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Analysis on the Formation Conditions of Jurassic In-situ Leachable Sandstone Uranium Deposits in the Huangtuya Area of the Southeastern Turpan-Hami Basin

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Abstract

This paper analyzes the formation conditions of the in-situ leachable sandstone-type uranium deposits in the Huangtuya area of the Turpan-Hami Basin. It is concluded that this area has rich uranium sources and good metallogenic conditions, which is reflected in the area as a large and gentle monoclinic structure. With a high-quality mud-sand-mud structure interbedded, well-developed redox facies belt, and the area has good hydrodynamic conditions, a complete complement-diameter-discharge system; and through the development of siderite in the strata. The research shows that the Xishanyao Formation has a good oxidation-reduction environment, and the mineralization conditions of in-situ leachable sandstone-type uranium deposits, and it has good prospects for exploration. Based on the sand/ground ratio data in this area and the range of green sandstone above the coal seam, the prospective uranium metallogenic area was determined.

Keywords

Turpan-Hami Basin; In-situ leachable sandstone-type uranium deposit; Metallogenic conditions; Siderite; Prospective prediction.

1. INTRODUCTION

China is not rich in uranium resources. Uranium resources are widely used in industrial and agricultural production, science and technology and national security. Uranium mining plays an important role in national security and nuclear energy utilization. In-situ leachable sandstone-type uranium deposits are now the main type of uranium mining in my country, which has the advantages of lower mining and treatment costs and better environmental protection. The formation of sandstone-type uranium deposits needs to meet the following basic conditions: large sedimentary basin area, stable caprock structure, arid climate, gentle stratum; sandstone body is well differentiated, has mud-sand-mud structure, shallow burial depth, and has good supplements- Radial-exhaust system, and rich in reducing agent [1, 2]. The metallogenic mechanism of this kind of uranium deposit is that under the leaching of surface water and underground oxygen-containing water, the uranium element is oxidized and transferred to the underground water, permeated through pores and fissures, and reduced and precipitated in a suitable geochemical barrier [3]. Dongsheng uranium deposit is one of the largest in-situ leachable sandstone type uranium deposits in China. According to previous studies, the uranium deposit has the characteristics of kerosene gas symbiosis. It belongs to low-temperature hydrothermal uranium deposit. Natural gas acts as reducing agent to form chemical barrier [2, 4-6].

The study area is located in the eastern part of the southern slope belt of Turpan Hami basin to the south of liaodun uplift. It has similar tectonic setting and sedimentary environment with Shihongtan uranium deposit in the west of Aiding Lake slope [7]. Turpan Hami basin is one of the three major oil and gas bearing basins in Xinjiang, with east-west distribution, north-south facing Tarim Basin and Junggar basin respectively [8]. Based on the comprehensive analysis of field outcrops, drilling data and lithologic association in the study area, this paper considers that Jurassic in this area has sandstone type uranium metallogenic conditions and prospecting prospects, and delimits the prospect area of in-situ leachable sandstone type uranium deposit.

2. REGIONAL GEOLOGY

The study area is located in the south central Turpan Hami basin, in the southwest of liaodun uplift, from Qiketai in the west, to Shisanjianfang in the East, and in front of Jueluotage mountain in the south. It is located in the east of the south side of the central uplift belt of Turpan Hami basin (Figure 1). This area is a large monoclinic structure gradually uplifted and uplifted to the South (Figure 3), which is mainly due to the fact that the central uplift zone established the basic structural pattern of strong thrust nappe to the south in the Yanshanian period, and strengthened to form the existing monoclinic structure in the Himalayan period.

