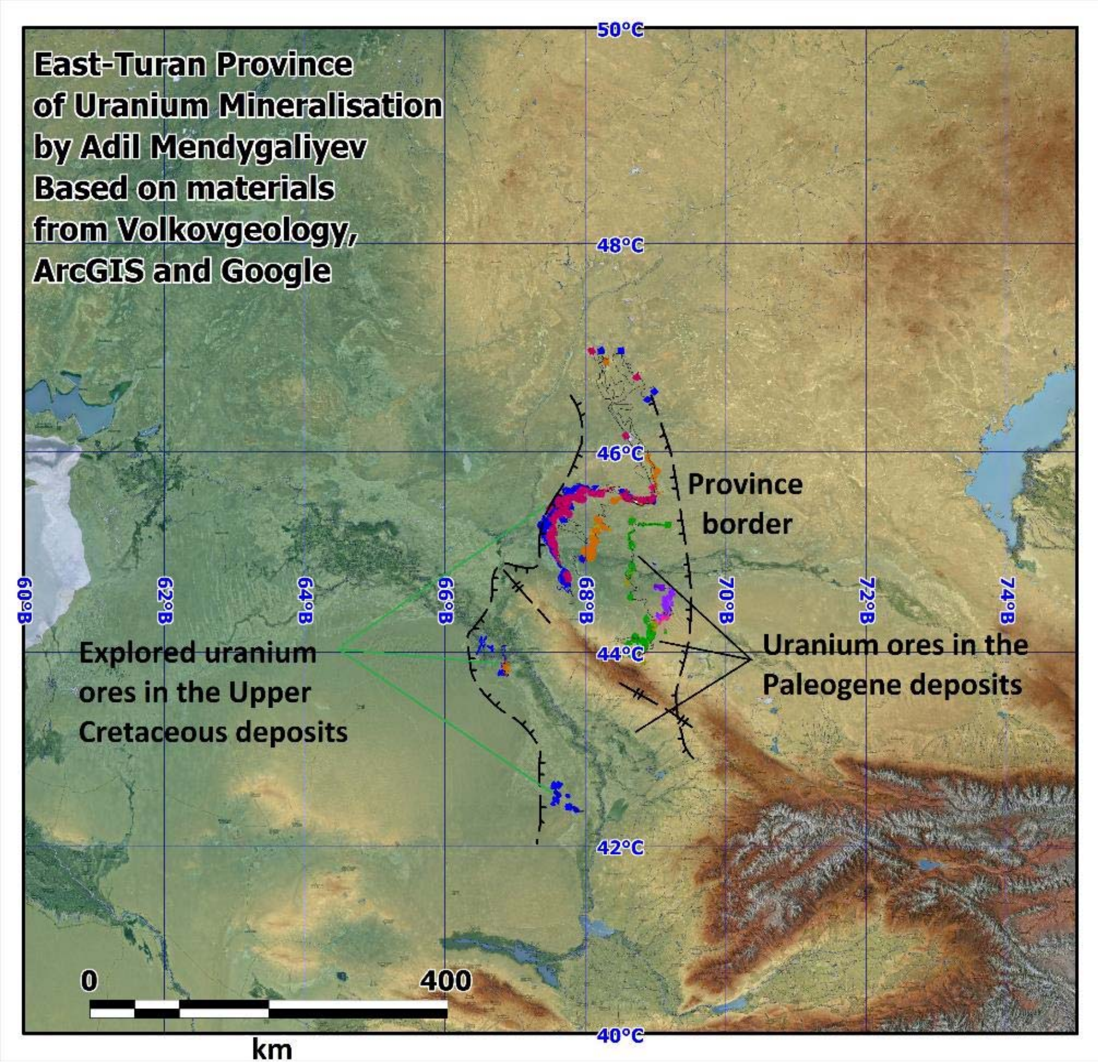

Figure 3 – East Turan uranium mineralization on map of multispectral satellite imagery

climatic situation of aquifer recharge area emerging to the surface in desert areas. The main source of sedimentation is the southern, southeastern and eastern continental uplifts from the side of the Tien Shan and the Kazakh shield towards the retreating Aral and Caspian seas. The East Turan province is divided into the Shu-Sarysu and Syrdarya by the younger Karatau uplift, the sharp uplift of which approximately occurred at the end of the Pliocene epoch [5]. The listed uplifts set the main directions of all ore-forming stratal water flows. Special attention should be paid to the Inkai-Mynkuduk ore arc (and its continuation) in the Upper Cretaceous deposits more than 100 km long, the shape of which exactly repeats the observed structure a few tens of kilometers north of the Sarysu-Teniz watershed, which directs the discharge area. To the east, in the area of the Zhalpak deposit, the ore strip unfolds by the uplift of the Kazakh shield. South of the Budennovskoe deposit, the ore strip is broken by the Karatau uplift and continues to the west of Karatau in the Syrdarya province (Karamurunskoe ore field, Zarechnoye, Asarchik, Zhautkan. [9]).

