Research on the Ore-controlling Factors and Ore-prospecting Indicators of Gaoaobei Tungsten Mines in Rucheng County of Hunan Province

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Abstract. By means of comprehensive analysis, the Gaoaobei tungsten mines in Rucheng County was studied and the results showed that: 1) the ores occurred in veins. The major ore minerals were black-tungsten ores, followed by molybdenite, cassiterite, chalcopyrite, stannite, native bismuth, etc. 2) Distribution of the ore bodies were mainly affected by the formation, the structure and magmatism; 3) There were quite a lot of obvious direct ore-prospecting indicators in the region, mainly including abandoned mining workings, quartz vein, alteration, structural feature.

Keywords: Tungsten Ore, Ore-controlling Factors, Ore-prospecting Indicators, Gaoaobei area.

1. Introduction
As an important strategic resource, Tungsten ore has high values. Gaoaobei Tungsten ore in Rucheng County of Hunan Province is a large ore deposit. There have been lots of studies on Tungsten Ore of China (Zhu et al., 2017; Deng et al., 2019; Dong et al., 2019; Chen et al., 2012; Xu et al., 2008; Sun et al., 2016; Wang et al., 2015; Lei et al., 2009). In this paper, the geological characteristics, ore-controlling factors and ore-prospecting indicators of the Gaoaobei Tungsten ore were studied, which provided the basic data for the study of the ore-forming mechanism of the deposit, and provided technical guidance for the exploration of the ore deposit in the area next.

2. Geological Background
Located in the direction of 64° north east of Rucheng County, Chenzhou, Hunan Province, with a straight distance of about 28km, Gaoaobei mining area is under the jurisdiction of Jiyi Township, Rucheng County. Located at the junction of the north-east corner of Jiyi Township of Rucheng County and Jiangxi Province, the mining area are connected with provincial highways S324 by rural roads in four directions. Thus, the traffic is quite convenient (Fig.1).
The exposed formation within the area is distributed from the Sinian System to Quaternary System. The distribution area is dominated by the Sinian-Cambrian system, followed by the Devonian-Permian and the Permian-Cretaceous system (Fig. 2). The Sinian-Cambrian system is mainly distributed in the two northeast uplift belts of Dayingdong-Dongping, Baiyunxian-Qingyandong, which is a set of large-thickness flyschoid and silicate deposits. The lithology is mainly of the shallow-metamorphic fine-grained quartz sandstone, the feldspar quartz sandstone, the slate, the sandy slate, the carbonaceous slate, the siliceous rock, etc., which generally has the normal-grain-order bedding, the horizontal bedding and the horizontal-grain bedding. With a width of 4-14km, Devonian(middle)-Permian(upper) system are exposed in Rucheng-Shatian North-East depression belt, which are distributed along the both sides of Daping reverse fault and Yanshou-Shatian reverse fault. The strata is marine continental or neritic facies clastic rock and carbonate sediment. There is a significant angle unconformity with the underlying anterior Devonian system. Of which, the upper Devonian at the southern end of the Rucheng-Shatian basin bears iron, the lower Carboniferous and Upper Permian System bears coal. The Jurassic-Cretaceous system is the coastal marsh sedimentation of the terrigenous clastics, which can only be discovered in Mesozoic-Cenozoic faulted basin. The area is mainly distributed in Yanshou-Shatian, Lujing-Yanziyan structural basins. Of which, the upper Triassic system-Jurassic basin generally contains coal with quite poor quality. The Quaternary system is merely limited to the alluvial layer and residual slope construction in the foothills of the valley.

In the region, there are five major tectonic movements, including the Xuefeng orogeny, the Caledonian movement, the Indosinian movement, the Yanshan movement and the Himalayan movement. Each stage of tectonic movement shows a long period of repeated movement, forming a tectonic cycle, which corresponds to five structural layers, respectively are Xuefeng structural layer, Caledonian structural layer, Indosinian structural layer, Yanshan structural layer and Himalayan structural layer. As a result, the structural pattern in the area is complicated, forming a basement structure in east-west direction, overlaid by the tectonic frameworks in north-south, north-west, north-east direction.

The exposed rock masses in the region generally belong to the Chu-kuang Mountains compound rock body, which are mainly distributed in the east and south central part of the area. The multi-cycle tectonic movement in the region is accompanied by multi-period magmatic activities, which has deep
and shallow intrusive rocks, and also has subvolcanic and volcanic extrusive rocks. The lithology not only contains the acidic granite, intermediate-acid granodiorite, but also neutral diorite, basic diabase and basalt. The rock mass is mainly based on batholith output. The dike, rock branch and vein are also very developed. The major rock masses include: Late Caledonian granite (Yijiang rock mass, Dongluo rock mass), Indosinian granite (hydrothermal rock mass), Yanshanian granite (nine-peak rock mass, goose-shape rock mass) and Himalayan diabase. Of which, activities of Yanshanian granite are strongest, which are characterized by homologous, multi-stage and multi-stage invasion. Complex granite rock masses often form in the region, which is the parent rock mineralized in the area. Among them, the Triassic rock mass is closely related to uranium deposits and rare earth deposits, while the Jurassic rock mass is closely related to tungsten, tin, Mo, bismuth and other non-ferrous metal minerals.