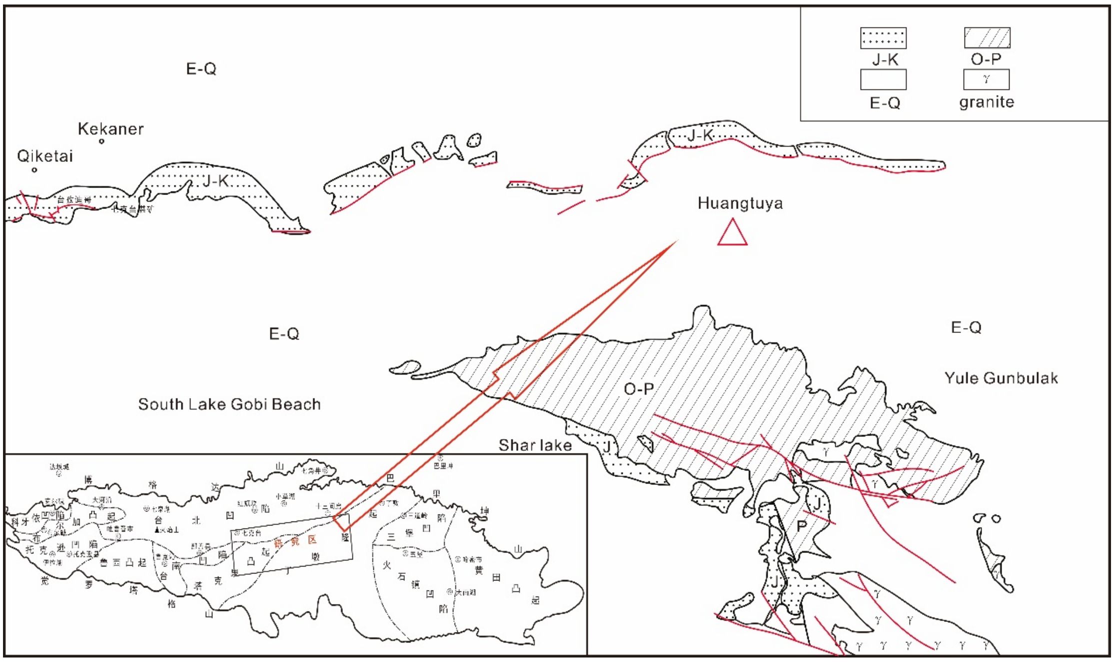

Figure 1. Regional structural location and geological diagram of the study area

1—J-K; 2—O-P; 3—E-Q; 4—Fault; 5—Granite

Surface outcrops and drilling data show that the upper Paleozoic Carboniferous Permian, Mesozoic Triassic, Jurassic and Cretaceous, Cenozoic tertiary and Quaternary are mainly developed in this area. The Carboniferous and Permian are composed of volcanic rocks and mudstone and sandstone dominated by lacustrine and fluvial facies, which constitute the basement of the Meso Cenozoic basin; The sedimentary cap rocks are mainly Mesozoic Triassic, Jurassic and Cretaceous. Triassic is composed of a set of light gray lacustrine facies, lacustrine facies mudstone and sandstone, Cretaceous is a set of braided river red coarse-grained deposits. Jurassic is the most complete and widely distributed sedimentary cover in the area, and also the main target stratum of sandstone type uranium exploration. It mainly consists of clastic rocks of river and lake facies and coal series strata of river marsh and lake biogas. The lithology is mainly conglomerate, sandstone, mudstone and carbonaceous shale, and is mixed with multiple sets of coal seams, which is in conformity or pseudo integration contact with underlying strata. The above is covered by large area of Quaternary conglomerate.

3. ANALYSIS OF METALLOGENIC CONDITIONS

The formation conditions of in-situ leachable sandstone type uranium deposits include abundant uranium source conditions, stable tectonic setting, specific hydrogeological and redox environment.

3.1. Uranium Source Conditions

A large area of K-feldspar granite is developed in Jueluotage mountain in the south of the study area, and a large amount of granite is also developed in liaodun uplift in the north of the study area. They may be the main uranium source areas of in-situ leachable sandstone type uranium deposits in the study area.

According to the single grain zircon U-Pb age test results, a large number of granite bodies in Jueluotage mountain were mainly formed at 386-230 Ma (Figure 2), and the corresponding geological age was Carboniferous-Permian [9]. Its lithology mainly includes biotite hornblende granite, K-feldspar granite and granodiorite. The phenomena of potassic, sodic, potash feldspar metasomatic dissolution plagioclase and albite metasomatic potash feldspar in granitic migmatite are obvious, which are conducive to the dissolution, separation and accumulation of uranium. The uranium content of granite in Jueluotage mountain is generally high, ranging from 2.9×10^{-6}-5.9×10^{-6} g/g[10], significantly higher than the average value of 2.7×10^{-6} g/g [11] and the average content of greywacke in crustal sedimentary rocks is 0.5×10^{-6}-2.10×10^{-6} g/g [12]. In addition, the structural fissures and weathering fissures in the large-area uranium rich granite are well developed, which is conducive to the infiltration of oxygen-containing atmospheric precipitation and the leaching of uranium, and can provide rich uranium sources [13].

