Ore-forming fluid system of bauxite in Zunyi area of northern Guizhou province, China

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Abstract. The ore-forming fluid system of Laowashan bauxite in Zunyi area of northern Guizhou Province was studied through field geological survey and observation of hand specimens. It was concluded that surface runoff, atmospheric precipitation and sea level changes played important roles in the formation of the aforementioned bauxite. Under the impacts of vertical leaching of ore-forming fluids, industrial bauxite deposit and pyrite deposit formed in the upper and lower parts of the ore-bearing rock series respectively.

1. Introduction
Zunyi, located in northern Guizhou Province of China, is a crucial metallogenic belt, where abundant bauxites developed during the Carboniferous-Permian period. There have been numerous studies on bauxites of this area (Liu et al., 1990; Gao et al., 1992; Yin et al., 2011; Weng et al., 2011; Liu, 2012; Liu, 2015, 2016). Notwithstanding lots of relevant research, attention has been mostly focused on bauxites of other mines instead of Laowashan bauxite, and Laowashan bauxite have been seldom explored, so it is necessary to perform related research.

Ore-forming fluids are critical for the formation of minerals, particularly phosphorus, aluminium, sedimentary iron and manganese. Furthermore, the enrichment of some rare elements is related to the roles of ore-forming fluids, which are seen in all stages during the formation of bauxites, so these fluids are critical for the formation. By investigating the roles of ore-forming fluids in the formation of ore-forming fluids, it will be of great significance for guiding prospecting of bauxites, because metallogenic environment, process and mechanism can be figured out. There has been a lack of research about the ore-forming fluid system of bauxites in northern Guizhou Province. Laowashan bauxite of Zunyi were major research objects of this paper, followed by Baiyan bauxite near Laowashan. This paper explored relationships among types of ore-forming fluids, size and metallogenesis of Laowashan bauxite by performing field geological surveys and observing hand specimens, thus providing more data for studying karst bauxites in Zunyi area.

2. Geological setting
In Zunyi area, bauxites are situated on the Yangtze platform. In the north, they are connected to the metallogenic belt of bauxites in the Wuchuan-Zheng’an-Daozhen (short for WZD) Area. In Zunyi, the strata exposed are mostly cambrian-triassic, among which Carboniferous Jiujialu Formation is an ore-bearing rock series (Liu et al., 1990; Gao et al., 1992), which is about 0 to dozens of meters thick. This
series is covered by black muddy share of the Liangshan Formation or limestone of the Qixia Formation. Under this series, there are dolomites of Cambrian Loushanguan Formation or ordovician Tongzi Formation. Regional strata exposed include cambrian Loushanguan Formation, permian Liangshan-Qixia Formation, and carboniferous Jiujialu Formation, which generally strike at 75° and inclines at 15°.

3. Features of ore-bearing rock series in bauxite of Zunyi area

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

**Fig.1** Geology map of the study area

**Fig.2** Natural type of Laowashan bauxite in Zunyi area: a, b. massive bauxite; c. clastic bauxite; d. oolitic bauxite
In Zunyi area, bauxites are mostly karst and bauxite deposits are in the upper parts of the ore-bearing rock series. The occurrence of deposits is generally the same as that of the ore-bearing rock series. As a whole, the deposits are lenticular, and their ore bodies change a lot in morphology, running from the northwest to the southeast and inclining at 10 to 20°. Ore minerals are mostly diaspores with massive and oolitic structures. The natural types of ores are similar to those of bauxites in WZD area of northern Guizhou Province. They may be divided into massive ore, oolitic ore, clastic ore and semi-muddy ore. In Laowashan bauxite, ores are mostly clastic and oolitic (Fig. 2).

4. Paleogeography in the investigated area
In Zunyi area, cambrian, ordovician and silurian strata are mostly sedimentary area, whereas there is no devonian stratum. After the silurian period, they strata were exposed on the surface (Fig. 3). It was important for the formation of bauxite in this area when strata were exposed on the earth’s surface, because long-time weathering and denudation created conditions for the formation. Under the impacts of karst, karst depressions of varying size formed. The metallogenic substances generated from weathering and denudation were transported to karst depressions, finally creating conditions for metallogenesis. Before the late silurian period, coastal neritic deposits were major parts of Zunyi area, where devonian-carboniferous deposits turned into denudation area and sea-land transitional faces (Fig.3, b). Impacted by sea level changes in the South China Sea, mineragenetic area were possibly transiently drowned by seawater for several times.

