Exploration and reserve calculation of the uranium deposits amenable to the ISL method in Kazakhstan

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Abstract. Exploration methods, study of ores and reserve calculation of the uranium deposits hosted in the Cretaceous sediments at the Chu-Saryssu ore region in Southern Kazakhstan, are shown in the paper. The Zhalpak, Mynkuduk, Akdala, Inkay and Budyonovskoe deposits form a unique uranium Ore Belt, and have been discovered and studied for 20 years, from 1971 to 1991. In the paper a very important conclusion is made on the key role of regional bed oxidation zones in forming such large-scale uranium ores. Drilling was the main study method. Several stages of study have been described in the paper: pre-search, search, preliminary exploration and detailed exploration. At the first stage, the study was carried out by reconnaissance drilling using previously created lithologic-facial plans for the predicted sediment horizons. Lines of drilling holes were situated taking into account the underground water flows from a recharge area and the position of grey-coloured channel facies among overall mottled sediments of the region. At the next stages, drilling hole grids of various densities were used for contouring and sampling ore bodies. The important role of geological description of the drilling core, geophysical and hydro-geological data as well as the results of modelling using laboratory filtration pipes for the creation of lithologic-filtration maps and the division of the ores into lithologic-filtration types were shown. Based on these data the reserve calculation was carried out using the "geological blocks" method. Thus in the paper, the complete sequence of operations -from discovery to reserve calculation- is demonstrated. It is shown that work at different stages could be carried out simultaneously across the entire Ore Belt. In this case, the peculiarities of the ore localization received at the detailed stage were used for the search and reconnaissance stage. It is also shown that exploration work was carried out at a rapid pace, widely using drilling without a core, employing geophysical data, and with a high efficiency of work. A high level of uranium recovery was proven by the results of the field tests.

1. Introduction

In 1956, while studying uranium deposits hosted in Cretaceous sediments on the territory of Uzbekistan, geologists V.M. Mazin and G.A. Pechenkin established a spacial relation for uranium ore between the boundaries of the yellow oxidized sand sediments of aquifers and un-oxidized grey sand sediments. Use of this peculiarity permitted the discovery of oxidation zone development among friable water-bearing sediments. These oxidized zones were later called bed oxidation zones, (BOZ) by Soviet geologists. Under further investigation, wide expansion bed oxidation zones were revealed among friable sediments of the artesian basins of Uzbekistan and the South of Kazakhstan. A whole series of uranium deposits amenable to the In Situ Leaching (ISL) method was revealed at the area of BOZ attenuation in favourable conditions. In connection with the later established important ore-generating role of BOZ for uranium deposits, such deposits were named BOZ deposits by Soviet geologists.

The search for BOZ deposits, on the territory of the depression structure of Kazakhstan, started in the late 50s. By this time, the favourable features of BOZ development and related uranium deposits were formulated:

(a) hydrodynamic conditions of infiltration artesian basins;
(b) arid climate conditions of the ore deposition epoch;
(c) favourable lithologic-geochemical type of host rocks (grey-coloured, easily permeable sediments).

Chu-Saryssu and Syr-Darya depressions were the most perspective territories. In this region 15 large and unique uranium deposits [1] were found in Cretaceous and Palaeogene sediments. Depressions were divided by the young uplift of the Karatau Range, but taking into consideration the commonality of the geological characteristics of the ore and sediment formation, they are joined in the united Chu-Syr Darya ore region (ChSR), which forms the foundation of Kazakhstan's uranium base (Fig. 1).

Uranium ore is primarily located in the Cretaceous sediments of the Chu-Saryssu depression (ChSD), which is the eastern sector of the Chu-Syr Darya ore region. In this depression the large and unique Zhalpak, Mynkuduk, Akdala, Inkay and Budyonovskoe deposits were discovered. These deposits form the unique Zhalpak-Budyonovskoe ore belt, containing about 800 000 tonnes of uranium. In connection with regional character of BOZ and the wide expansion of large fluvial systems in the Cretaceous, favourable conditions were created for almost continuous BOZ ore in the sediments of these systems. Ore bodies form uranium deposits in this unique uranium region. This region was studied for 20 years, during the period between 1971 and 1991. In this period a very efficient method of search and exploration work was developed. This method used experience accumulated during the exploration of the uranium deposits amenable to the ISL method in Uzbekistan and Kazakhstan.