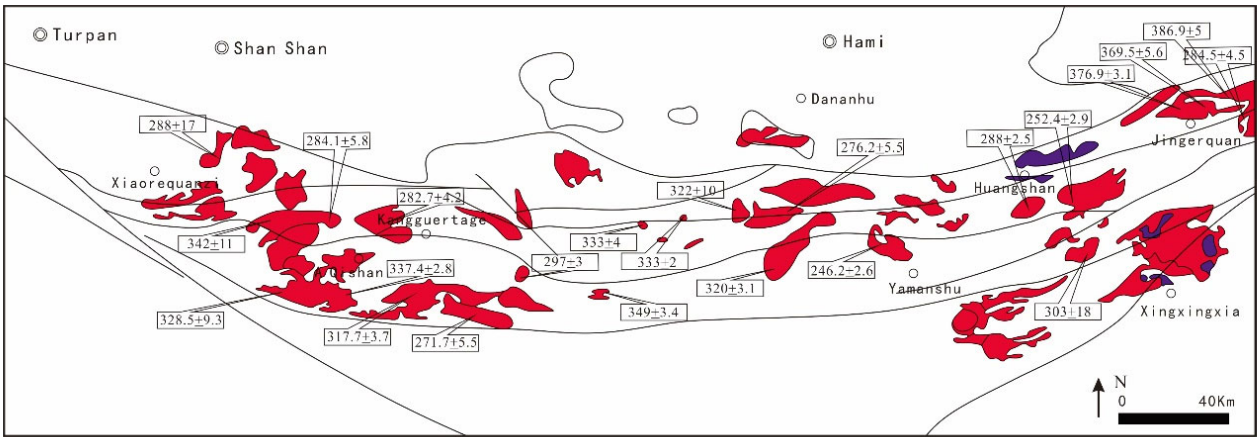

Figure 2. Distribution of granites in the Jueluotag area(according to Gong Xiaoping, 2004)

3.2. Tectonic Conditions

The study area belongs to the superimposed basin of Late Paleozoic and Mesozoic Cenozoic which suffered from multiple tectonic movements. It is a large-scale wide and gentle monocline structure gradually uplifted from north to south, with simple deformation and only small secondary syncline (Figure 3). The lower Jurassic and pre Jurassic, upper and Paleogene Shanshan groups in this area are in unconformity contact, and the Jurassic, Paleogene and Neogene gradually thinned to the Jueluotage mountains in the South until pinchout (Figure 3).

The lower Permian Yier rare earth formation and the Middle Permian taodonggou group were deposited in the study area from early Permian to late Jurassic. Affected by the Yanshan movement, the Bogda structural belt in the northern margin of the basin was thrust napped to the Taibei sag, and the Silurian coal measure strata were decolled and napped to the surface along the Qiketai line, forming a thrust front belt, and the Silurian system was exposed to the surface. At the same time, it caused the tilting action from takquan to the southern part of Leidun uplift under the action of nappe compression, and the whole Jueluotage uplifted, forming the early monoclinic structure [7]; During the Cenozoic, the thrust nappe continued to strengthen, and the sedimentary thickness from Paleogene to Neogene in the slope area was thick in the north and thin in the south. The nappe makes the area from takequan to the south of liaodun uplift become an ancient slope environment, which is high in the East and low in the west, high in the South and low in the north, The structural slope zone where the study area is located is characterized by large scale and gentle width, which is conducive to the continuous infiltration of uranium bearing groundwater into mineralization [14].

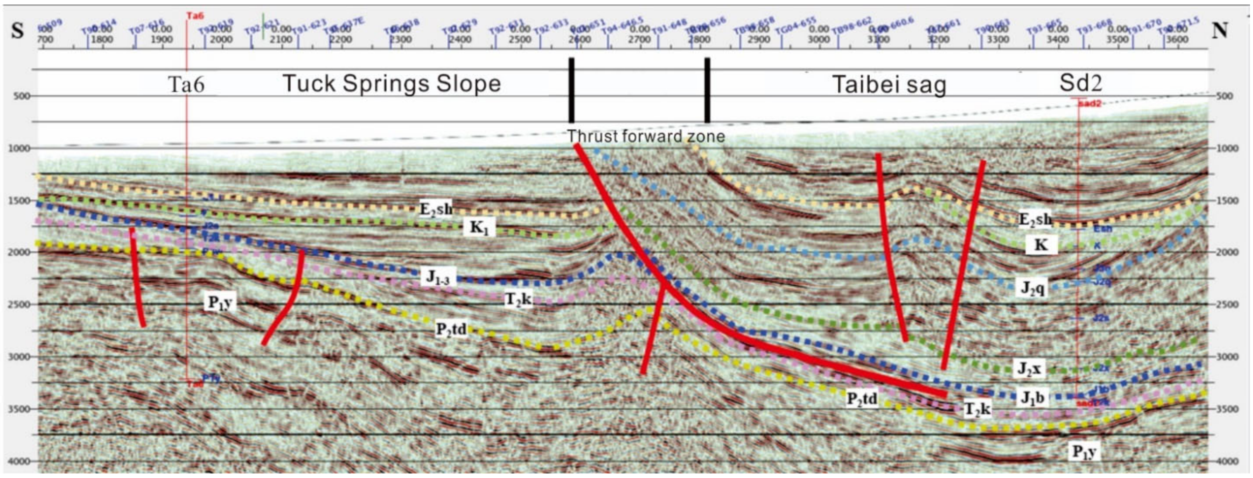

Figure 3. Two-dimensional T87-265 geological section map of the Takequan slope zone

3.3. Hydrogeological Conditions

The in-situ leachable sandstone type uranium deposit is formed in the infiltration type artesian basin, and needs a relatively complete set of recharge runoff drainage system of interlayer confined water in the ore bearing strata. The recharge area is generally the atmospheric precipitation, ice and snow melt water and bedrock fissure water of the peripheral mountain system, which are transferred in the form of infiltration into the underground. The discharge area is located in the low-lying area of the basin, The runoff area is located in the area between the two, which is also a favorable area for the development of mineral resources.