5. Roles of fluid transport during metallogensis of bauxite
After the formation of karst depressions or negative relief, metallogenic substances are transported to depressions and accumulated there. They are mainly transported through flowing water. The depressions are located at a relatively low altitude, so the metallogenic substances of surrounding areas are transported to the depressions under the impacts of the intermittent water flow. In addition, the metallogenic substances will be also transported to the depressions in the event of short-term transgression, which may be deemed as a type of intermittent water flow. Due to the intermittent water flow, lots of fragments and particles not only appear in bauxites, but also tend to be a little directional with oolitic particles (Fig. 4). Although the formation of oolitic particles is a complicated process, it is undeniable that its formation is associated with actions of fluids. It is intermittent water flow that plays major roles in transporting metallogenic substances during the formation of Laowashan bauxite, whereas it generally can’t transport the substances for quite a long distance. In spite of shorter time in transporting through hydraulic forces, a range of chemical reactions still take place in this process,
including conversion of kaolinite into chlorite, conversion of hematite into pyrite and generation of diaspore.

Wind transport is also more or less helpful for accumulation of metallogenic substances. Additionally, eolation can transport fine-grained substances over a long distance, whereas no evident sign of wind transport has been detected.

Fig.4 Samples in Baiyan bauxite: a. direction of oolities; b. direction of particles

6. Roles of fluid leaching during metallogensis of bauxite

6.1. Leaching of surface water
The intermittent water flow on the earth’s surface not only transports metallogenic substances to karst depressions, but also spreads to the bottom under the gravity forces after it enters karst depressions (Fig. 5). A range of chemical reactions happen in this process, throughout which plenty of elements such as aluminum, silicon, iron and rare earth elements are migrated. The migration laws differ among varying elements, and some elements are enriched in distinct parts of the ore-bearing rock series.

6.2. Direct leaching of atmospheric precipitation
Atmospheric precipitation covers two steps. First of all, it is turned into intermittent surface runoff, which is effective for transporting, accumulation and surface water leaching. Next, it directly falls into depressions for leaching. The leaching process and effects are similar to those of surface water leaching.

6.3. Fluid actions induced by sea level changes
The sea level might increase and decline repeatedly in the metallogenic area. Their fluctuations are favourable for the formation of bauxite. When seawater recedes, hazardous impurities will be taken away the ore-bearing rock series. Furthermore, a vertical leaching process will take place when the bauxites are submerged by sea water.

6.4. Relationships between Fluid Actions and Metallogenesis of Bauxite
The fluid actions control the formation of bauxite, and the vertical leaching from the earth’s surface to the bottom contribute to migration of all elements in bauxite. In the course of leaching, aluminium, silicon, iron and rare earth elements migrate (Yu et al., 2013; Wang et al., 2013; Cui et al., 2013), accompanied by the transport of ore-forming fluids. Bauxites form in the ore-bearing rock series, while elements such as iron and silicon migrate to the bottom. If groundwater discharge is smooth at the bottom, these elements may be discharged out of depressions. Although bauxite deposits also form at the bottom of the ore-bearing rock series, the discharge conditions are generally not quite favourable at the bottom of depressions, and substances like iron or silicon can’t be discharged in large quantities
with ore-forming fluids, so bauxites or pyrite deposits with higher content of light green-dull green iron form at the bottom of the ore-bearing rock series (Fig. 5).

The fluids don’t act once and for all. Instead, ternary grey (low grade bauxite), light grey (bauxite) and light green (ferruginous layer) structures form on the ore-bearing rock series under the impacts of fluids with repeated atmospheric precipitation and sea level changes (Fig. 6).

7. Conclusion

After research, conclusions are reached as follows: 1) Ores are mostly clastic and oolitic in bauxites of Laowashan bauxite. 2) In mines, it is mainly surface runoff, atmospheric precipitation and sea level changes that contribute to the actions of ore-forming fluids. 3) Owing to the actions of ore-forming fluids, industrial bauxite deposits and high-Fe bauxitic rocks or pyrite deposits form in the upper and bottom parts of the ore-bearing rock series respectively.
Acknowledgements
This work was supported by the Key support disciplines of Mineral prospecting and Exploration from Guizhou Province (ZDK[2014]20), the Startup Projects of High-level Talents of Guizhou Institute of Technology (No.XJGC20140702), Guiyang, 550003, China, and the joint fund of the science and technology department of Guizhou province (No.LH[2014]7358).

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