The nature of the ore zones in the Paleogene deposits is more complicated by the Karatau uplift, but otherwise practically repeats the character of the Cretaceous deposits, only a few hundred kilometers to the south-east, closer to the feeding zones near the Tien Shan zones. Continuing the topic of the use of multispectral data of remote sensing of the earth, more detailed specialized studies should be noted. On November 7, 2019 in Almaty at the IX International Scientific and Practical Conference "Actual Problems of the Uranium Industry" a report was presented (vol. 1, pp. 55-63) on the data obtained using the RMP method at the Mynkuduk Vostochny deposit [10]. In a discussion with colleagues, the method was perceived skeptically, since the high convergence of the results obtained with the explored ore strip was left without theoretical explanations, and thermal anomalies could be caused by the result of operating enterprises. But personal attention was exacerbated by the predicted undiscovered ore strip, the prerequisites for which, by professional accident, were noticed earlier in some single wells of the neighboring area "Central Mynkuduk". Despite the fact that the ore strips themselves could not be detected by the infrared and color radiation used in the method due to the powerful (several hundred meters) roof sedimentary cover, this method could fix their inherent surface soil anomalies. In 2010, at the International Scientific and Practical Conference "Actual Problems of the Uranium Industry-2010", a joint report by the employees of JSC "Volkovgeology" I.A. Shishkov, T.Ya. Chesnokova and FSUE "VIMS" A.E.Bakhur, T.M. Ovsyannikova in which the obtained results of isotopic soil anomalies ^{210}Po and ^{210}Pb were presented at the surface of stratal-infiltration uranium deposits. Their theoretical explanation was given by means of an independent migration of elements upward through the zones of water exchange to the water surface and further penetration into the soil by capillary-diffuse rise, which was previously clearly explained in the thesis by A.E. Bakhur. [11]. In addition, at uranium deposits of this type, surface anomalies of methane, hydrogen and the amount of heavy hydrocarbons are everywhere noted [5].

The significance of the latter most likely explains the formation of sufficient recovery barriers directly above the oil and gas bearing areas (in spite of the assignment of the provinces to detritus), which is a topic for a separate discussion.

Conclusion. Modern computer solutions greatly simplify data processing, improve their quality and open up new opportunities. Space and airborne remote sensing technologies have provided geological services with highly justified public and commercial solutions for forecasting and prospecting for ores. The obtained convergence of the results is theoretically substantiated and the use of this method should bring forecasting and prospecting of reservoir-infiltration uranium deposits to a new level, simplifying and improving the quality of geological exploration at all stages. To carry out the first steps in predicting new uranium ore zones with the auxiliary use of this method, it was decided to build in this way and analyze the world map. According to the results obtained, the most promising were the territories of the Arabian Peninsula, the prospects of which are expected in the sediments of the Meso-Cenozoic artesian basins near the area located above the oil and gas bearing area of the Ghawar field. The visualized territories have large-scale areas for the formation of similar systems of penetration of ore-forming infiltration flows over long distances and depths, and the underlying oil and gas areas should create powerful recovery sources communicating with the overlying horizons to meet the infiltration flows, which can form large sandstone uranium deposits of the Kyzyl Kum and Australian types [12, 13].

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УРАННЫҢ ҚАБАТТЫҚ-ИНФИЛЬТРАЦИЯЛЫҚ КЕНОРЫНДАРЫН БОЛЖАУ ЖӘНЕ ІЗДЕУ КЕЗІНДЕ ЖЕРДІ МУЛЬТИСПЕКТРЛІ ЗОНДТАУ ДЕРЕКТЕРІН ҚОЛДАНУ ПЕРСПЕКТИВАЛАРЫ