The braided river deposits of Jurassic and alluvial fan deposits of Cretaceous indicate that rainfall occurred frequently in this period. Even in Cenozoic, lake deposits were dominant in Turpan Hami basin, with abundant rainfall. In the water supply areas such as Jueluotage and liaodun uplift, the bedrock fissure water is also relatively rich, and the bedrock fissure water in Jueluotage tends to increase with the decrease of altitude from west to East [15]. The wide and gentle monoclinic structure in this area makes the uranium rich groundwater flow slowly along the bedding. As the catchment area of this area, the surface water and groundwater are discharged to the ground through the fault structure, completing the groundwater circulation in this area. In addition, the recharge and discharge of Jueluotage and liaodun uplift provide a complete set of supplement runoff drainage system for the formation of uranium deposits in this area.

3.4. Lithology and Lithofacies Conditions

The Jurassic is divided into Badaowan Formation, Sangonghe formation, Xishanyao Formation and Toutunhe Formation. The Xishanyao Formation of Middle Jurassic in the study area is mainly a set of fluvial deposits, including a set of glutenite, medium coarse sandstone, with a small amount of brick red and maroon mudstone and a thick coal seam. The thickness of the stratum tends to decrease from west to East and from south to north; Gray and gray white fine sandstones are developed in the underlying lower Jurassic, and gray black mudstone interbeds with gray white fine sandstones and gravelly sandstones are developed near the bottom; The overlying Toutunhe Formation is composed of medium coarse sandstone, gravelly sandstone and glutenite with a small amount of purplish red mudstone. In the vertical sequence, the mud sand mud structural layer is formed (Figure 4).

According to the drilling data of coalfields and oilfields, through the statistics of sand / ground ratio and the analysis of dominant facies method, it is inferred that the sedimentary environment in this area is mainly lacustrine and fluvial facies, and the coal seams are mainly developed in swamp and floodplain environment. There are two nearly north-south ancient rivers in the Loess cliff area, which originated near the Jueluotage mountain and provided the main sediment source of Xishanyao Formation. The area from Qiketai to Bogda in the North may be a part of the lake.

