Researches on the metallogenic paleogeography and ore-prospecting indicators of bauxite in Meitan-Fenggang area, northern Guizhou, China

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Abstract. Based on the previous study, combined with regional data, this paper studied the paleogeography and prospecting indicators of bauxite in Meitan-Fenggang area. The results show that: 1) The humid and hot paleoclimate is the favorable condition for bauxite formation; 2) The paleogeomorphology is closely related to the formation of bauxite, and the Karst depression plays a controlling role in the formation of bauxite; 3) The bauxite is formed in the near lake environment affected by seawater, and the property of water body is weakly alkali reduction. 4) There are a series of effective prospecting indicators in this area, mainly including macro geomorphological, stratum, color and underground water indicators.

Keywords: Paleogeography, Ore-prospecting Indicators, Bauxite, Meitan-Fenggang area.

1. Introduction
In the northern part of Guizhou, there are abundant resources of bauxite. The Wuchuan-Zheng’an-Daozhen (short for WZD) bauxite and bauxite in Zunyi area are most famous. The Meitan-Fenggang Area is located between those two regions, which has certain potential of ore prospecting. There are many previous studies on WZD bauxite and Zunyi bauxite(Du et al., 2007; Wu et al., 2008; Jin et al., 2009; Du et al., 2013; Gu et al., 2013; Lei et al., 2013; Cui et al., 2013; Liu et al., 2018), and the genesis of mineral deposit has been deeply understood. Meitan-Fenggang bauxite is on the southern edge of WZD bauxite, and the metallogenic mechanism of which is quite similar to that of WZD bauxite. There are fewer studies on the bauxite in Meitan-Fenggang area. This paper analyzed the paleogeographic environment and the ore-prospecting indicators in Meitan-Fenggang area, and also provided basic data for researches on bauxite in this area, which has certain guiding significance for the further exploration of bauxite in the future.

2. Geological Background
Deposits in the study area are located at the southeast part of the bauxite metallogenic belt in Northern Guizhou, the south-central section of Wuchuan syncline (Fig.1). From old to new, the exposed strata are mainly Cambrian, Ordovician, Silurian, Carboniferous, Permian and Triassic. The middle and upper
Silurian and Devonian are missing. The lithology is dominated by marine carbonate rocks, followed by clastic rocks dominated by clay rocks. The middle Permian Liangshan Formation P2l is the bauxite bearing mineral rocks. The roof is the middle Permian Qixia Formation P2q limestone. The floor strata is mostly Silurian System Hanjiadian formation S1-hj mudstone (shale) and the local part is the middle carboniferous Huanglong formation C2hn limestone. This area has experienced many tectonic movements. Characterized by fold development, it is mainly Wuchuan synclinorium, which presents NNE direction in the axial direction to the south of Wuchuan County. The southern tip has evolved into a parallel distribution with the Yongxing syncline and Yichuan syncline. The northern Wuchuan presents NE direction. The fault structures have developed in the southern part of the synclinal region, mainly represented by small unknown faults in NE and NNE orientations. There is no magmatic activity in the area.

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

**Fig.1** Geological map of the study area (Jin et al., 2018)
3. Geological Characteristics of Ore Deposits

3.1. Ore Body Characteristics
In the research area, the strata thickness of ore-bearing minerals Permian Liangshan formation is in the range of 0-10m, most of which are concentrated in 3-6m. The lithological combination can be roughly divided into three layers. From top to bottom, there are carbonaceous (coal) rock series, aluminiferous rock series and chlorite rock series (Fig. 2). Usually, the carbonaceous (coal) rock series are quite weak or missing; the aluminiferous rock series are mostly off-white aluminiferous mudstone or bauxite, which containing plastic fossil fragments of plants. Due to pyrite, the earth surface is mostly weathered, presenting brownish yellow and brown red. Generally, the thickness of the mining area increases from south to north, ranging from 1m to 4m. There is history of mining pyrite in local parts of this section. The chlorite rock series are mainly gray-green chlorite mudstone and silty mudstone, containing pyrites. The thickness is usually 1m-3m. Of which, it can reach 4m in the south. Small strata in the ore-bearing rock series are often underdeveloped. Only 4 or 6 layers can be found in some projects. The fifth layer is the main seam of the mining area. The Al₂O₃ content of the 4th and 6th can reach 50%. However, the content of silicon is quite high, which is usually more than 20%. Therefore, whether it is the ledge depends on the content of silicon.