2. Search and exploration method

In carrying out work on the discovery and exploration of uranium BOZ deposits, three main stages can be identified: pre-search, search and exploration. Each stage is characterized by a specific set of tasks. The general effectiveness of work depends on the high-quality fulfilment of investigation at all three stages. The work of each stage must be carried out strictly in sequence. Considering the large dimensions of depression structures, work of the second and third stages can be carried out in parallel in different parts of the investigation region. I.e., if in one part of the depression exploration work is already being carrying out, in other parts search work can be only beginning. In this case, particularities of the ore localization that are determined at the exploration section can be successfully used during searches at other sections.

2.1. Pre-search stage

2.1.1. Search preconditions and region selection for search work

One of main preconditions for investigation region selection is the existence of depression structures with an infiltration artesian basin. Other important preconditions are the existence of permeable grey-coloured sediments formed in humid period sedimentation, the existence of sedimentation breaks in the arid period, or the existence of overlying red-coloured and mottled sediments that also characterize arid periods. Besides, an essential condition is the existence of young intensive uplifts of mountain systems adjacent to a depression (activation of the mountain surroundings). This fact determines the possibility for active penetration deep-ward of the artesian basin oxygen-bearing water and active BOZ development. The existence of over-clay and under-clay of grey-coloured sand horizons are favourable factors for directional BOZ development. Signs of epigenetic oxidized sand sediments in the core of drilling holes indicating possible BOZ development and higher radioactivity on the logging data (radioactive anomaly) are direct preconditions for ore detection. The region of investigation is selected based on the presence of the above features.