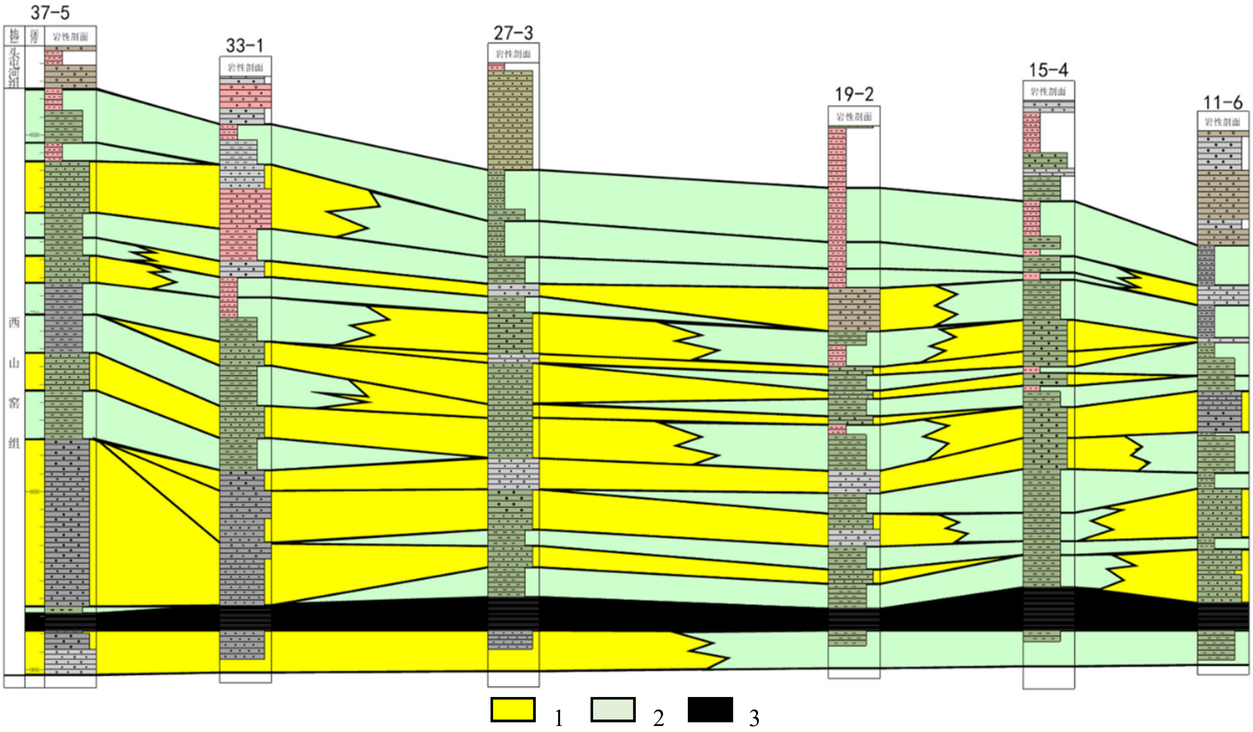

Figure 4. Sedimentary facies profile of coalfield drilling continuous wells

1- Channel deposits; 2- Floodplain deposits; 3- Coal seam

4. METALLOGENIC MECHANISM

4.1. Formation Mechanism of Sandstone Type Uranium Deposit

The formation of in-situ leachable sandstone type uranium deposit is affected by its geochemical behavior and can be divided into two stages. The first stage is the dissolution of uranium from the host rocks into water-soluble uranyl complexes; In the second stage, uranyl complexes are transported to the underground rocks by water and reduced to solid minerals in suitable redox geochemical phases.

(1) Dissolution stage

The large area of potash feldspar granite developed in the Jueluotag structural belt has obvious uranium loss in the geological history. For example, the △U of volcanic clastic rocks and clastic rocks are both negative, and the △U of clastic rocks reaches -69%, indicating There is a large amount of uranium loss in the formation [16-17]. Because uranium element has relatively active geochemical properties, uranium-rich granite and other rocks are leached and denuded, and uranium minerals are dissolved out. Under natural conditions, they are easily oxidized to form hexavalent uranyl complexes and dissolve in surface water. Or in the groundwater; at the same time, the carbonate rocks developed in the Carboniferous in Rotag decompose to make the surface water and groundwater rich in HCO_3^- and CO_3^{2-}. When they encounter U^{4+}, they can form soluble uranyl carbonate complexes, such as $Na_4[UO_2(CO_3)_3]$ and $Na_4[UO_2(HCO_3)_6]$.

In addition, when a large number of plant debris and coal were exposed on the surface or distributed near the surface of the Early Middle Jurassic, they would oxidize and decompose a large amount of humic substances. They can also form uranyl humic acid complexes when combined with uranyl. -Formed under weak alkaline conditions, such as $Na_4[UO_2(C_nH_mCOOH)]$.

(2) Enrichment stage

The Xishanyao Formation and its overlying strata are developed with multi-layer glutenite. The good permeability of glutenite is that the groundwater carrying uranyl complex infiltrates downward under the action of river, sheet flow and seepage, or gradually infiltrates into the underlying strata from structural fissures. Meanwhile, the hydrochemical environment gradually transits from oxidation to reduction.

The reduction and precipitation of uranium requires a good reduction environment and a large amount of reducing agent. Xishanyao Formation in huangtuiya area develops a set of coal seams with considerable thickness and abundant coalbed methane. According to previous studies, the coal and rock of Xishanyao Formation in nearby Shaerhu is in the stage of low metamorphic lignite long flame coal, with RO ranging from 0.31% to 0.70%. There are two types of coal-bed methane, i.e. pyrolysis and biogenic gas, with the characteristics of low ash to ultra-low ash, which is conducive to the adsorption of organic components on methane [18]. The gas content of adsorbed gas of coal samples is relatively high, among which the gas content of raw coal of 22 coal samples in Shashi 1 well is 0.73-3.09 m^3 / T, and the total hydrocarbon content of gas measured in Shashi 1 well and Shashi 2 well is 11.5% - 18.5% and 8.5% - 40% respectively (Table 1). Even the thin coal seam has high gas content [19]. The volume method is used to estimate the amount of coalbed methane resources in this area up to 900×10^8 m^3, the reserve abundance can reach 1.0×10^8 m^3/km^2[20-21]; Secondly, the ash content of the main coal seam in this area is low, and the coal matrix interlayer fractures, intergranular pores, plant tissue pores, stomata and other pores are very developed, with porosity of 11.1% - 15.03% [22], which is the main adsorption space of coal seam methane; In addition, large pores such as large interlayer fractures are not filled, which is the main reservoir space of free gas and water-soluble gas, and also the main seepage channel [23]. A good set of mudstone and siltstone developed at the top of the Jurassic Xishanyao Formation has a good trap function, so as to preserve coalbed methane.

