Localization conditions of apometaterrigenous non-carbon tungsten mineralization at the Sarykul deposit of the Karatyubinsky ore district in Uzbekistan

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Abstract. This article explores the occurrence of apometaterrigenous non-carbon tungsten mineralization at the Sarykul deposit in the Karatyubinsk Mountains. Initially considered unpromising, this newly discovered tungsten mineralization was found during gold mining operations. The prospecting activities targeting calcification zones in metaterrigenous rocks revealed their tungsten-bearing nature. This discovery has reshaped the understanding of tungsten mineralization genesis, lithological and structural conditions, and the overall minerogenic potential of the Karatyubinsky ore field. Apometaterrigenous tungsten mineralization originates from coarse flysch rocks transformed into shale rocks in the contact zone with a tungsten-specialized granitoid intrusive. The mineralization is associated with multicomponent metasomatites formed on aluminosilicate metaterrigenous rocks. Significant correlations exist between tungsten and elements such as Pb, Ag, Au, Be, Cu, Mo, V, and Mn. Scheelite mineralization forms autonomously, followed by the combination of different stages within mineralized zones. The regional trog structure, characterized by the formation of an olistostromic stratum due to high granulometric dispersion, is also linked to the apometaterrigenous mineralization.

1 Introduction

A new promising direction of metallogenic research is developing, operating with quantitative indicators when identifying patterns of ore deposit placement based on high-tech computer technologies. In particular, in developed countries, such as Russia, China, USA, or Canada, similar studies are conducted to identify promising areas, discover mineral deposits, and assess their reserves. The advantage of such a scientific approach is efficiency, the possibility of multidimensional comparisons, and a quantitative assessment of the reliability of established dependencies [1-4].

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Uzbekistan is the territory of numerous industrial deposits of tungsten of the skarn-scheelite formation studied in detail. However, the main reserves of these objects have either been exhausted or represented by base ores. The search for new objects of the skarn-scheelite formation has taken many years, which allowed identifying only ore occurrences that did not pass into the rank of industrial deposits \[5-7\]. The urgent task of replenishing reserves of tungsten ores, primarily at the expense of high-quality ores, requires developing criteria for searching for tungsten mineralization of non-carbon genesis \[8-10\].

Tungsten is one of the main profiling metals of Uzbekistan, which has been a well-known tungsten ore province of the world for more than 50 years. Tungsten ore facilities are concentrated in three mining and economic regions of the republic:

1. Pritashkent (Chatkalskoy ore district with deposits of Sargardon, Barkrak, and Chavata-Dyke quartz-greisen type);
2. Samarkand (Zirabulak ore district with deposits of Ingichke, Chakylkayansky–Yakhton, Karatyubinsky–Karatyube, North Nuratinsky–Koytash, South Nuratinsky–Lyangar); these deposits of the skarn type are confined to granitoids with \(P_1\) in the Zarafshan–Alay and Zarafshan–Turkistan metallogenic zones of the Southern Tien Shan;
3. Kyzylkums (Turbaysky ore district with Sarytau and Soutbay deposits in the South Bukantau zone of the Southern Tien Shan) \[11-13\].

Therefore, for tungsten deposits, the main prospect industrial types of the republic are skarn and apakoskarn–skarnoid deposits: gumbiets and greisen types, which mostly have an indicator value for large deposits, although in socially, geographically, and economically favorable conditions, they can serve as a subject of exploitation. The considered reserves of tungsten in the republic, taking into account repayment, are estimated quite high. Forecast resources are estimated twice as much \[14,15\].

In 1931, for the first time on the territory of Uzbekistan, I.M. Evfimenko discovered wolframite on the ore occurrence of Chagat (Chatkal Mountains). In 1938, A.S. Kaiser discovered wolframite in the washings on the area of the Sargardon deposit (Chatkal Mountains). The search for tungsten ores in Uzbekistan began in 1934 after the discovery of scheelite in the washings on the area of the Karatyubinsk Mountains \[16\].

The discovery at the Sarykul deposit of non-carbon tungsten mineralization with presumably industrial prospects in the northeastern part of the Karatyubinsky ore district in 2010, confined to polycomponent metasomatites on aluminosilicate metaterrigenous rocks, significantly changed the understanding of the genesis of tungsten mineralization and lithological and structural conditions of localization of ore bodies and the minerogenic potential of the Karatyubinsky ore district on tungsten in general \[17-19\].