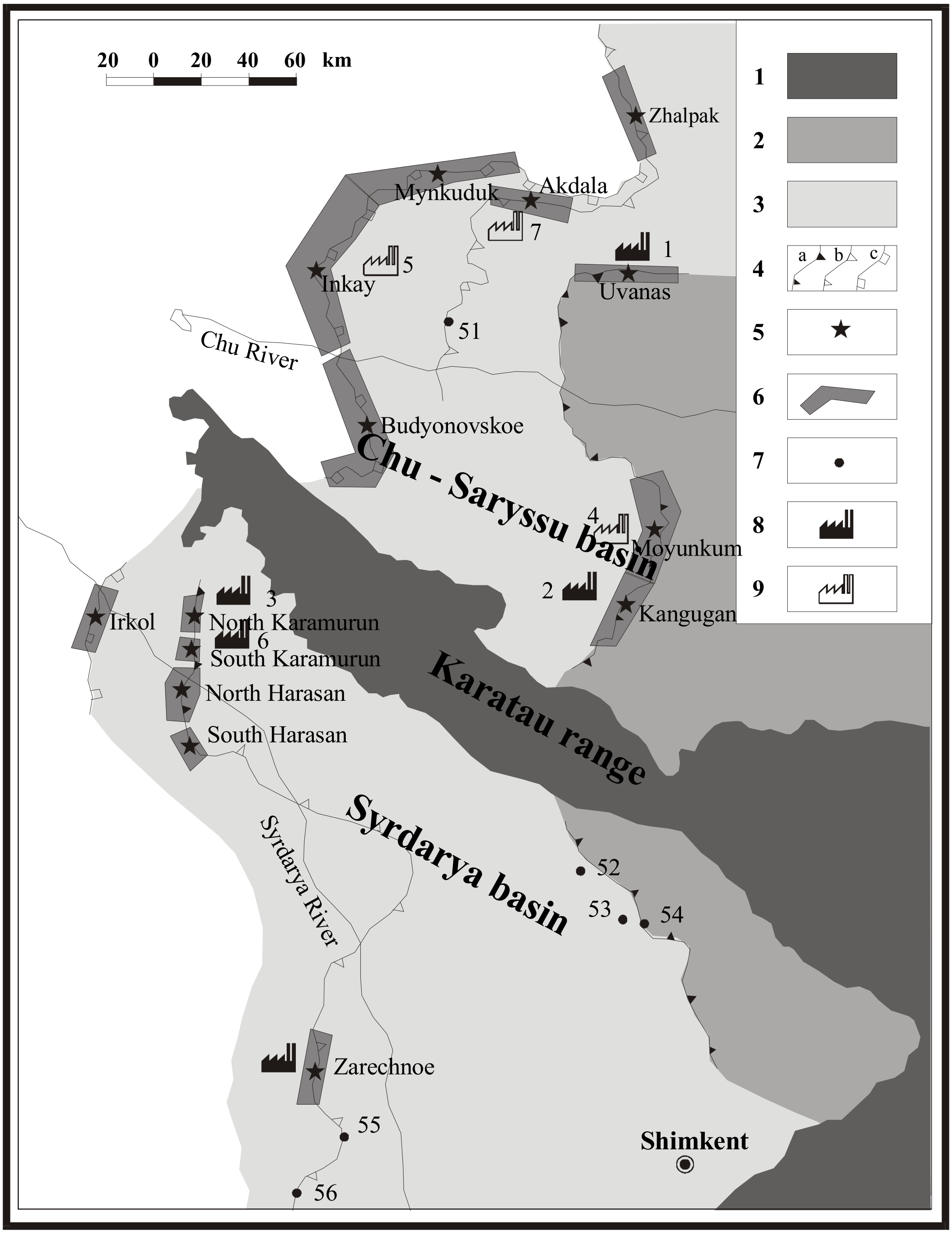

FIG. 1 Distribution of uranium deposits in the Chu-Syrdarya ore region in Kazakstan

1 - Outcrop of Pre-Mesozoic rocks, 2 - Area of the bed oxidation zone development on whole thickness of Cretaceous-Paleogene sediments, 3 - Area of the bed oxidation zone development in Cretaceous sediments only, 4 - Redox-front a) in Paleogene sediments, b) in Zhalpak horizon of the top upper Cretaceous, c) in Mynkuduk-Inkuduk horizon of middle part of upper Cretaceous, 5- Commercial uranium deposits amenable for ISL, 6 - Ore-fields of the commercial uranium deposits, 7 - Unprofitable uranium dePosits, 8 - Operating production centres (1-Stepnoe, 2-Tsentralnoe, 3-№6, 6-South Karamurun, 8-Zarechnoe), 9 - Planned field test production centres (4-Katko, 5-Inkay, 7-Akdala)
Unprofitable deposits: 51 - Sholak-Espe, 52 - Kyzylkol, 53 - Lunnoe, 54 - Chayan, 55 - Zhautkan, 56 - Asarchik

2.1.2. Compilation of facies-lithological horizon maps

A very important phase of the pre-search stage is the compilation of facies-lithological maps of perspective horizons that are identified for investigation. Areas of favourable sediment formation (channel facies or other sections of grey-coloured sediments, organic material accumulation and so forth), signs of epigenetic oxidation into sand sediments are shown on these maps. When compiling these maps, all sources of geological information (state geological survey data, search drilling well data from oil, hydro-geological and other organizations) are used. As a result of the analysis of horizon map data, a possible BOZ attenuation position can be found and the character and direction of the reconnaissance drilling hole lines for the confirmation of facies-lithological map data can be determined.

2.1.3. Drilling of the reconnaissance borehole lines

Reconnaissance borehole line drilling is carried out using voluntary line spacing and with a distance between wells of 12.8-6.4 km. The line spacing is determined by the features of the geological forming sediment conditions and may be as large as 30-40 km. In this case, particular emphasis must be placed on the well core quality and quantity. Permeable sand sediments of the borehole core must not be contaminated by mud fluid. Borehole core quantity of sand sediments must be 70% or more. Otherwise, the identification of the direct signs of BOZ development will be complicated and this can lead to mistaken conclusions. According to reconnaissance borehole line data, the direction of underground water flows during an ore-forming period and possible position of BOZ attenuation are determined. In this case, the details of geological condition formation of horizon sediments (paleo-valley orientation and so forth), and the position of recently activated young mountain surroundings must be considered.

An ore formation period is preliminarily determined by the mountain system activation age and the age of arid periods under the formation of the sediment series. According to the reconnaissance borehole line drilling results, perspective uranium deposit areas are segregated.

