Scientific and Social Research, 2024, Volume 6, Issue 10
https://ojs.bbwpublisher.com/index.php/SSR
Online ISSN: 2981-9946
Print ISSN: 2661-4332

Geological Features and Ore Formation Pattern of Jinzhong Bauxite Mine, Shanxi Province, China

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Abstract: Bauxite is located in the lower part of the Benxi Formation, and the prospecting project shows that the distribution of bauxite ore bodies in the area is discontinuous, and there are differences in the thickness of the ore bodies. To have a clearer understanding of the bauxite ore bodies and metallogenic pattern in the census area, this study has made use of the prospecting project data, sample analysis results, etc., and combined with the geological and tectonic background of the area, the stratigraphic spreading characteristics of the bauxite ore body spatial spreading, ore characteristics and ore controlling factors in the area have been explored and researched. The bauxite ore bodies in the study area are stratified but the ore-bearing rock system is influenced by the Ordovician paleokarst geomorphology and intermittently distributed horizontally, which can be distinguished into three different ore bodies. The bauxite ore body and Shanxi-style iron ore are associated with hard clay ore, in which the ore minerals are mainly monohydrate duralumin. The natural ore type can be divided into dense bauxite and oolitic bauxite. Bauxite in this area mainly originated from the basal Ordovician carbonate rocks, with a combination of iron-rich and aluminum-rich layers, and is a typical carbonate rock sedimentary deposit of ancient weathering crust.

Keywords: Bauxite; Orebody characteristics; Ore-control factors; Metallogenic pattern

Online publication: November 5, 2024

1. Introduction

Bauxite is rich in a variety of important metal deposits, including aluminum, gallium, and rare earth elements [1–2]. Bauxite is mainly classified into lateritic bauxite deposits, karstic bauxite deposits, and sedimentary bauxite deposits [3]. China has a complete range of bauxite deposits, with sedimentary bauxite deposits dominating, and karstic bauxite deposits and lateritic bauxite deposits being less common [3–8]. Sedimentary bauxites are sequentially weathered, stripped, leached, and finally enriched during mineralization. The hot and humid climate, sufficient ore holding space, and sufficient weathering time have a significant impact on the size of the ore body and ore flavor [9–10].

Shanxi Province is rich in bauxite mineral resources, which are mainly endowed in the Benxi Formation of the Carboniferous system, and the morphology is controlled by the upper erosion surface of the Ordovician system, usually accompanied by Shanxi-style iron ore, hard clay ore, etc [11–13]. The deposit type is dominated by paleo-weathered crustal sedimentary bauxite deposits, the ore body is produced in layers and seemingly strata, the ore grade is medium (A/S is about 4–6), and the ore type is dominated by monohydrate stibnite [3, 12–14], with a high degree of exploration and a low degree of difficulty in mining.

In Jinzhong, Shanxi Province, bauxite deposits with certain resource potential were found during the survey of bauxite and hard clay ores. Detailed exploration of the geology of the surrounding area was carried out, and combined with the work already done by the predecessors, the geological features and ore characteristics of the census area were studied to find the mineral source of bauxite formation and summarize the metallogenic pattern, to provide a reference for the study of bauxite resources in Shanxi.

2. Geological setting of the deposit

The census area is located at the northeastern edge of the North China Fault Block (II), the Luliang-Taipei Fault Block (III), and the Qinshui Block depression (IV), which is adjacent to the Wutai uplift area in the north and connected to the Taihang uplift area in the east. The tectonics of the area are relatively simple (**Figure 1**), and the stratigraphy is dominated by monoclinic tectonics, with the general direction being northeast to southwest, and the dip angle ranging from 5° to 25°. Folds and fractures are not developed and no igneous rocks are exposed in the area.

The exposed strata in the region mainly include the Paleozoic Ordovician Middle Fengfeng Formation (O_2f), Carboniferous Middle Benxi Formation (C_2b), Carboniferous Upper Taiyuan Formation (C_3t), and Quaternary Formation (Q_3). In general, the stratigraphy is distributed in a band from east to west, from old to new.

Upper Pleistocene: Mainly loess, with a small amount of red clay, which is widely distributed in the mining area with varying thickness.