2 Materials and methods

The paper aims to substantiate the conditions of localization of non-carbon apometaterrigenous tungsten mineralization at the Sarykul deposit and determine the prospects of the Karatyubinsky ore district for unconventional apometaterrigenous tungsten mineralization. The research objects are mineralized zones of the Sarykul deposit in the Karatyubinsky ore district \[20-23\].

The research methods include a complex of field observations (geological search routes; geological documentation and sampling; compilation of lithological, mineralogical, and structural sections, etc.); mineralogical, petrographic, and petrological studies of host rocks; circum-ore metasomatites and ores; geological and structural conditions of localization of mineralization; and modern high-precision analytical studies (mass spectrometer, ICP-MS, microprobe, Jeol, DRONE-3, etc.) \[24\].

The history of developing the mineral resource base of tungsten mineralization in Uzbekistan includes three main stages.
Note:
1. Quaternary (undifferentiated); 2. Carboniferous system (hornstones, sandstones, siltstones, argellites, shales, etc.); 3–4. Devonian system (limestones, dolomitic limestones, dolomites, flints and siliceous mudstones, marble); 5. Silurian system (calcareous dolomites, limestones and marbles); 6. Quartz veins; 7. Pegmatites rare - metal-ceramic, pegmatoid granites (RS-P); 8. Ketmenchinsky subcomplex of two mica and leucocratic granites (muscovite granites, muscovite-biotite fine-medium-grained, and tourmaline containing, sometimes with garnet); 9. Karatyube-zirabulak adamellite granite subcomplex (granodiorites biotite, hornblende-biotite, porphyritic); 10. Granite aplites; 11. The Tymsky gneiss-granitoid subcomplex. Biotite gneiss granites; 12. Granodiorite-gneiss, quartz diorite-gneiss, granite-gneiss biotite medium-grained; 13. Atkamarsky gabbro-diorite granodiorite complex. Granodiorites, quartz diorites, amphibole-biotite fine-grained gabbro-diorites; 14. Diorite-porphyrites; 15. Two-mica granodiorites and granites; 16. Skarns, skarnoids; 17. Olistolites and olistoplaks: carbonate (a) and siliceous rocks (b) C2-3 mr; 18. Zones of altered rocks: calcification (o), sulfidization (p), tourmalination (t), albitization (a), greissenization (d), marbling (m), biotitization (b); 19. Geological boundaries: traced (a), assumed (b); 20. Disjunctive dislocations: traced (a), assumed (b); 21. Thrusts: traced (a), assumed (b); 22. Faults of different orders according to MAKS data; 23. Zones of increased permeability; 24. Elements of occurrence: a) rocks, b) disjunctive dislocations, c) intrusive bodies; 25. Sarykul (a) deposits (estimated WO3 resources by cat. Р1-8,462 t); 26. Angirlinskaya square (b); 27. Tungsten deposit: 1) Karatyubinsky; Mineralization points: 28) identified through furrow testing; 29) identified by crushed samples; 30. Tin ore occurrences: 2) Beshbarmaksk; 3) Karaguzarskoye; 4) Occurrence 1; 5) Occurrence 2; 6) Occurrence 3; 7) Occurrence of Chunkaymysh.

Fig. 1. Schematic geological map of the Karatyubinsky ore district. The first stage embrases 1930–1960. In 1936–1946, the deposits and ore occurrences of the scheelite-bearing skarns such as Koytash, Ugat (M.G.Kazakov), Karatyube (I.A.Eisenstat, L.S.Svidskaya), Ingichke (A.M.Engalychev, A.V.Purkin, etc.), Chashtepe (S.N.Popanko), Yakhton (A.A.Konyuk, S.N.Popanko) and others were discovered. During the same period, the deposits of Lyangar, Sargardon, and many others (O.A.Kaiser, N.A.Smolyaninov, etc.) were also identified.
V.I. Biryukov, M.G. Kazakov, I.A. Eisenstat, L.S. Svidskaya, N.V. Nechelyustov, N.D. Ushakov, etc.) were declared as promising. Formation of the mineral resource base implied the discovery, exploration, and development of tungsten ore deposits, namely Lyangar, Koytash, and Ingichke (N.D. Ushakov, N.V. Nechelyustov, M.D. Troyanov, etc.), as well as prospecting exploitation of small occurrences, such as Karatyube, Sazagan, Barkrak, and others. The first metallogenic generalizations also refer to this period (H.M. Abdullaev, A.V. Korolev, I.H. Khamrabaev, etc.) [25, 26].

