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MINERALOGICAL AND GEOCHEMICAL CHARACTERISTICS OF THE GUIGANG SALENTO-TYPE BAUXITE DEPOSITS, WESTERN GUANGXI, CHINAYing-Yi ZHANG^{1,2*}, Peng HU³, Zheng-Yan ZHANG⁴, Yuan-Hong QI¹ and Zong-Shu ZOU²¹ State Key Laboratory of Advance Steel Processes and Products, Central Iron and Steel Research Institute, Beijing 100081, China² School of Material and Metallurgy, Northeast University, Shenyang 110819, China³ National Engineering and Research Center for Continuous Casting Technology, Center Iron and Steel Institute, Beijing 100081, China⁴ Department of structurale Steels, Central Iron and Steel Research Institute, Beijing 100081, China

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ABSTRACT

The Guigang bauxite belongs to the rich iron Salento-type bauxite with low alumina silica ratio. Mineralogical investigations show that gibbsite ($\text{Al}(\text{OH})_3$), diaspore ($\text{AlO}(\text{OH})$), goethite ($\text{FeO}(\text{OH})$) and hematite (Fe_2O_3) are the major mineral components in the bauxite ores, anatase (TiO_2), quartz (SiO_2) and Calcite (CaCO_3) are minor accessories. Geochemical investigations reveal that the Al_2O_3 (24.31–26.46 %), Fe_2O_3 (38.33–44.03 %), SiO_2 (8.76–12.27 %) are the major geochemical compositions in the bauxite ores. SEM+EDS analysis shows that most of the diaspores are cryptocrystalline with a small particle size and mainly coexists with ferrosiderite. Kaolinite is the major clay mineral in the Quaternary bauxite and mainly coexists with gibbsites and anatase, which may have formed partially at the expense of gibbsite. Ferrosiderite and goethite are the major iron oxide in the Quaternary bauxite and they were formed during the Quaternary weathering.

1. INTRODUCTION

Bauxite deposits can be classified into two main categories according to the bedrock. Bauxite lying on carbonates is identified as karstic regardless of whether the bedrock surface is karstified, and that lying on aluminosilicate rocks is termed lateritic bauxite (Bárdossy, 1982; Mameli et al., 2007). The Guigang bauxite in western Guangxi, China occur in Quaternary ferrallitic soil profile and belongs to Salento-type bauxite (Liu et al., 2008, 2010.; Wang et al., 2004), which has a great deal of economic value, and more than 0.5 billion tons of Salento-type bauxite has been explored in the last 20 years (Wang et al., 2011).

Ore compositions and ore-forming process of the bauxite in western Guangxi have been studied by several researchers. They confirmed that the Salento-type bauxite deposits mainly derived from the Permian bauxite deposits through karstification and weathering since the Early Pleistocene (Zhang, 1999; Dai et al., 2003; Wang et al., 2004; Liu et al., 2008). Most researchers suggested the underlying carbonates are the major source rocks (Zhang, 1999; Wang et al., 2004). A few studies proposed that the mafic rocks in the middle Permian may have provided some ore-forming materials (Chen and Lan, 1991). Other studies proposed metamorphic rock series as source rocks in the ancient land (Li and Yang, 1996).

In this paper, we systematically utilized X-ray diffraction (XRD), scanning electron microscope and energy dispersive spectrometer (SEM-EDS), and electron microprobe analyzer (EPMA), and carried out

detailed mineralogical and geochemical investigations on the Salento-type bauxite in Guigang, Western Guangxi.

2. GEOLOGICAL SETTING

Bauxite is abundant in China and is mainly distributed in the Shanxi, Guangxi, Henan and Guizhou provinces. Huge quantities of bauxite ores have been discovered in western Guangxi in recent years. Karstic bauxite deposits in western Guangxi (Liu et al., 2008) are widely distributed in Napo, Pingguo, Jingxi, Debao and Guigang counties. The bauxite deposits can be further subdivided into two types according to their host rocks. The first subtype, the Permian bauxite deposit, is hosted with in the Permian carbonate rocks overlying the paleokarst surface on the middle Permian Maokou formation (Zhang, 1999; Deng et al., 2010). The Permian deposit is very similar to the bauxite deposits of North Viet-Nam in terms of geographical and geological characteristics (Kömlössi, 1976; Mindszenty, 1979). The second type belongs to the Salento-type bauxite deposit (Bárdossy, 1982), and it lies within Quaternary ferrallitic soil profile (Liu et al., 2008).