2.2. Search stage

2.2.1. Selection of borehole line orientation

It is very important to select an accurate drilling line orientation when search work is only just beginning so as these lines can become integrated into a future joint exploration system, including wells of the detail exploration stage. Generally BOZ area attenuation and related ore bodies have a very complex configuration of their details. This is connected with the generally alluvial character of sediments and the considerable variation in the lithologic-geochemical features of the rocks. Therefore, the first-phase search drilling lines must be orientated in the direction of paleo-flows and perpendicular to the area of the main BOZ attenuation. Under more detailed searches, the drilling lines can be perpendicular to the initial line direction. This orthogonal line system is preserved at the exploration stage, and allows to obtain the proven reserves with optimized costs using data on the boreholes of all stages under reserve calculation. The results of the ore bodies detailing under different drilling densities are shown in Figure 2.

2.2.2. Justification for search and exploration line grid of drilling holes

The drilling lines of the initial search phase are situated with a spacing of 25.6 km. But often this distance is decreased to either 12.8 or 6.4 km depending on the results of reconnaissance work and the dimensions of the revealed prospect areas. Generally, the dimensions of the favourable facies expansion area and the position of the BOZ attenuation at these areas are determined by the drilling lines data of this stage. Additionally, at this stage it is already possible to reveal the direct signs of uranium ore. This can indicate the possible potential resources of the region.

Using a line spacing of either 3.2 or 1.6 km will already allow one to draw a conclusion on the possibility of commercial uranium ore discovery.

To determine the commercial character of the revealed uranium ore, preliminary exploration is carried out using a drilling grid of 800-400×200-50m revealing the EAR-1 reserves. According to the results of preliminary exploration, a decision is taken on carrying out a detailed exploration on the 200-100×50-25m grid, revealing the RAR reserves.

The grids used for each stage of the drilling work and the corresponding confidence in the revealed resources and reserves is shown in the following Table.

Stage	Scale of work	Line spacing, m	Distance between wells on the line, m	Resource confidence, reserve category
Reconnaissance	1:500 000	30.000-40.000	6.400-100	SR (P_3)
Search stage	1:200 000	25.600	6.400-100	SR (P_3)
	1:100 000	12.800-6.400	3.200-100	SR (P_2)
	1:50 000	3.200-1.600	800-(100-50)	EAR-2 (P_1)
Preliminary exploration		800-400	200-50	EAR-1 (C_2)
Detailed exploration		200-100	50-25	RAR ($B+C_1$)

Note: Categories of resources and reserves in the classification system of the former USSR (used in Kazakhstan) are shown in brackets in the resources confidence column.

2.3. Exploration stage

Exploration stage work is undertaken after a proof of the possible commercial significance of the revealed uranium ore. All work of this stage is aimed at obtaining comprehensive data for carrying out the reserve calculation and the technological description of the reserves.

The goal of the exploration stage is to segregate both the preliminary explored reserves (EAR-1) and the detailed explored reserves of the commercial category (RAR). In this case all boreholes are drilled with a core recovery of 75% or more through the ore zone. All boreholes of each stage with ore intersections are sampled for all kinds of assaying. Such boreholes are included in an exploration grid of the detail exploration stage and are used for the reserve calculation.

3. Reserve calculation [2]

3.1. Geo-technological mapping

One of the main features of ore bodies is the geo-technological properties of the ore sediments. Technological sorts of the ore are segregated taking into consideration these properties. The task of studying the geo-technological properties of ore includes the investigation of the lithologic-filtration and engineering-geological properties of sediments, and is decided by geo-technological mapping. Various data from borehole core geological description, hydro-geological, geophysical, laboratory investigation, technological trials assaying, and modelling with laboratory leaching pipes–are used for carrying out geo-technological mapping.