The second stage (1960–1975) is characterized by numerous discoveries of small occurrences but, at the same time, a general decrease in the growth of reserves of tungsten ores, which is due to conjunctural reasons and the exhaustion of the fund of traditional skarnogenetic types of mineralization. During this period, T.M. Matsokina, M.S. Kucukova, V.D. Otroshchenko, V.N. Ushakov, I.H. Khamrabaev, N.K. Jamaletdinov, M.I. Ismailov and others generalized the regularities of the formation and placement of skarn tungsten mineralization.

The third stage (1975–present) is characterized by an increase in the volume of exploration for tungsten and, most importantly, the strategic direction of the search has changed with the broad involvement of large-scale predictive studies (R.V. Tsoi, Yu.A. Chernyavsky, V.N. Ushakov, B.B. Shaakov, V.L. Shadrin, etc.). The sharp expansion of the mineral resource base of tungsten was due to the discovery and exploration of new deposits in the Kyzylkum region (Sarytau, Soutbay) and the increase in reserves on the flanks of well-known objects (Ingichke, Yakhton) [27].

Further, exploration work was mainly done at the Ingichke, Koytash, and Ugat fields, while in the Karatyube and Chakylkalyan mountains, the works were mainly prospecting and exploration in nature. Tungsten, the main minerogenic potential of the Chakylkalyan-Karatyubinsky district, has been long associated with the skarn formation, represented by several deposits such as Choshtepa, Karatyuba, Hadzhadik, Yakkhton, and many large ore occurrences.

Apometaterrigenous tungsten mineralization was studied at the Sarykul deposit in the western part of the Karatyubinsk Mountains. The area of distribution of this type of tungsten mineralization, new for the region, used to be considered unpromising due to the results obtained on skarn bodies, in which tungsten mineralization has no industrial significance (Figure 1).

The magmatites of the Karatyubinsk Mountains are represented by a consistently differentiated series of rocks of the granitoid series, demonstrating a trend of increasing tungsten contents from early to late phases. For the Sarykul and adjacent Karatyubinsk intrusive, magmatism manifestations were differentiated into 4 phases, which caused the sequential formation of diorite, granodiorite, granite, and alaskaite series. Rocks of the granodiorite series mainly occupy the peripheral parts of most massifs. Rocks of the granite series make up most of the Karatyubinsky and Sarykul intrusives to the Ketmencihinsky subcomplex (U3-P1k) of the Karatyube, Zirabulak adamellite-granite complex.

Intrusive rocks in the area of the Karatyubinsk Mountains occupy the predominant part of the area, composing a series of intrusions of different ages. The largest of them is Karatyubinsky intrusive, around which Sarykul, Aksaysky, Atkamarsky, Gurmaksky, and Lolabulaksky intrusions are located. All intrusives are part of the Southern Tien Shan collisional granitoid belt.

In granodiorites and granites of the Sarykul intrusive, tungsten is also found in the form of scheelite, which, along with the tungsten content of rock-forming and accessory minerals, is an indicator of the ore-generating properties of such granitoids. However, if scheelite is epigenetic in ore-generating granodiorites, then it is syngenetic in aplites and leucocratic granites. In granodiorites and biotite granites, scheelite occurs in the form of veins, clusters,
3 Results
The granitoids of the Sarykul intrusive belong to the moderately alkaline type, the potassium sodium series, mainly high alumina, with a low degree of femicity, medium and high degree of oxidation (Table 1).