Table 1. Table of coal seam microscopic composition and analytical gas content in Shaerhu Sag (according to Li Xinning et al., 2015)

Well location	Number of samples	Coal seam thickness m/ Number of layers	Analytical gas content /m³/t	Vitrinite /%	Inertinite /%	Exinite /%	Mineral /%
Shashi 1	22	149/13	0.73~3.09	47.52	45.76	7.76	0.76
Shashi 2	6	140/10	1.55~2.93	51.45	36.350	8.43	2.18
Shashi 3	17	170/11	1.06~1.84	48.91	39.36	5.92	5.21
Shamei 1	40	151/11	0.27~2.13	52.60	29.40	17.50	0.70
Shamei 2	40	162/35	0.18~1.89	77.10	3.30	19.10	0.50
Shamei 3	2	59/25	0.14~0.31	9.00	85.00	5.20	0.90
Shamei 5	9	218/21	0.06~1.77	53.30	40.10	6.00	0.60
Shamei 7	3	76/24	0.15~1.32	36.20	30.20	11.80	21.8
Shamei 11	11	58/35	0.15	39.40	8.80	8.20	43.4

Coal bed methane can not only reduce and precipitate uranium directly, but also reduce sulfate to hydrogen sulfide or other sulfides under the action of bacteria, which can be used as precipitant of uranium. In the Loess cliff area, which has the same sedimentary environment and paleoclimate environment as the Shaerhu coalfield, although the coal seam is not as thick as the Shaerhu coalfield, it should have similar characteristics of coal rock analytic gas. Therefore, there should be enough coal bed natural gas as the reducing agent for the formation of Middle Jurassic Xishanyao Formation in-situ leachable sandstone type uranium deposit in the Loess cliff area, and provide an adequate and sustainable reduction environment.

As discussed above, uranium minerals are reduced to UO_2 under the action of CH_4 near the reduction zone, which enriches mineralization, and also accompanied by calcite and siderite production, and the reduction process is [24]:

$$UO_2^{2+} + CH_4 + 3H_2O \rightarrow 4UO_2\downarrow + HCO^- + 9H^+$$

$$2[UO_2(CO_3)_3]^{4-} + CH_4 + 4Fe^{2+} \rightarrow 2UO_2\downarrow + 4FeCO_3\downarrow + H_2O$$

4.2. Siderite: A Prospecting Indicator

Dongsheng large-scale in-situ leachable sandstone uranium deposit is associated with a large number of carbonate rocks [5-6], which is an important prospecting indicator. In the Xishanyao Formation of the study area, there is also rich carbonate mineral siderite. Siderite is mostly lenticular, pod, ellipsoidal, spherical, distributed along the layer, with concentric circle, nodule and cementation inside. The long axis direction is basically parallel to the stratigraphic plane, but not parallel to the modern surface, It shows that siderite is a secondary mineral formed in a certain geological history period and has nothing to do with the leaching of modern surface water (Figure 5).

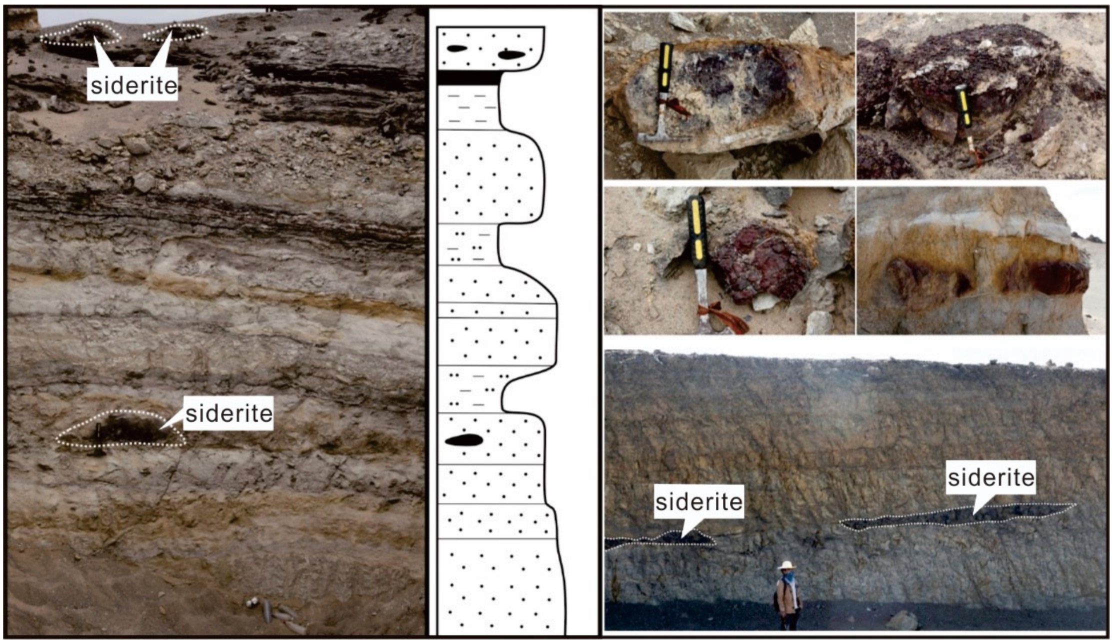

Figure 5. The paleo-redox profile of the Xishanyao Formation in the study area and the occurrence characteristics of siderite

Siderite is a carbonate mineral of iron ($FeCO_3$). The formation of siderite is strictly affected and restricted by redox conditions, acid-base environment and other factors. Eh Ph diagram shows that only when the oxidation potential (Eh) is 0-0.2 and Ph is between 7-7.8, the medium weak alkaline environment is most favorable for the formation of Siderite (Figure 6), The dissolution of coalbed methane from Xishanyao Formation into groundwater can reduce the redox potential and promote the reduction and precipitation.