![Geology map of the study area](image)

**Fig. 2** Geology map of the study area

### 3. Geological Characteristics of Ore Deposits

#### 3.1. Ore Characteristics

The ore in the mining area is quartz vein type (fine vein belt type) molybdenite wolframite ore (Fig.3). According to the field observation and the microscopic identification, the ore contains 36 kinds of mineral compositions. The ore minerals are mainly wolframite and molybdenite (Fig.3), followed by cassiterite, chalcopyrite, yellowish tin ore, natural bismuth. The Gangue minerals are mainly quartz, potassium feldspar, plagioclase and dolomite (Table 1).
Table 1. Mineral composition of Gaoaobei mine

| ore type               | ore mineral                  | gangue mineral                  |
|-----------------------|------------------------------|---------------------------------|
| thin quartz veinlets   | wolframite                   | topaz,biotite,sericite,fluorite,tourmaline,sphene,chlorite,zircon,apatite,rutilite |
| wolframite molybdenite| tinstone,copper pyrites,    | potash feldspar, anorthose,quartz, muscovite |
| stone                 | stannite, bismuth, bornite,  |                                  |
|                       | chalcocite, magnetite,       |                                  |
|                       | sphalerite                   |                                  |
|                       | topaz, biotite, sericite,    |                                  |
|                       | fluorite, tourmaline, sphene,|                                  |
|                       | chlorite, zircon, apatite,   |                                  |
|                       | rutile                       |                                  |

The structure of ore refers to the form and size of mineral grains, and also distribution characteristics of space. The main structures of ore in the mining area are as follows: xenomorphic crystal structure, semi-automorphic xenomorphic crystal structure, euhedral crystal structure, euhedral and semi-euhedral crystal structure, metasomatic texture, metasomatic rimmed texture, poikilitic texture. Because the mining area is micro-fine quartz vein type (fine vein belt type) molybdenite wolframite, the structure of the ore is mainly veined or veined at the macro level. According to the vein amplitude of ore-bearing quartz vein, it can be divided into large vein, stringer vein, micro-veined structure and parallel vein, stringer vein structure and so on. The ore structures in the mining area are mainly as follows: micro-vein, stringer vein and stringer-vein structure, strip structure, disseminated structure, annular structure inside mineral crystal particles.

3.2. Ore Body Characteristics
All ore bodies in the area are hosted in the ore-containing alteration, which is located in the internal contact zone between Cambrian Xiangnan formation and Indochina granite. Controlled by the F1 fault in the east-west direction, the northern boundary is F1, the southern mining area is from the mining area to the opposite drainage area, the strike is 285 -295°, the total length is about 1.8 km and it covers an area of about 1.0 km². The total area is vein-like. The deposits are generally occurred as the veins. Development of ore-bearing quartz veins are contained in mineralized bodies. When the ore-bearing quartz vein reaches a certain density, the ore body is then formed. There is no obvious boundary between the mineralized body and the surrounding rock, which belongs to the gradient relationship. The
mineralization boundary depends on the mineralization and density of quartz stringers. The ore-bearing erosion variants are exposed to the surface because of weathering and denudation in the eastern part of the mining area, while the western part is completely hidden under the Cambrian strata.

4. Ore-controlling Factors
According to the comprehensive study and analysis of the metallogenic area, the formation of tungsten ore is mainly controlled by strata, structure and magmatism.

4.1. The Controlling Effect of Strata on Mineralization

4.1.1. The Influence of the Chemical Composition of the Formation Rocks on the Mineralization. The mining area belongs to the posterior Caledonian uplift area. The lithology of the mining area and its surrounding from the basement to the cover layer is clastic rock, calcium deficiency can be found in rocks as a whole and the chemical property is more stable. The Indosinian granites in the region are the products of the locally-melted shell-source sediments, and the Yanshanian granites in the ore-forming period are also evolved from the Indosinian granites, which determines that both types of granites are poor in calcium. This property determines that the ore body in the area is in the form of filling rather than metasomatic, and the main mineral phase of tungsten is the wolframite rather than the scheelite.