<table>
<thead>
<tr>
<th>Component</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>Avg.</th>
<th>Value K</th>
<th>Coef. (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MgO</td>
<td></td>
<td></td>
<td></td>
<td>0.08</td>
<td>1.83</td>
<td>9.6</td>
</tr>
<tr>
<td>K₂O</td>
<td></td>
<td></td>
<td></td>
<td>0.27</td>
<td>8.62</td>
<td>125</td>
</tr>
<tr>
<td>CaO</td>
<td></td>
<td></td>
<td></td>
<td>0.23</td>
<td>0.43</td>
<td>1.32</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td></td>
<td></td>
<td></td>
<td>0.41</td>
<td>1.32</td>
<td>1.32</td>
</tr>
<tr>
<td>MnO</td>
<td></td>
<td></td>
<td></td>
<td>0.18</td>
<td>1.83</td>
<td>9.6</td>
</tr>
<tr>
<td>TiO₂</td>
<td></td>
<td></td>
<td></td>
<td>0.08</td>
<td>1.83</td>
<td>9.6</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td></td>
<td></td>
<td></td>
<td>0.18</td>
<td>1.83</td>
<td>9.6</td>
</tr>
<tr>
<td>Na₂O</td>
<td></td>
<td></td>
<td></td>
<td>0.23</td>
<td>0.43</td>
<td>1.32</td>
</tr>
<tr>
<td>P₂O₅</td>
<td></td>
<td></td>
<td></td>
<td>0.08</td>
<td>1.83</td>
<td>9.6</td>
</tr>
<tr>
<td>K₂O + Na₂O</td>
<td></td>
<td></td>
<td></td>
<td>0.23</td>
<td>0.43</td>
<td>1.32</td>
</tr>
<tr>
<td>FeO + MnO</td>
<td></td>
<td></td>
<td></td>
<td>0.18</td>
<td>1.83</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Note: Petrochemical coefficients:

- MgO: MgO/(FeO+MgO)
- K₂O: K₂O/(FeO+MgO)
- CaO: CaO/(FeO+MgO)
- Al₂O₃: Al₂O₃/(FeO+MgO)
- MnO: MnO/(FeO+MgO)
- TiO₂: TiO₂/(FeO+MgO)
- Fe₂O₃: Fe₂O₃/(FeO+MgO)
- Na₂O: Na₂O/(FeO+MgO)
- P₂O₅: P₂O₅/(FeO+MgO)
- K₂O + Na₂O: (K₂O+Na₂O)/(FeO+MgO)
- FeO + MnO: (FeO+MnO)/(FeO+MgO)

The analysis of the nature of the structure of the sections of the region allowed us to identify three stages of development of terrigenous formations. Thus, the Sarykul intrusive, in the exocontact zone of which apometaterrigenous tungsten mineralization is developed, is predominantly composed of rocks of the late phases of the intrusive activity, tungsten of predominantly magmatic origin was invo...
The uneven tungsten content in various types of granitoids of these formations is due to its unequal distribution in rock-forming minerals, their quantitative ratios in rocks, and accessory scheelite. When comparing the tungsten content of minerals, we established that the main minerals with a concentration of tungsten are plagioclase and biotite. Given that tungsten is contained in the anionic part of plagioclase, it can be easily removed from it due to the manifestation of postmagmatic processes widely manifested in the area. The studied granitoids with a predominance of sodium in alkalis and accessory scheelite were subject to albitization and muscovitization, resulting in tungsten released from the crystal lattices of feldspar together with sodium passed into an alkaline solution in the compound Na\(_2\)WO\(_4\). As a result of contact, regional, and dynamic metamorphism, the primary sedimentary rocks were transformed into micaceous and amphibole shales. At the deposit, a special group of W-containing rocks was formed by metasomatically altered limestones (with a relatively low degree of marbling, they contained carbonaceous graphite substance and aluminosilicate admixture scattered in the rock mass). The non-carbonate admixture of limestones undergoes significant metasomatic changes (before the formation of albite-quartz segregations), serving as the main medium for the deposition of scheelite in them. The saturation of the metasomatic transformation of limestones leads to a significant decrease of carbonates in their composition (the CaO content can decrease to 15%), the formation of MgO in an amount of up to 1.2%, and an increase in the volume of quartz rock up to 12%). The ore process has a three-fold addition of Ca, accompanied by the accumulation of P and a slight addition of Fe (Table 2). At the pre-ore stage of localization of metasomatites, Na, Mg, and Al are removed from the circum-ore space.

**Table 2.** Distribution of the main elements in aluminosilicate metasomatites.

<table>
<thead>
<tr>
<th>Petrogenic elements</th>
<th>Na</th>
<th>Mg</th>
<th>P</th>
<th>Ca</th>
<th>Al</th>
<th>K</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content of the elements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium concentration</td>
<td>13,039</td>
<td>16,559</td>
<td>3,482</td>
<td>74,689</td>
<td>58,409</td>
<td>11,393</td>
<td>54,373</td>
</tr>
<tr>
<td>Accumulation coefficients</td>
<td>0.7</td>
<td>0.76</td>
<td>3.7</td>
<td>3.4</td>
<td>0.9</td>
<td>0.56</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Source: Compiled by the authors.