Upper Carboniferous Taiyuan Formation (C_3t): No surface outcrop, exposed by engineering. Locally exposed in the study area, it is the lower part of the Taiyuan Formation, with siliceous shale at the bottom, brownish-black in color, not too well developed, hard in texture, and sandy shale and coal line at the top, which is in consolidated contact with the underlying Benxi Formation.

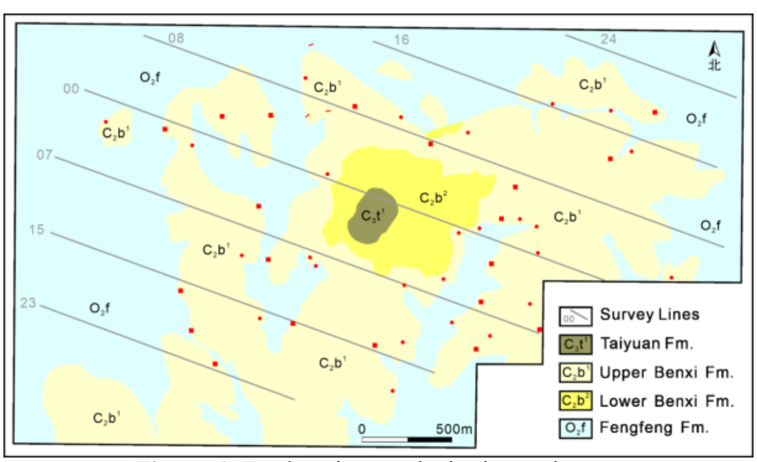

Figure 1. Exploration works in the study area

Middle Carboniferous Benxi Formation (C_2b): Natural outcrops are sporadically exposed in the central and southwestern parts of the mine area, and the lithology of the upper layer is mainly composed of fine sandstone and sandy shale, gray-brown. A thin layer of coastal tuff and black shale is seen above isolated outcrops of claystone. The lower strata, mostly exposed by artificial mining, are exposed in the southern and central gullies of the study area and in the western part of the mountain range above the erosion surface of the Ordovician chert, which is in parallel unconformable contact with the chert. Ideal conditions from top to bottom are composed of claystone, refractory claystone, bauxite, ferruginous claystone, and Shanxi-style iron ore. In general, the iron content gradually increases from top to bottom, and the rock layers gradually change from grayish white and dark gray to tawny and purplish red in color. Most of the C_2b^1 layers are exposed as gray, yellow, purple-red, and other mottled claystone and ferruginous claystone.

Middle Ordovician Fengfeng Formation (O_2f): Distributed in the northwestern part of the country.

3. Characterization of the ore body

3.1. Characterization of the ore body

The ore body is located in the middle of the lower part of the Benxi Formation of the Middle Carboniferous system, and the Al_2O_3 content decreases downward and changes into the basement hard refractory fireclay ore or claystone, and the boundary between the two is not clear. The overall strike of the ore body is NE-SW, and the dip is SE, with an average dip of 110°, and a dip angle between 5° and 25°, with an average of 15°, and locally influenced by the undulation of the basement paleogeomorphology, the dip angle is slightly larger. There is a small number of inclusions in the ore body, the lithology is aluminous claystone, hard claystone, or claystone, the chemical and mineralogical composition is approximately the same as that of the ore, and they are circled as inclusions because the content of Al_2O_3 is less than 40% or the A/S value is less than 2.6.

The bauxite ore bodies in the study area are divided into three different ore bodies (**Figure 2**), of which No.1 is larger and No.2 and No.3 are smaller. No. 1 ore body is located in the central part of the study area, and the ore body is laminar or laminar-like, with a dip angle between 5° and 25°, an average of 15°, and an average thickness of the ore body of 1.30 m. No. 2 ore body is located on the southwest side of No. 1, and the ore body is laminar or laminar-like, with a dip angle between 8° and 17°. The average thickness of the ore body is 0.88 m. The No. 3 ore body is located at the southeastern edge of the study area, the ore body is smaller in size and is produced in a stratified, stratiform-like manner, the thickness of the ore body is 1.50 m.