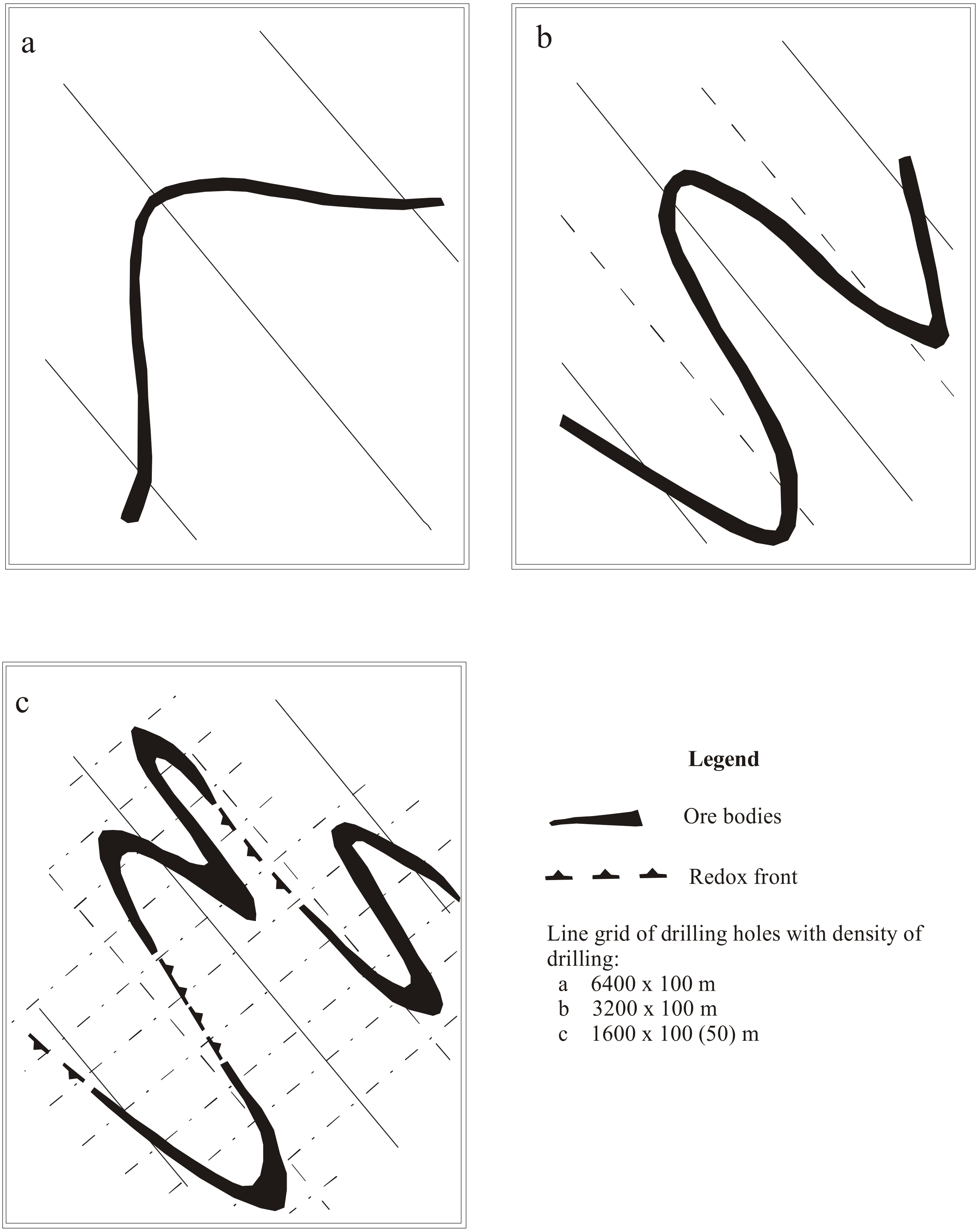

FIG. 2 The use of the orthogonal line grids of drilling holes for the ore body contouring

3.1.1. Geological borehole core description

One of the main sources of obtaining information about lithologic-filtration ore properties is a borehole core geological description. This description is accompanied by sampling using the appropriate grid to determine the carbonate content of ore and sediments and their grain composition. Sediment colour, grain composition, and percentage of clay in sand must be denoted. Geological description data are the main primary documents for boreholes and are used to compile cross-sections, maps, and calculation plans.

3.1.2. Hydro-geological investigation

The main goal of hydro-geological investigation under geo-technological mapping is the determination of the filtration coefficients of aquifer sediments using pumping tests. Use of pumping tests is the most objective method for aquifer sediment filtration coefficient determination. At the same time, some factors interfering the accurate determination of the filtration coefficient must be taken into account.

3.1.3. Geophysical investigation

Using electro-logging interpretation data, cross-sections for boreholes without core selection are drawn. In addition, geophysical investigation is used for the determination of the filtration coefficients of the ores and sediments. Values of the filtration coefficient of separate beds of the ore horizon and ore intersections are determined using a re-counting coefficient and data from an electro-logging interpretation in conjunction with the results of grain analysis and data from hydrological filtration coefficients.