The western Guangxi in Southwestern China is geologically a part of the South China plate (Fig. 1(b)). The Guigang bauxite deposit is located in the Wuming-Binyang-Wuxuan-Guigang karst bauxite belt in the western part of Guangxi province, China (Fig. 1(a)). The Guigang bauxite deposits belong to Salento-type bauxite which has a great deal of economic value, and more than 0.5 billion tons have

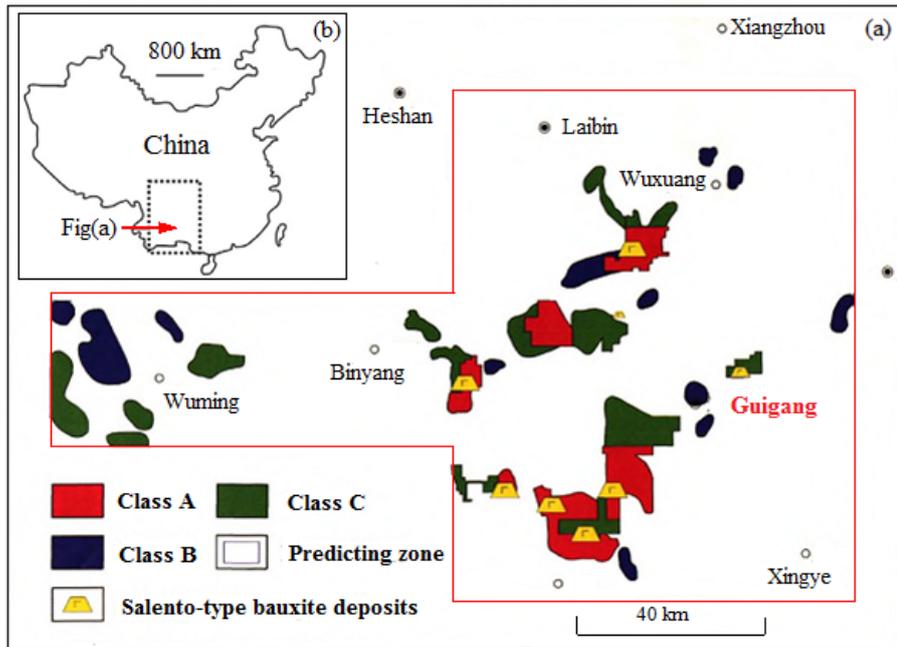


Fig. 1 Guigang bauxite deposits in the western part of Guangxi province, China.

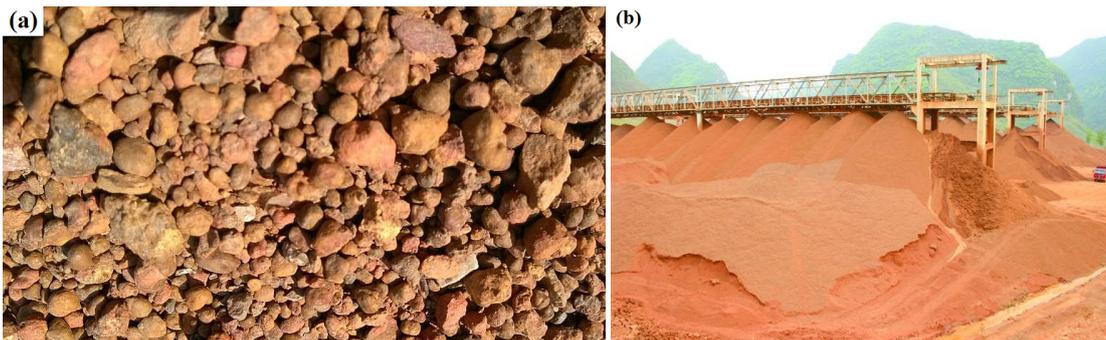


Fig. 2 The Guigang bauxite raw ore (a) and mineral powder (b).

been explored in the last 20 years. However, a large number of Guigang bauxite resources have not been effectively utilized in China (Fig. 2).