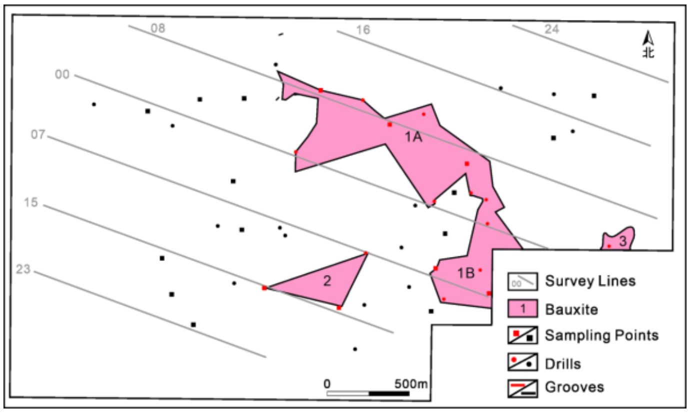

Figure 2. Location of bauxite ore body

3.2. Ore characteristics

The ore is gray to dark gray with the structure of oolitic, pisolitic, and dense ore. The ore structure is mainly massive, with some ores having a slightly layered structure. The mineral composition of monohydrate stibnite is dominated by the hard texture, clay minerals are kaolinite, followed by hematite, limonite, trace minerals such as ilmenite, chlorite, acicular ferrite, anatase, rutile, and so on. As the clay mineral content increases, the ore becomes brittle, swells in water, and is of relatively poor quality. The natural types of ores in this area can be divided into oolitic and pisolitic ores and dense ores according to their structure and composition (**Table 1**). The natural type of ores is monohydrate stibnite bauxite according to its main aluminum mineral composition. According to the industrial type of this district, the ore is a water-hard alumina type, low iron, low sulfur type bauxite, grade V.

Table 1. The average content of the main chemical components of each ore type (%)

Rock	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	A/S
Oolitic bauxite	66.81	14.17	2.38	2.94	4.76
Dense bauxite	65.64	15.32	2.46	2.83	4.94
Iron mine	21. 60	16. 82	48. 14	1. 05	1. 37
Claystone	43.23	37.13	1.63	2.03	1.25
Al-claystone	45.21	31.57	5.01	2.00	1.49
Fe-claystone	27.28	25.05	29.01	1.57	1.13

3.3. Chemical composition of ore

The main chemical composition of bauxite ore is Al_2O_3, SiO_2, Fe_2O_3, and TiO_2, which accounts for more than 80% of the total chemical composition (**Table 2**), and the other components are CaO, MgO, K_2O, Na_2O and so on. The main chemical composition in the deposit has a certain pattern of change, vertical to the middle of the ore-bearing layer Al_2O_3 content is higher, SiO_2 content is lower, relative A/S value is higher, downward Fe_2O_3 content increases, along the tendency of the Al_2O_3 content overall increase, SiO_2 content is lower, A/S value is relatively higher, along the main chemical composition of the strike change is not large. The Al_2O_3 content in the zone is mostly between 55% and 70%, SiO_2 content is mostly between 5% and 20%, Fe2O3 content is mostly between 0.61 and 3%, TiO_2 content is mostly between 2% and 3.5%, and A/S values are mostly between 2.6 and 7.4.

Table 2. Calculation of average grade and thickness of bauxite ore body in the study area

Number	Thickness (m)	Average content (%)				A/S
		Al2O3	SiO2	Fe_2O_3	TiO_2	
Orebody 1	1.30	62.78	15.66	2.55	2.85	4.01
Orebody 2	0.88	66.69	13.73	1.17	2.99	4.86
Orebody 3	1.50	64.94	14.40	1.17	2.95	4.51