3.1.4. Laboratory investigation and modelling using laboratory-leaching pipes

Exploration work is accompanied by wide set of laboratory investigations. The main kind of laboratory analyses is a chemical analysis for uranium in borehole core samples and radiometric analysis for radium. Data from these analyses form the basis for a radioactive disequilibrium study at different sections of the ore bodies, and for the determination of the correction factor for gamma-logging data using these factors under reserve calculation.

Other methods are also used to comprehensively describe the ore bodies. These are: mineralogic-petrographic determinations of the ore and sediments, determinations of carbonates, organic material, and associate element contents, as well as the determination of grain composition, iron valence, general iron content, and density of the ore.

Technological samples for carrying out an investigation, using laboratory-leaching pipes, are selected from the core material. Study of the technological ore parameters (filtration coefficient, velocity and recovery fullness, acid costs, etc.) are carried out using material from these samples. Selection and analysis of the technological samples at the location of the field test and whole deposit area allow one to interpolate the results of the field test for the whole deposit, characterizing the technological properties of the ore at the various sections of the deposit.

3.2. Compilation of the lithologic-filtration maps and segregation of the lithologic-filtration sorts of the ores.

Lithologic-filtration maps describing the filtration heterogeneity of the ore sediments are compiled using geo-technological mapping data. On these maps, the areas of sediments with close filtration coefficients values are segregated. These maps are used to determine the calculation block boundaries. During deposit mining, the map data allow one to select the optimal line grid of drilling holes and well density for the well pattern formation.

3.3. Selection of the reserve calculation method

The reserve calculation is carried out using data from the gamma-logging interpretation with using correction factors for radioactivity disequilibrium and for the conditions of carrying out gamma-logging – squeezing of radon into well side during the initial (main) logging. These corrections have different values at different deposit sections. They are determined by specific investigations. The reliability of the corrections is confirmed by the chemical analysis data and the results of the direct determination uranium logging. Corrections factors may reach 20% or more.

Carrying out of the reserve calculation using gamma-logging data allows one to drill a considerable portion of the wells without core recovery. In this connection, the speed and efficiency of exploratory work increases considerably.

The geological block method was chosen for the reserve calculation. The choice of the calculation method was determined by the complex ore body morphology and by the use of the ISL method for deposit mining. Calculation blocks in the cross-sections are formed taking into consideration the entire volume of the sediments, which is subject to acid influence. On the calculation plan, the blocks are contoured by wells with profitable ore. For the optimal selection of the mining conditions, the calculation blocks are formed taking into consideration the data of the lithologic-filtration plans. The boundaries of the blocks are drawn taking in account the field boundaries with close filtration coefficients values.

3.4. Analysis of conditions used for reserve calculation

Special requirements, called conditions, are determined for the reserve calculation. These conditions are confirmed by authority bodies and contain some parameter restrictions for the well, which are attributed to profitable ones and are included into the calculation. The main restrictions are the cut-off grade (0.01%), and cut-off grade x thickness (line productivity – 0.600). In addition, conditions are determined by carbonate content restrictions (2% of CO_2) and ore permeability (filtration coefficient of 1m/day or more). Some other restrictions are determined by the geological blocks method calculation. Such restrictions are specially considered. Confirmed conditions at practically all deposits of the Zhalpak-Budyonovskoe ore belt are in good accordance with morphological and other ore features, and qualitative parameters of the ore bodies. This is confirmed by the fact that only a very small portion (about 2%) of the uranium ore was assessed as sub-profitable ores, as well as the fact that uranium recovery price from profitable ores at the Mynkuduk deposit are not high (USD 20.0 per kilogram of recovered uranium).

3.5. Carrying out of the field tests

Uranium recovery field tests using the ISL method are carried out to prove the cost-effectiveness of calculated reserves for uranium production and to determine the project parameters of profitable production. Investigations are carried out at special test polygons using different borehole placing schemes (well patterns). The most common well patterns are polygons with 3 injection and 6 recovery wells. Pattern with 2 wells are also often used.