4 Discussion

In 2000–2004, in the Lyangarskoye deposit, advanced specialized prospecting for gold, rare metals, and other minerals in promising areas in the central part of the Karatube Mountains and an assessment of forecast resources according to categories were conducted. P

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At the beginning of the new stage of work, the potential of Southern Uzbekistan for tungsten was considered limited. However, exploration by employees of the State Unitary Enterprise Gissargeologiya allowed identifying industrial tungsten mineralization of new ore-formation types. We implemented the ideas of a possible wide distribution of unconventional tungsten mineralization localized in aluminosilicate rocks of the matrix of olistostromic strata (apometaterrigenous type), as well as in granitoids of intrusive collisional complexes in the open areas of Southern, Western, and Eastern Uzbekistan, which is confined to ore-bearing metasomatites (apogranitoid type), the substrate for the formation of which was primarily sedimentary rocks deeply transformed by metamorphic processes.

The approximate calculation of the possible potential tungsten content of the intrusive was based on the following data: let the tungsten content in granodiorites be 0.0006% (6 g/t); the approximate volume of the intrusive body of the western part of the Karatyubinsky sector is 10×5×4 = 200 km$^3$; then the mass of granodiorites in half of the volume (the other half is granite) will be 100×2,500,000,000 (weight 1 km$^3$ of granite) = 250,000,000,000 tons, and the amount of tungsten will be 250,000,000,000 tons × 6 g/t = 1,500,000 tons. Even with lower tungsten contents in the melt from which the intrusive body was formed, the amount of metal is assumed to be sufficient to form a large or medium deposit.

The formation of dozens of large scheelite deposits in the Karatyubinsky district from the parent magma with a tungsten content of 0.01%–0.02% (taking into account the transition to postmagmatic ore-bearing solutions of 1/100 of the initial amount of tungsten). Nevertheless, there is only one small deposit of the skarn-scheelite formation (Karatyubinsky with reserves of no more than 4 thousand tons) and a series of manifestations of this formation with mineralized zones that are not of industrial interest within this area.

Suppose the considerations above are at least partially correct. In that case, the answer to the question of the discrepancy between the potential of the ore-generating magmatic complex and the actual reserves of explored tungsten objects is the presence of non-carbon tungsten mineralization within the Karatyubinsk megablock. Despite the research results achieved, not enough attention has been paid to the issues of lithological and structural conditions of localization, the relationship of mineralization with magmatic formations, ore-generating sources, ore-containing rocks, the material composition of ores and ore-modified rocks of a new, non-carbon apometaterrigenous and apogranitoid type of mineralization, in the Karatyube-Chakylyan ore region, Special targeted studies on the development of search and forecast criteria and signs of non-carbon tungsten mineralization were unsystematic or appeared to be beyond the contour of the forecast areas. Therefore, these issues should be solved using a complex of geological, mineralogical-petrochemical, geochemical, and chemical-analytical research methods.

5 Conclusions

- Mineralized zones are confined to a fragment of the trog structure containing rocks of the Olistostromic strata, characterized by a genetically determined high granulometric dispersion;
- Proximity to the zone of near exocontact of intrusive collisional granitoids, geochemically and accessory specialized on tungsten;
- Mineral composition of ore-bearing zones, the features of which combine scheelite, disulfide, bismuth, and tin-polymetallic associations;
Complex structure of the geochemical field with an emphasis on the elements of the typomorphic complex of apometaterrigenous tungsten mineralization (W-Bi-Cd-Te-Be-Au-Zn-Cu-Sn).

The research significance lies in identifying sources of ore matter for new types of tungsten mineralization, establishing a connection with certain magmatic complexes, as well as determining the nature of ore-conjugated metasomatosis and its influence on the features of the ore process, the role of ore-controlling structures, and the development and recommendations of search criteria, signs, and new types of tungsten mineralization.

The practical significance of the research lies in the allocation of local areas for conducting prospecting and evaluation work in the central part of the Karatyubinsky ore district in the zone of near exocontact of the Sarykul granitoid intrusive to identify industrial tungsten mineralization of the apometaterrigenous type, as well as the allocation of the Kamangaran and Hodzhadyk areas.

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