3.2. Ore Characteristics
Ores in this area are mainly composed of diaspore (the content of diaspore in ore is usually 30%-90%), soft alumina, a small amount of kaolinite and other clay minerals, limonite. The main structural types of ore are mud crystal structure, grain (gravel) chip structure and unequal crystal structure. The ore structure is mainly dense structure, followed by soil structure, semi-soil structure and clastic structure, occasionally pisolithic structure and oolitic structure.

| Stratigraphic code | Thickness (M) | Cylindrical diagram | Characterization of Lithology |
|--------------------|---------------|---------------------|------------------------------|
| P₂q+m             | 180-230       |                     | Deep grey medium to thick layer mud crystal limestone, biological clastic Limestone, flint Tuberculosis |
|                    | 0-0.3         |                     | Mottled, grey clip light yellow or carbon black aluminum soil, carbon mud shale |
|                    | 0-1.0         |                     | Grey, light grey green dense iron-bearing aluminum-soil rock (bauxite) |
|                    | 0-2.5         |                     | Gray, light gray earthy or clastic bauxite |
| P₂l               | 0.5-4.0       |                     | Grey Green, brown green iron containing, aluminum soil containing bean mudstone (aluminum soil rock) |
|                    | 0.5-2.5       |                     | Grey, brownish yellow aluminum-containing mudstone (pyrite granules) |
|                    | 0-1.5         |                     | Grey-green, turquoise or iron-green sandstone |
|                    | 0-1.5         |                     | Grey, light gray thick layer coarse crystalline limestone, dolomite limestone |
| C₂hn              | 0-2.0         |                     | Purple red, grey-green thin layer shale sandwich powder sandstone, sandstone and limestone |
| S₁-2hj            | >300          |                     |                                             |

Fig.2 Bar chart of ore-bearing rock series
4. Metallogenic Paleogeography

4.1. Paleoclimate
According to oxygen isotope geothermometer of diaspore and kaolinite in Northern Guizhou (Liu, 1990), the annual temperature of weathered mineralization of bauxite is 33.4-40.1℃, which represents a hot climate. Under the condition of hot and humid climate, a large amount of microorganisms and organic matter are decomposed to produce a lot of \( \text{CO}_2 \), H\(_2\)S and organic acid, and the pH value and the Eh value of the water medium are greatly changed, so that the weathered crust rocks are subjected to strong weathering. In addition, the crust of the study area is also relatively stable and suitable for weathering, which is beneficial to the occurrence and development of karstification. It promotes the remigration and enrichment of aluminum-rich weathered materials in the suitable environment, which is beneficial to the formation of bauxite. Besides, according to the study on ore structure within the area (Liu, 1990), the oolitic structure of beans is extremely developed in bauxite ores. The oolitic surface is often attached to limonite, the ring zone of goethite and thin film, the radial and convergent inward dry shrinkage cracks. It also reflects that the bauxite metallogenic period is the humid and hot climate and the tropical rain forest climate conditions of alternating dry and wet. However, the southern China changed into a humid climate after Permian, which indicated that bauxite mineralization in WZD area should not be formed before Permian (Hao et al., 2007).