4. Geological properties of the zhalpak-budyonovskoe ore belt

4.1. Geological characterization of the region and conditions of uranium ore formation

4.1.1. Formation history of the sediments of the Chu-Saryssy depression

The Chu-Saryssu depression is located on the edge of the large Turan Plate and is filled with friable sediments from the Cretaceous to the Quaternary. The foundation of the depression is Palaeozoic lithified sediments lying at a depth of up to 700-800 m. The platform sediments are friable continental Cretaceous rocks of up to 320 m in thickness, marine and shallow-marine Palaeogene sediments of up to 200 m in thickness, and red-coloured sandy-clay Oligocene-Quaternary formation. The formation of the red-coloured sediments is connected with the young Alpine orogeny and mountain uplift in the East and, principally, in the Southeast of the Tian-Shan mountain system region [3]. The main stages of the regional geological history connected with uranium deposit formation are [4]:

(a) The formation of the thick permeable Cretaceous series;
(b) The ubiquitous presence of overlying marine Palaeogene clay series which can carry out the function of regional upper confinement;
(c) The existence of arid periods after Cretaceous sediment formation;
(d) The intensive uplift of the Tian-Shan mountain system in the Southeast of the region, which facilitated the active penetration of oxygen-bearing waters into the aquifer of the friable platform sediments;
(e) The formation of the large Chu-Sarysu infiltration type artesian basin.

The main uranium ore in the Chu-Saryssu basin is hosted in Cretaceous rocks, which are sediments of a large alluvial plain and for the most part, are grained sediments from fine-grained sand to gravel. Cretaceous rocks include clay beds amounting to not more than l0–20% of series thickness.

The alluvial origin of the Cretaceous sediments makes it difficult to divide the series into individual aquifers. At the same time, the separation of such stratigraphic units is very important for jointing ore intervals at various well lines. This was especially important during the first stages of the search, when imprecise jointing could lead to mistakes in choosing the direction and density of the exploration line grid of drilling holes. Additionally, the rate of exploration work may be decreased and costs increased.

Based on the sediment cycle segregation data and using electro-logging, the Cretaceous sediments were divided into 3 horizons. Each of these horizons is in turn divided into sub-horizons. Practically all the sub-horizons host uranium ores to a various degree. Thus, there are 9 ore-bearing sub-horizons within the Cretaceous sediment.

Tectonic activity weakly influences the distribution of ore bodies in the Cretaceous sediments within the Chu-Saryssu basin. Apparently, favourable facies distribution more effectively influences ore body distribution. The position of these facies depends on the expansion and orientation of the paleo-valleys. At the same time, in the Palaeogene sediments in the south of the region tectonic activity is more intensive.

The Cretaceous and Palaeogene sediments are a hydro-geologic complex, including a huge volume of the underground waters of the artesian Chu-Syr Darya Basin. The recharge area of these waters is the Tian-Shan mountain system region. The Tian-Shan range dictated the hydrodynamic regime of the basin and the northwest direction of the underground water flow. This flow direction was preserved despite the Karatau Range uplift in the Quaternary. The uplift of the Karatau Range had little influence on the basin hydrodynamic. Changes in the mineralization and the direction of the underground waters are noticeable only near the Karatau Range, and are practically non-existent in the Zhalpak-Budyonovskoe ore belt region. Discharge of the underground waters occurs beyond the Zhalpak-Budyonovskoe ore belt region. The natural velocity of the ground water movement is not more than 2 m/day. The level of mineralization of Cretaceous waters varies from 1 to 6 g/1. The water in the Palaeogene is fresh and is a source of drinking water for the local population.

4.2. *Bed oxidation zone expansion, formation and morphology of ore bodies*

The expansion of the bed oxidation zone is a very important factor in ore formation in the permeable Cretaceous sediments of Chu-Saryssu basin. The BOZ is developed from the Tian-Shan mountain range and extends up to 500 km. The infiltration nature of the artesian basin and long-continued (beginning from Oligocene [3]) period of BOZ development created very favourable conditions for BOZ expansion. In addition, the primarily speckled-coloured character of the basin sediments did not require significant oxygen consumption. Therefore, the redox front expanded such a significant distance and is located in the grey-coloured sediments of the paleo-valleys.