In the Quaternary laterite profile from top to bottom, three different layers can be distinguished (Fig. 3). The upper layer is mainly composed of a small amount of bauxite blocks, carbonate fragments and soils. The middle layer comprises bauxite blocks mixed with small amount of bauxitic clays, this layer is the investigated Salento-type bauxite ore body. The bauxite ores are randomly scattered in the ore body layer making it shows an even chemical distribution. The lower layer is dominated by laterite (Fig. 3). The ores have various colors such as red, brownish red and dark red and are mostly characterized by pelitomorphic, nodular, pseudoporphyrific, and ooidic textures (Fig. 2a). The mostly ores size is 0.1~20 mm, thus the element and mineral distributions from top to bottom of the bauxite layer are generally even. In addition, the geochemical and

mineralogical compositions in different Salento-type ore bodies are approximately homogeneous.

3. SAMPLING AND ANALYTICAL METHODS

According to the ore surface color, texture and structure, 32 Salento-type bauxite samples were collected from the middle layer of the ferrallitic soil profiles in 4 major ore bodies. The bauxite ores are irregularly scattered in the ore body layer making them show an even chemical distribution. Therefore, we randomly collected samples in each ferrallitic soil profile.

For whole rock geochemical analyses, the samples were crushed into 200-mesh by using an agate mill. The major elements were determined at the Geological Survey and Laboratory Center of Central Iron and Steel Research Institute of China. The major constituents were determined by chemical analysis.

The mineralogy and texture of the ores were studied by microscope (12 samples), X-ray diffraction

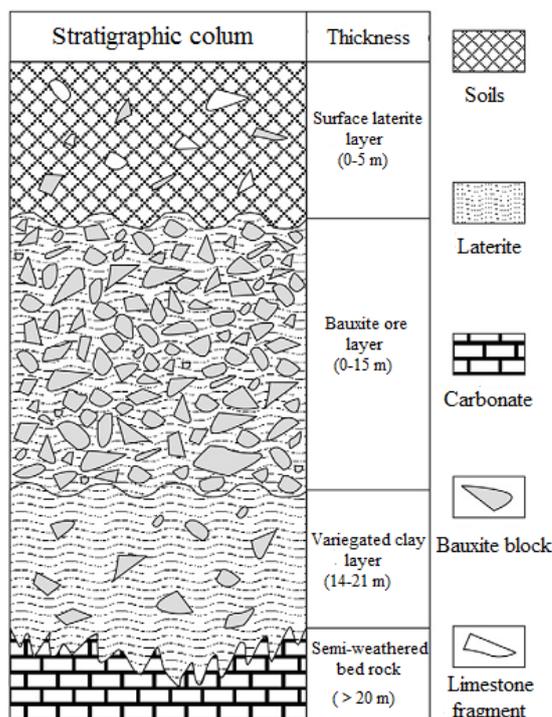


Fig. 3 The stratigraphic columnar section of the Salento-type bauxite deposits in the Guigang, western Guangxi.

(8 samples), and SEM-EDS (12 samples). XRD analyses were carried out at the Petroleum Geology Research and Laboratory Center of Beijing using a Rigaku D/Mac-RC and Cu K α 1 radiation with the following operating conditions: voltage 40 kV, beam current 80 mA; graphite monochromator, continuous scanning, scanning speed 8 °/min, slit DS=SS=1°, ambient temperature 18 °C, and humidity 30 %. The mass percentage contents (mass %) of the main

mineral phases were semi-quantitative estimates by XRD. SEM-EDS analyses were carried out at the University Of Science and Technology Beijing by using a Hitachi S-3400N SEM equipped with a Link Analytical Oxford IE 350 ED X-ray spectrometer and a Shimadzu EPMA-1600 with the following operating conditions: accelerating voltage, 15 kV; beam current, 1×10^{-8} A; lifetime, 50 s and a beam diameter of 1 μ m.

4. GEOCHEMICAL AND MINERALOGICAL COMPOSITIONS

4.1. GEOCHEMICAL COMPOSITIONS

The major geochemical compositions of bauxite samples are listed in Table 1. It can be seen that the Al₂O₃ (24.31-26.46 %), Fe₂O₃ (38.33-44.03 %), SiO₂ (8.76-12.27 %) are the major component in the bauxite ores. The bauxite samples have a high ignition loss (LOI 16.01-16.38 %) and the CaO shows the largest variations (0.75-10.17 %). The TiO₂, MnO, V₂O₅ and MgO display low values and vary in a narrow range (0.12-1.57 %) and the harmful elements (S, P) content is lower in bauxite (0.23-0.081 %). This bauxite belongs to rich iron, low aluminum silicon ratio type (1.98-2.78) bauxite.