4.2. Paleogeomorphy
Bauxite mineralization and thickness change are often related to paleogeography and geomorphology. Rich and thick deposits are often formed at the bottom of paleo-terrain. In the protruding karst isolated peak and the greatly-changed paleo-weathered surface, the bauxite layer tends to become thinner, ore quality becomes worse, or ore-free skylight is formed. Liu Xunfeng (1990) classified the paleogeomorphology of ore-bearing rock series in Xifeng-Chuannan bauxite metallogenic area. This region belongs to the paleogeomorphic area of Sichuan-Guizhou ridge valley, which is composed of a series of ridge karst valley, depressions, and eroded valleys. The floor rock is mainly composed of mudstone, shales and sandstones in the non-soluble Middle and Lower Silurian Hanjiadian formation, interbedded with carbonate rocks. These ancient geomorphic features are not interconnected with each other, so that the bauxite rock layer and the bauxite mineral layer have a strong phase change and a large thickness variation. According to the dissection of ore in Daozhen Chijiagou (Du et al., 2007), the karst palaeogeomorphology plays an obvious role in controlling the thickness of bauxite ore-bearing rock series strata. The thickness of ore-bearing rock series and ore layer is small in the protruding part of karst uplift surface. However, the thickness of bauxite ore-bearing rock series in the depression of karst uplift surface is 4-7 times higher than that of normal strata. The isopach line of ore-bearing rock series and the ore body thickness also show that the paleogeography and geomorphology are closely related to bauxite mineralization.

4.3. Paleoenvironment
According to the characteristics of V, Zr, Sr, Ba, combined with previous research results, it is considered that the study area belongs to the coastal lake-swampy environment affected by transgression of sea (Luo et al., 2016). In the middle Permian Liangshan formation, this region was a relatively inland river and lake-swampy depression environment. Local parts were limited sea areas and the water body was relatively quiet, the degree of desalination and limitation was relatively high. The water showed weak alkaline reduction conditions, rich in HS\(^-\). Therefore, it was not conducive to the precipitation of Fe\(_2\)O\(_3\) colloidal chemistry. Only a small amount of free Fe\(^{2+}\) and S combined to form pyrite. Consequently, the pyrite mineralization and red iron mineralization in the area were not developed within the area, which was consistent with the objective reality. However, in central Guizhou, the sedimentary environment of bauxite was a weak acid condition of oxidation during the formation of bauxite. A large amount of Fe\(_2\)O\(_3\) was formed in the environment. When the PH value gradually changed to be neutral, a large amount of Al\(_2\)O\(_3\) was precipitated. The SiO\(_2\) was increased with the PH value, and the solubility was increased.
Therefore, in space, the iron rock series of red iron layer was often formed at the bottom of bauxite layer, and the natural sequence of Fe / Al / CaCO$_3$ / SiO$_2$ was formed from bottom to top. According to the lithofacies paleogeographic map of Guizhou Province, most of the periods of Middle and Late Silurian, Devonian, Early-Middle Carboniferous and late Carboniferous were the distribution areas of Upper Yangtze Palaeocontinent, which were subjected to weathered denudation and flattening for a long time. Therefore, it reflected that the denudation time was long and the material sources were rich. Bauxite deposits could be formed in favorable sedimentary environment. Thus the prospect of mineral exploration is quite good.

5. Ore-prospecting Indicators

Based on the comprehensive analysis of regional data, combined with the comparison of bauxite deposits in adjacent areas, this paper considers that there are a series of ore-prospecting indicators in Meitan-Fenggang area, which can effectively indicate the exploration engineering of bauxite, as described below.

5.1. Geographic and Geomorphic Indicators

The overlying layer of ore-bearing layer is limestone of Qixia-Maokou formation of Middle Permian, which has strong resistance to weathering. Judging from the remote sensing image and field survey, it can be found that, suspended rocks and steep ridges are mostly formed in the two wings of each oblique region, and the uplifting&turning ends of WZD in northern Guizhou. The Liangshan formation is located under those rocks and ridges with prominent geomorphological characteristics. The underlying layer is mainly mudstone of Hanjiadian formation of Middle and Lower Silurian, shale (some of them are thin crystal limestone and dolomite of Upper carbon Huanglong formation). Most of them form gentle slope, so most of the aluminum deposits in northern Guizhou are located in the transition between high cliff (> 100m) and gentle slope. The macroscopic geomorphological prospecting indicators are quite obvious.