Under expansion at such a significant distance, the BOZ oxidized the large volume of sediments and also mobilized and transported a large quantity of uranium from the oxidized rocks. Organic material was also oxidized, with the generation of hydrocarbon gases, which could create reducing conditions. The generation of hydrocarbon gases explains large-scale ore formation on the redox front. Cretaceous sediments are characterized by a low organic carbon content (not more than 0.04%), and this fact does not allow one to explain the creation of the essential reducing conditions.

Thus, BOZ directly fulfilled several functions. These include:

(a) uranium mobilization from oxidized sediments;
(b) uranium transportation in a dissolved state over significant distances;
(c) reduced conditions of formation on the redox front;
(d) uranium sedimentation on the redox front.

Therefore, the BOZ is the ore-generating and ore-forming agent and the uranium deposits formed in the friable sediments at the redox front should be called BOZ deposits.

The alluvial character of the sediments conditioned a formation of horizons and sub-horizons, such as the large sediment macro-cycles. They are divided into a great number of micro-cycles with varying permeability, in which small tongues from 1-2 to 5-10 m in thickness are developed. At the attenuation of such tongues, in favourable conditions the ore bodies form both rolls with different wing lengths, as well as bed bodies with a form, which depends on the lithological composition of the sediments. Various conditions caused the variety of the ore body morphology. Nevertheless, the main morphology elements are the bag and wing parts of the rolls. The bag part reaches some 10-20 m in thickness, and the wing parts reach several metres as well. Uranium ore sometimes extends along the redox front for 10-20 km, forming the highly profitable ore bodies.

4.3. The degree of study of the Zhalpak-Budyonovskoe ore belt

At present, the Zhalpak-Budyonovskoe ore belt has not been uniformly studied. Zhalpak, Akdala and Mynkuduk deposits have been explored up to commercial categories. At the same time, at the Inkay deposit only one (Central) section has been explored up to commercial categories. At the Budyonovskoe deposits, only search-estimation work has been carried out, and at one section preliminary exploration has begun. However, the revelation of 280,000 t of proven uranium reserves at the Mynkuduk and Inkay deposits and as well as the results of the estimation work along the entire Zhalpak-Budyonovskoe ore belt allows one to include this region in the ranks of large world uranium regions.

Field tests of uranium production by the ISL method are carried out at the Mynkuduk, Inkay, Akdala deposits. Commercial uranium production is being successfully carried out at the Eastern section of the Mynkuduk deposit. Starting this year, the second field test was begun at the Inkay deposit to study uranium recovery from ore bodies without lower confinement. At the Akdala deposit a test-commercial trial is being carried out with the extremely successful results. The uranium concentration of the pregnant solution averaged 600 mg/l for a period of 10 months.

5. Summary

The proposed search and exploration method includes wide experience obtained during the carrying out of uranium exploration in Uzbekistan and Kazakhstan. The use of the described method when studying the Zhalpak-Budyonovskoe ore belt allows us to successfully realize these important advantages of the method:

(a) High-speed exploration was conducted and the high commercial value of the Zhalpak-Budyonovskoe ore belt was determined over a short period (1971-1991) using the wide practice of drilling without core recovery.
(b) All reserve calculation data were obtained using gamma-logging interpretation with the use of the necessary correction factors determined by special investigations.
(c) The technological properties of the ore were characterized using the integrated method of geo-technological mapping.
(d) The applied geological block method for reserve calculation was simple and effective and took into account in the best possible way all the peculiarities of uranium extraction by the ISL method.
(e) A high level of extraction from uranium ores with low costs for the leaching reagent (up to 20-100 kg per 1 kg of extracted uranium) has been proven by field tests.

6. Conclusion

Use of the proposed method allows one to very effectively reveal, estimate and explore uranium deposits. Thus, at the Mynkuduk deposit where commercial category reserves are 95% of total deposit resources, about 2.4 million meters of wells were drilled with total costs of about USD 71.0 million, including spending for roads and settlement construction for personnel. In this case, specific costs are about USD 0.50 per 1 kg of explored uranium reserves.

For comparison we may turn to world data [5] where specific costs for 1 kg of explored uranium reserves widely vary, beginning at USD 0.48 (Australia, 1967-1983) up to USD 12.41 (USA, 1971-1983). World cost data for 1 kg of explored uranium reserves averages USD 2.50-2.80.

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