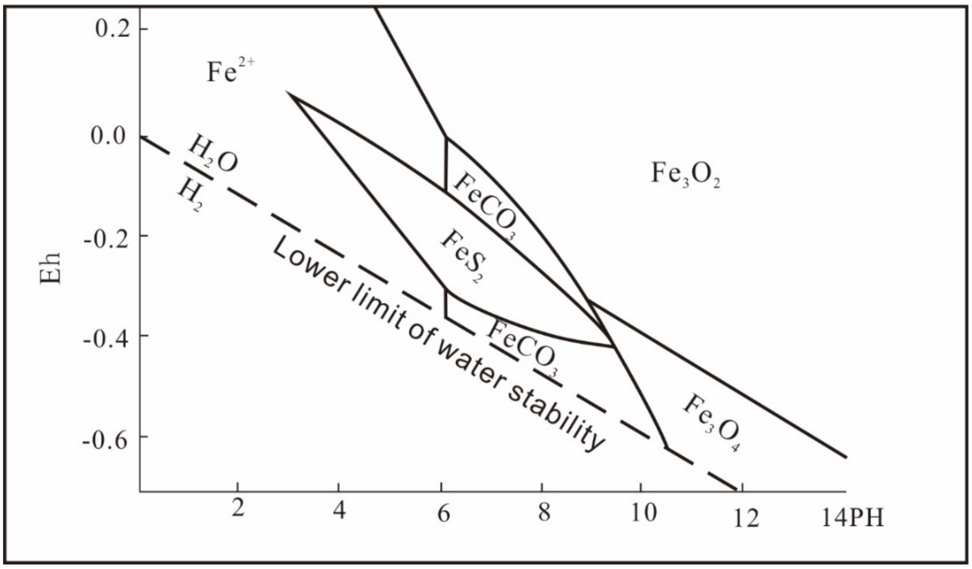

Figure 6. Eh-Ph diagram of iron (according to Rao Jilong, 1978)

At the same time, siderite has obvious regularity in the sedimentary section, and the iron ores from the surface to the deep part of the basin change in turn: iron oxide phase, iron silicate phase, iron carbonate phase and iron sulfide phase, reflecting the existence of oxidation-reduction sedimentary environment from the surface to the deep part of the basin (Table 2), which also shows that siderite was formed in a weak reduction environment.

Table 2. Sedimentary geochemical facies of iron (according to Li Tong, 1979)

mutually	Iron ion	Major iron minerals	Sediment	Organic matter	Eh	Ph
Oxidation phase	Fe^{3+}	Hematite, limonite	Sandy silty clastic rock, deposited a small amount of siliceous or calcareous nodules	nothing	>0.2	7.2~8.5
Transitional phase	$Fe^{3+}>Fe^{2+}$ $Fe^{2+}>Fe^{3+}$	Glauconite, Lepidochlorite	Silty, argillaceous clastic rocks, diatomite and phosphorite	less	0.2~-0.1	
Weak reducing phase	Fe^{2+}	Siderite, Oolitic chlorite	Argillaceous deposits and abundant clay minerals	many	0.0~-0.3	7.0~7.8
		Ferrodolomite	A large amount of dolomite and limestone were deposited	quite a lot	-0.3~-0.5	>7.8
Strong reducing phase		Pyrite, Marcasite	Organic clay, black shale, organic rock			7.2~9.0

In conclusion, iron element is sensitive to redox environment. The formation of siderite represents the existence of weak reduction environment, which is almost consistent with the formation environment of in-situ leachable sandstone type uranium deposit. The existence form of iron can change regularly with the dissolution, migration and enrichment of uranium, and they interact with each other. Therefore, the chemical change of iron can reflect the chemical change of uranium, and the formation of siderite can reveal the enrichment of uranium mineralization, which can be used as one of the prospecting indicators for in-situ leachable sandstone type uranium deposits.

5. URANIUM PROSPECT EVALUATION

The formation of siderite reflects that there is a special redox environment in this area, which is almost consistent with the ore-forming environment for in-situ leachable sandstone type uranium deposits. At the same time, the sandstones above the Xishanyao Formation coal seams are widely greenized (Figure 4). Some people think that the greenization is the result of secondary reduction, which plays a role in ore preservation and is the result of reduction alteration [25]. The greenization of sandstone and the development of siderite confirm the existence of paleo redox zone in this area, and the greenization controls the formation and distribution of uranium deposits [7].