4. Mineralization pattern

4.1. Ore-controlling factors

The morphology of the ore body in the study area is consistent with the ore-bearing stratigraphy of the Carboniferous Benxi Formation, which is controlled by the Carboniferous Benxi Formation, and the stratigraphic morphology of the Benxi Formation is significantly influenced by the erosion surface of the basal Ordovician Fengfeng Formation. The mineral-bearing Benxi Formation is parallel and consolidated over the Fengfeng Formation, and the uneven paleoerosion surface of the Fengfeng Formation provides a good site for bauxite enrichment [3,14]. The paleogeomorphic depression area is a good bauxite deposition area, and the larger the depression area, the easier it is to form bauxite bodies with stable thickness and medium grade. The paleogeomorphic uplift area, on the other hand, is difficult to form high-grade bauxite or even no ore formation [3]. In the study area, three bauxite bodies of different sizes were formed in the paleogeomorphic depression area, and the topographic undulation led to the decrease of Al_2O_3 content in the ore-bearing rock system between the three bodies. According to the revelation of prospecting projects Yk110, Yk122, etc., the aluminum-bearing rock system of paleogeomorphic uplift area with the Al_2O_3 content lower than less than 40% or the value of A/S is less than 2.6, so it is aluminum-bearing clay rock or clay rock, and it cannot be labeled as a bauxite mine (**Figure 3**).