Аннотация. Қабатты-инфильтрациялық уран кенорындары қазіргі кезде әлемдегі уран шикізатының негізгі және Қазақстанда жалғыз көзі болып табылады. Олардың экологиялық тазалығы, өнімділік және минималды өндірістік шығындар түріндегі басты артықшылығы оларды әлемнің әр түкпірінде одан әрі анықтауға мүмкіндік береді. Көп сатылы, қымбат және қиын геологиялық барлау жұмыстарын қол жетімді инновациялық шешімдермен болжау және іздеу мақсатында оңайлату және жетілдіру маңызды. Қол жетімді мультиспектралды ғарыштық суреттер уран кенді провинцияларын зерттеу үшін жаңа мүмкіндіктер ашты. Мультиспектральды ғарыштық түсірілім негізінде уран кенді провинцияларының карталарын жасау оларды геологиялық және геофизикалық зерттеулердің белгілі бір негізгі рудалық бақылау мәліметтерімен салыстыруға мүмкіндік береді. Геотектоникалық құрылымдардың, климаттық жағдайлардың және белдемдік ауытқулардың жер бетіне жақын көрінетін табиғаты заманауи ғарыштық технологиялар мен компьютерлік шешімдердің көмегімен оңай әрі сапалы түрде көрінеді. Геотектоникалық және климаттық жағдайлармен байланысты корреляцияны түсіндіру уран қабатты-инфильтрациялық кенорындарын болжау, іздеу және барлау сапасын жеңілдету және арттыру мақсатында мультиспектральды кескіндерді қолдануға мүмкіндік береді. Әуе мен ғарышты қашықтықтан зондылаудың анағұрлым жетілдірілген әдістері кеннің осы түрімен байланысты жер бетіндегі ауытқуларды анықтауға мүмкіндік береді. Осы ауытқулардың табиғатын және олардың кен түзудің геологиялық-генетикалық моделіндегі рөлін ғылыми тұрғыдан түсіндіру геологиялық барлау әдістемесін жетілдіруге сенімді теориялық негіз жасайды. Алынған нәтижелердің жинақталуы, оларды теориялық тұрғыдан түсіндірілуі, нәтижелердің қарапайымдылығы мен сенімділігі уранның бақылау аймағының бірнеше негізгі факторлары үшін қабаттық-инфильтрациялық уранның аудандарына жаңа болжамдар жасауға және осы әдіснаманы геологиялық барлау жұмыстарының барлық кезеңдеріндегі аймақтық және жергілікті зерттеулерінің басқа да мәліметтермен бірге қолдануға мүмкіндік береді.

Түйін сөздер: уран кендері, қабатты-инфильтрациялық кен орындар, геологиялық барлау, іздеу, болжау, мультиспектральдық зондылау, ғарыштық суреттер.

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ПЕРСПЕКТИВЫ ПРИМЕНЕНИЯ ДАННЫХ МУЛЬТИСПЕКТРАЛЬНОГО ЗОНДИРОВАНИЯ ЗЕМЛИ ПРИ ПРОГНОЗИРОВАНИИ И ПОИСКАХ ПЛАСТОВО-ИНФИЛЬТРАЦИОННЫХ МЕСТОРОЖДЕНИЙ УРАНА

Аннотация. Пластово-инфильтрационные месторождения урана на сегодняшний день служат главным действующим источником уранового минерального сырья в мире и единственным в Казахстане. Главное их достоинство в виде лучшей экологичности, производительности и минимальной себестоимости добычи создаёт перспективы к их дальнейшему обнаружению в различных уголках планеты. Многостадийные, дорогостоящие и трудновыполнимые геологоразведочные работы с целью их прогнозирования и поисков позволяют актуально упрощать и улучшать в качестве доступными инновационными решениями. Доступные мультиспектральные космические снимки открыли новые возможности для исследования урановорудных провинций. Создание карт урановорудных провинций по данным мультиспектральных космоснимков позволяет сопоставить их с определенными ключевыми рудоконтролирующими данными геологических и геофизических исследований. Приповерхностный видимый характер геотектонических структур, климатические обстановки и зональные аномалии более легко и качественно визуализируются с помощью современных космических технологий и компьютерных решений. Объяснение выведенных корреляций с геотектонической и климатической обстановкой позволяет использовать мультиспектральные снимки с целью упрощения и повышения качества прогнозирования, поисков и разведки пластово-инфильтрационных месторождений урана. Более продвинутые аэро- и космо – методы дистанционного зондирования земли позволяют выявлять сопутствующие данному типу руд поверхностные аномалии. Научное объяснение природы данных аномалий и их роли в геолого-генетической модели образования руд создаёт прочную теоретическую основу для усовершенствования геологоразведочной методологии. Сходимость полученных результатов, их теоретическое объяснение, простота и убедительность результатов позволяют сделать новые прогнозы перспективных районов пластово-инфильтрационных урановых районов по нескольким из ключевых рудоконтролирующих факторов и использовать данную методологию в совокупности с другими данными региональных и локальных исследований на всех стадиях геологоразведочных работ.

Ключевые слова: урановые руды, пластово-инфильтрационные месторождения, геологоразведка, поиски, прогнозирование, мультиспектральное зондирование, космоснимки.

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