Secondly, the target horizon of Xishanyao Formation in this area is shallowly buried. Within the range of 100-1000 m, combined with the range of sand / ground ratio greater than 0.4, it is the main relative development area of sandstone and glutenite. Based on this, the possible uranium metallogenic prospect areas are identified (Figure 7).

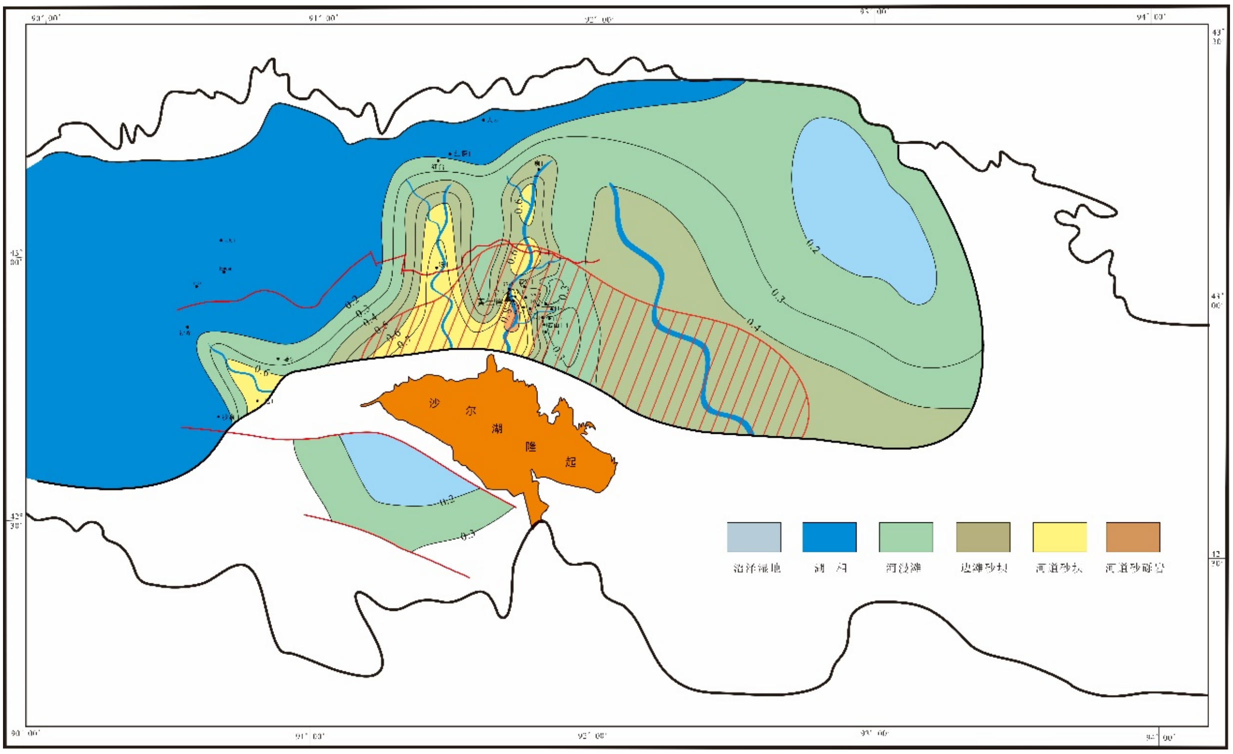

Figure 7. Uranium mineralization prospect evaluation map of the Middle Jurassic Xishanyao Formation in the southern Turpan-Hami Basin

1. Swamp wetland; 2. Lake; 3. river flat; 4. Beach dam; 5. Channel bar; 6. Channel glutenite

6. CONCLUSION

(1) The uranium rich granite in the exposed area of Jueluotage structural belt has high uranium content and rich uranium source; The favorable sedimentary facies belt is developed, continuous and widely distributed in the area, with wide and gentle monoclinic structure and a complete system of supplement, runoff and drainage. The hydrodynamic conditions are good, and the basic conditions for the formation of in-situ leachable sandstone type uranium deposits are available.

(2) The abundant siderite indicates that there is a good paleo redox environment and hydrochemical conditions in the huangtuya area, while the formation of sandstone type uranium deposit is almost identical with that of siderite, which proves that the area has the environment for the formation of uranium deposit. Siderite can be used as one of the prospecting indicators.

(3) Combined with the sand / ground ratio of Xishanyao Formation, the distribution and buried depth of green sandstone above the coal seam, the uranium metallogenic prospect area is determined. It is considered that Xishanyao Formation in this area is shallow buried and has good development value, so this area is a favorable uranium mining area.

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