The bauxite series in this area mostly occur under the steep cliff, and the terrain is cut strongly, so it is easy to form bauxite boulder. Therefore, when bauxite exists, bauxite boulder and fragments can be frequently found in the slope layer of the lower slope of the ore-bearing rock series.

5.2. Floor Strata Indicator of Ore-bearing Rock Series

When the floor of ore-bearing rock series is the purplish red mudstone and shale of the middle and lower Silurian Hanjiadian formation, or the crystal dolomite limestone of the Huanglong formation with very thin thickness (1-2m), the ore-bearing strata often contains ore; when the Huanglong formation of the floor strata is thicker (> 6m) and continuously stable, the ore-bearing strata is usually ore-free. Reasons: The former shows that, due to the low-lying negative terrain of the ore-bearing layer, there is few residual limestone and the ore-bearing rock is thick; the latter shows that, the paleo-topography of the basement is mostly a high-convex, positive topography, which is not conducive to the deposit of the ore layer.

5.3. Thickness Indicator of Ore-bearing Rock Series

In the region, when the thickness of the ore-bearing layer is large (about 3 -10m), there are often ore deposits. If the ore-bearing layer is thicker, the ore layer is much thicker with better mineral quality. When the thickness of ore-bearing layer is less than 2m, there is no ore. This reason may be related to the local protruding of the floor topography when the ore-bearing layer is deposited. Due to the thin ore-bearing layer, it is not easy for the bauxite to be separated or enriched, further to form mines. However, in the survey area, the thickness of aluminite series is generally in the range of 2 - 5 m, and the stability of thickness is positively correlated with mineralization, that is to say, the more stable the thickness of aluminite series is in a certain range, it is more able to be enriched for mineralization.
5.4. Lithologic Indicator of Ore-bearing Rock Series
When there are many small strata (generally 5-7 small layers or more) in the ore-bearing rock series, and there are bauxite at the bottom of the ore-bearing rock series, bauxite usually exits; when the ore-bearing rock series have a small amount of strata (3-4 layers), most of them are ore-free. Especially, when the thickness of carbon shale at the top becomes larger (0.7 - 1.0 m and above), most of them are ore-free. The reason may be the swamping environment in which the sedimentary environment changes obviously, the desilication and aluminum enrichment is poor. On the contrary, there may be a certain resilication, which is not conducive to the sedimentary enrichment of the ore layer. In the shallow part of the surface, the syncline uplift section and the turning point of the formation bend; in the deep part, the syncline bend end, especially in these parts where the strata floor of the ore-bearing rock series is the karst depression of Carboniferous limestone, are the favorable parts of the bauxite and its ore-bearing rock series formation thickening.

5.5. Color Indicator of Ore-bearing Rock Series
Overlooking the ore-bearing rock series, if they are mostly light gray, gray or yellow gray, there is usually occurrence of the bauxite. When the ore-bearing rock series is brown-red, dark gray and so on, most of them are ore-free. In this area, most of the bauxite deposits are iron-bearing and medium-iron, and their color are quite dark. Consequently, this indicating significance should be given special consideration in this area.

5.6. Underground Water Indicator
At the top and bottom of the ore-bearing rock series, there are often spring water outbursts or larger water outflows, which is due to the fact that the overlying layer of the ore-bearing rock series is a thicker carbonate formation and an aquifer. However, the ore-bearing rock series is shale, clay rock, mudstone (gray) rock, which is the insulating layer. Therefore, the water outlet point is more common in the area with low terrain and strong cutting. This indicator is particularly important in areas where geomorphic signs are not obvious.

6. Conclusion
Through comprehensive analysis, the following conclusions can be drawn: 1) Paleoclimate is beneficial to the formation of bauxite in Meitan-Fenggang area; 2) Paleogeomorphology is closely related to the formation of bauxite in Meitan-Fenggang area; 3) Bauxite is formed in the near-lake environment affected by the ocean, and the water body is weakly alkali reduction; 4) The transition between high cliff and gentle slope, color, underground water and underlying strata are effective ore-prospecting indicators in this area.

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