4.2. MINERALOGICAL COMPOSITIONS

Mineralogical investigations show that gibbsite (Al(OH)₃), diaspore (AlO(OH)), goethite (FeO(OH)) and hematite (Fe₂O₃) are the major minerals in the bauxite ores, anatase (TiO₂), quartz (SiO₂) and calcite (CaCO₃) are minor accessories (Table 2 and Figs. 4 and 5). Semi-quantitative XRD results show that diaspore (25.2-56.3 %), gibbsite (0-33.6 %), hematite (4.0-26.2 %), goethite (0-24.4 %), and calcite (0-21.6 %) vary widely in their abundance. The quartz (2.6-3.2 %) and anatase (2.8-3.5 %) abundance are relatively consistent. The calcite abundance accounts for 17.2 and 21.6 % in samples 3 and 4, respectively.

Table 1 Main chemical compositions of lateritic bauxite (mass %).

| Sample | Fe ₂ O ₃ | FeO | Al ₂ O ₃ | SiO ₂ | CaO | MgO | TiO ₂ | MnO | V ₂ O ₅ | Ga | S | P | LOI | A/S |
|--------|--------------------------------|------|--------------------------------|------------------|-------|------|------------------|------|-------------------------------|-------|-------|-------|-------|------|
| 1 | 40.31 | 0.21 | 26.46 | 11.74 | 1.38 | 0.48 | 1.57 | 1.21 | 0.16 | 0.005 | 0.047 | 0.071 | 16.38 | 2.25 |
| 2 | 44.03 | 0.06 | 24.32 | 12.27 | 0.75 | 0.25 | 1.36 | 0.41 | 0.18 | 0.008 | 0.049 | 0.073 | 16.25 | 1.98 |
| 3 | 39.14 | 0.14 | 24.74 | 9.03 | 8.61 | 0.38 | 1.51 | 0.87 | 0.13 | 0.007 | 0.038 | 0.079 | 16.08 | 2.74 |
| 4 | 38.33 | 0.09 | 24.31 | 8.76 | 10.17 | 0.26 | 1.25 | 0.57 | 0.12 | 0.009 | 0.023 | 0.081 | 16.01 | 2.78 |

Table 2 Semi-quantitative mineral abundances (mass%) determined by XRD in the bauxite samples.

| Sample | Hematite | Goethite | Diaspore | Gibbsite | Quartz | Anatase | Calcite |
|---------|----------|----------|----------|----------|--------|---------|---------|
| 1 | 26.2 | - | 56.3 | - | 2.6 | 2.8 | - |
| 2 | 9.5 | 24.4 | 26.3 | 33.1 | 3.2 | 3.5 | - |
| 3 | 4.2 | 11.9 | 26.7 | 33.6 | 3.1 | 3.3 | 17.2 |
| 4 | 4.0 | 11.2 | 25.2 | 32.1 | 2.8 | 3.1 | 21.6 |
| Average | 10.98 | 11.8 | 33.6 | 24.7 | 2.9 | 3.2 | 9.7 |