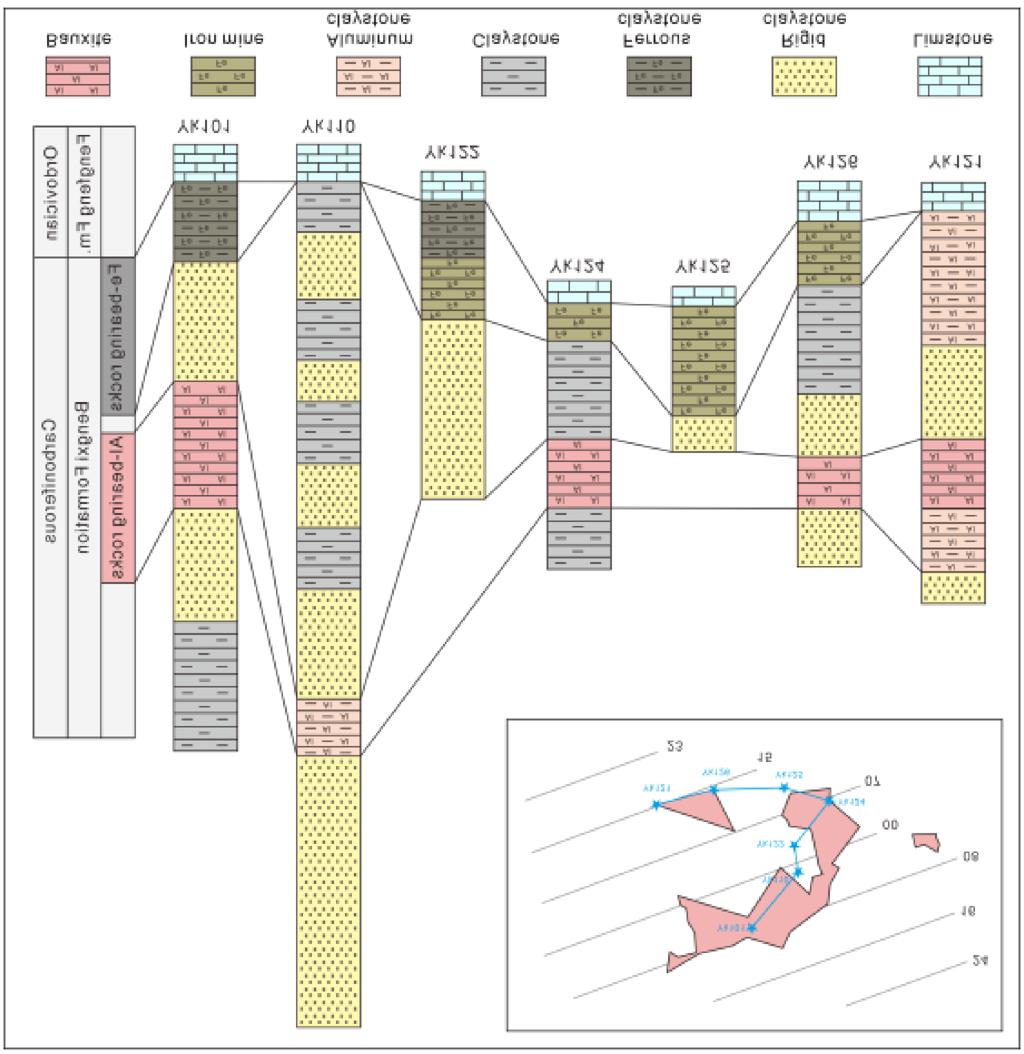

Figure 3. Comparison of ore-bearing rock systems in the study area

4.2. Accompanying mineral deposits in the study area

According to the revelation of the prospecting project, the upper and lower plates of the bauxite ore body in the study area are accompanied by hard clay ore and Shanxi-style iron ore. Bauxite and its associated deposits form a vertical sequence of Fe-Al-Si layers from bottom to top in the vertical direction. Hard clay ore is a common bauxite coeval mineral and an important component of the ore-bearing rock system [3, 12–13]. In the district, the hard refractory clay ore is relatively stable in the vertical stratigraphy, and the ore body is endowed with Shanxi-style iron ore and ferrous claystone on top and under the bauxite layer, or on top of the bauxite layer and under the loess. The production status is the same as that of bauxite, and it is produced in layers and apparent layers. It is widely distributed in the area, with a high occurrence rate and good continuity. Shanxi-style iron ore is distributed in the lower part of the bauxite layer, the Ordovician tuff on the erosion surface, mostly mixed with yellow claystone or aluminum claystone and so on. Due to the influence of ancient terrain undulation, the morphology is extremely irregular, and the ores are mainly limonite and hematite, with low flavor and large variation in thickness, which cannot be considered as a complete ore body.

4.3. Bauxite mineral sources and orogenesis patterns

The bottom-to-top Fe-Al-Si vertical stratigraphic sequence indicates that the bauxite deposits in the study area are typical calc-erythrite sedimentary deposits of paleo-weathering crusts of carbonate rocks, and the mineralogenic sources are mainly from basal Ordovician carbonate rocks [3, 14]. The Caledonian Movement uplifted the whole North China region and formed a quasi-plain topography through long-term weathering and stripping, and the Ordovician carbonate rocks formed a calcareous laterite type weathered crust through long-term weathering, and the crust started to slowly decline and sea erosion occurred in the Benxi Period. The iron-based upper materials of the paleo-weathered crust at the edge of sea erosion were first transported by surface water and tidal water in a mechanical state (or partially dissolved) to the offshore basin for deposition. Due to the differences in paleomorphology and original rock compositions, the deposition of iron-bearing sediments showed the characteristics of uneven rock material composition, agglomerates, no lamination, and large thickness variations. The Shanxi-style iron ore and iron claystone were formed in different areas of the study area, with uneven distribution, which is consistent with the extremely irregular morphology of Shanxi-style iron ore and iron claystone under bauxite, which are irregularly nested or lenticular outcrops, as exposed in the prospecting project consistently. After the iron-based upper materials were transported, the aluminum-based materials in the weathering crust were fragmented, transported, and redeposited to form bauxite. The amount of aluminum-bearing materials in the weathering crust is higher than that of iron-bearing materials, and a larger area, greater thickness, and regular morphology of aluminum-bearing rock systems were deposited on top of the Shanxi-style iron ores and iron claystone. Finally, there is the fragmentation, transportation, and redeposition of the softer siliceous materials in the weathering crust, forming claystone and hard refractory clay ore. When the sedimentary basin is recharged with the above materials, there will be repeated changes in the above vertical sequences, so that repeated Fe-Al-Si vertical sequences can be seen in the mine area, and iron clay rocks can be seen in the upper part of the formation of bauxite.

5. Conclusion

First, there are three bauxite ore bodies of different sizes in the mining area, and the Al_2O_3 content in the ore-bearing rock system between the three ore bodies is reduced, which cannot be circulated as bauxite.

Second, the mineral body of the ore is monohydrate duralumin. The main chemical composition in the deposit has a certain pattern of change, vertically upward to the middle of the ore-bearing layer, Al_2O_3 content is higher, SiO_2 content is lower, the relative A/S value is higher, and downward Fe_2O_3 content increases.

Third, the genesis of bauxite can be categorized as carbonatite paleo-weathering crust calcium laterite sedimentary deposits, and its mineralization material mainly originated from the basal Ordovician carbonatite.

Disclosure statement

The authors declare no conflict of interest.

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