4.1.2. The Influence of Shielding System of Strata on Mineralization. Owing to the thermal metamorphism, Cambrian strata in the area have already been transformed into dimica-rich hornstones during Indosinian magmatic activity. With quite good toughness, the hornstone is compact and water permeable. It is easy to deform and not easy to break under the action of external force, thus this area has the basic elements of shielding layer. The contact surface between Cambrian strata and Indochina rock mass is just a stress release surface. As an ore-bearing surrounding rock, the non-regional stress in Indochina granite in metallogenic period is difficult to be transmitted to the strata through the contact surface, and it is difficult to produce ore-bearing fissures in the strata. Due to the property of the formation, the temperature was not easy to diffuse when the magmatic hydrothermal fluids were active in the ore-forming period. The pressure was not easy to release, and the high-temperature and high-pressure fluid could easily reach the super-critical temperature and pressure point, further to form the super-critical fluid. The continuous high-pressure environment was also susceptible to the generation of a large amount of cracks in the shielded Indosinian granites to release the increasing pressure. Dense and subtle cracks generated from it. A large amount of minerals were also provided with a containable space.

4.2. The Controlling Effect of the Structure on Mineralization
The controlling effect of the regional structure on the magmatic rock: the mining area is located in the northwest side of the Nancheng-Suichuan fault zone, and the south section of the north-south giant granite belt of Wanyangshan-Zhuguangshan. These structures often have ductile shear characteristics in the deep parts. The deep P-T disturbance caused by the intense activity in the Indosinian period has resulted in the partial melting of the deep shell-source deposits, and the formation of the shell-source magma, the formation of the Indosinian rock mass after intrusion in place. The re-activation of Yanshanian ductile shear structure changed the temperature and pressure conditions of the deep magmatic chamber again, resulting in the melting of the remaining magmatic chamber in the later stage of Indochina evolution and the invasion of magma again. Because this magma was evolved, it was rich in fluid and minerals, which was the main ore-forming parent rock of tungsten ore.

The controlling effects of the secondary faults in the upper part of the Indochina rock mass on the Yanshanian granitic veins: the Yanshanian magmatic rocks developed along the fault structure and fracture filling in the Indochina rock mass and Cambrian strata, showing fine granitic veins or granitic fine grain veins.
The controlling effects of fracture structure on mineralization in metallogenic period: during the ore-forming period, with the rising of the Yanshanian ore-bearing hydrothermal fluid, the fractures formed in the rigid granite of the Indosinian period provided the channel and the space for the migration and the occurrence of the ore-bearing hydrothermal solution, which were the ore-bearing and ore-controlling structure of the mining area.

4.3. The Controlling Effects of Magmatic Rocks on Mineralization

The magmatic activity of Indochina provided a preliminary source for tungsten: from the point of view of trace elements, the Bi of Indochina magmatic rocks in the mining area was 4400 times of its Vickers acid value and W was 42.7 times of its Vickers acid value, which was bound to provide a certain material source for the formation of ore bodies during the metallogenic period. The magmatic activity of Yanshanian period further accumulated tungsten: with the magmatic rock activity of Yanshanian period, the ore-bearing hydrothermal solution surged along the cracks formed by the fracture of Indochina granite, heated and boosted the Indochina granite in the surrounding areas, which made the ore-bearing hydrothermal solution and tungsten in Indochina granite to be mineralized into ore deposits. Indosinian granite provided an occurrence place for the stationing of tungsten deposits.

5. Ore-prospecting Indicators

Through the comprehensive discovery of regional ore bodies, this region mainly includes the following ore-prospecting indicators, respectively are abandoned mining working indicator, quartz vein indicator, alteration indicator and structural indicator. The abandoned mining working indicator: The small-scale indigenous tungsten mining began in the 1960s; since the 21st century, small enterprises in the region have also carried out the mining of the tungsten ore in the name of the quarries and the silica mine, thus the abandoned mining working and the ore dressing waste residues is one of the direct prospecting indicators in the area. The quartz vein indicator: the tungsten ore in the area mostly exit in the quartz fine vein, and the vein density of the quartz fine vein is directly proportional to the mineralization intensity. The quartz vein width is positively correlated to the size and degree of crystallization of the mineral in the vein, thus the stock-work quartz vein can be considered as one of the most direct prospecting indicators in the area. Alteration indicator: the mineralization zone in the area is often strongly altered and the types of alteration are complex. Of which, potash feldspathization, albitization, silicification and greisenization are closely related to mineralization in mining areas. The stronger these alterations are, the better the mineralization is. Therefore, potash feldspathization, albitization, silicification and greisenization can be considered as the direct ore-prospecting indicators. Structural indicator: The ore bodies in this area are generally controlled by the NWW--SEE structure, and the ore bodies also exist in the north-west-west--south-east-east structural fracture zone, therefore, the NWW-SEE structural fracture zone is also one of the direct ore-prospecting indicators in the area.

6. Conclusion

Through the study, the following conclusions can be drawn: 1) The main minerals of the Gao’aobei tungsten ore in Rucheng County are wolframite. The ores generally occur in veins. 2) The ore-controlling factors mainly include the formation ore-controlling, the structural ore-controlling and magma ore-controlling. 3) The ore-prospecting indicators mainly contain the abandoned mining working indicator, quartz vein indicator, alteration indicator and structural indicator. Of which, the reticulate quartz vein, the NWW-SEE tectonic fracture zone is an important direct ore-prospecting indicator in the area.

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