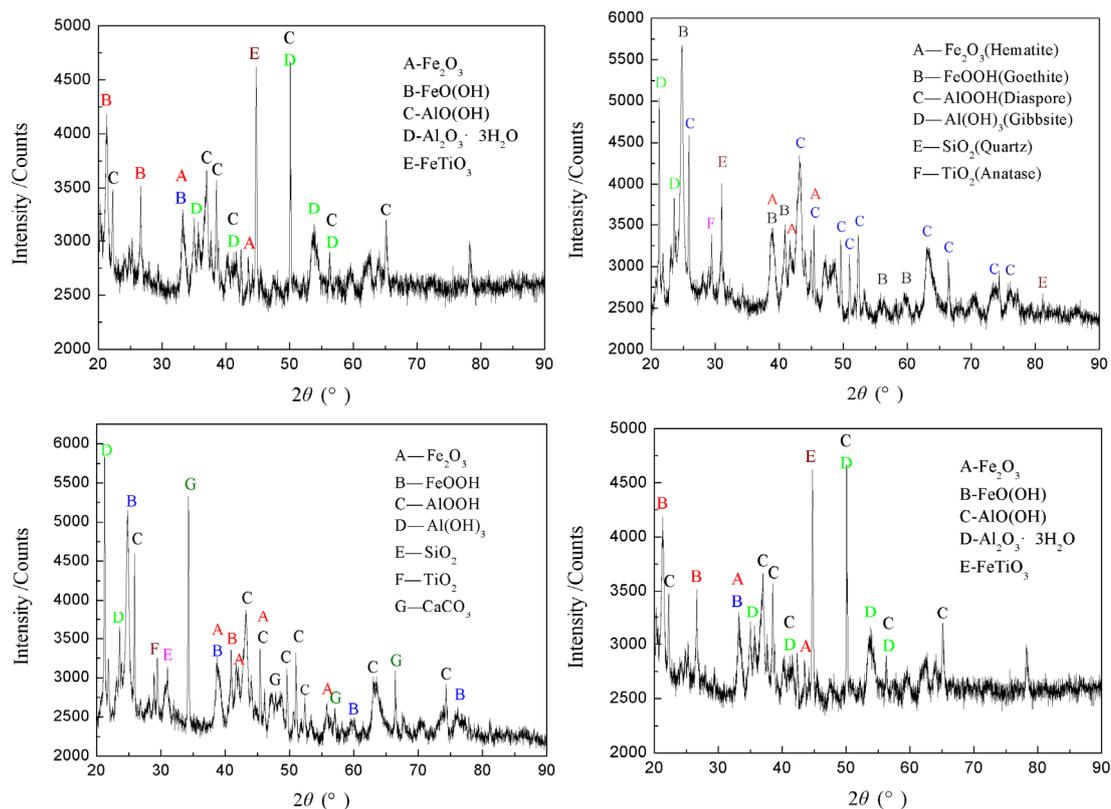


Fig. 4 XRD patterns of four typical bauxite samples. (A-Hematite, B-Goethite, C-Diaspore, D-Gibbsite, E-Quartz, F-Anatase, G-Calcite).

5. MINERALOGICAL CHARACTERISTICS

The ore microscope observation shows that the matrix mineral components in the bauxite ores are cryptocrystalline diaspore, hematite, ferroydrite, kaolinite, anatase, vanadium titanomagnetite and chamosite (Figs. 5 (a)-(g)). It can be seen that most of the diaspores are cryptocrystalline with a small particle size and mainly coexists with ferroydrite (Figs. 5(e) and (g)). Kaolinite is the major clay mineral in the Quaternary bauxite (Liu et al., 2010). Kaolinite mainly coexists with gibbsite and anatase, and the edges of the gibbsite that are adjacent to the kaolinite show clear corrosion (Fig. 5(b)), suggesting that kaolinite may have formed partially at the expense of gibbsite. Although most of the gibbsite are lamellar (Fig. 5 (a) and (c)), small amounts of euhedral-hypidiomorphic gibbsite (50-300 μm) could be discovered in the matrix of the bauxite ores (Fig 5(b)). Most of the gibbsite in nature was transformed from K-feldspar and clay minerals during laterization processes, and it is characterized by a small crystal size (Bárdossy and Aleva, 1990). And the gibbsite with relatively perfect crystals was commonly formed via precipitation from Al-rich solutions within the bauxite horizon (Bárdossy and Aleva, 1990). Anatase commonly precipitated in a reducing condition in the formation of the karst bauxite deposit (Özlu, 1983; Zarasvandi et al., 2008; Haniçli, 2013). It

can be seen that the anatase coexists with kaolinite and they are precipitated under the Permian reducing condition (Fig. 5(d)). Ferroydrite and goethite are the major iron oxide in the Quaternary bauxite, Occurrences of ferroydrite and goethite (Fig. 5(e) and (g)) in the Quaternary ores suggest that they were formed during the Quaternary weathering (Anand et al., 1991; Bárdossy and Aleva, 1990). Their formation is resulted from oxidization of Fe^{2+} , which was released from abundant chamosites (Temur and Kansun, 2006; Haniçli, 2013).

6. CONCLUSION

Mineralogical investigations show that gibbsite ($\text{Al}(\text{OH})_3$), diaspore ($\text{AlO}(\text{OH})$), goethite ($\text{FeO}(\text{OH})$) and hematite (Fe_2O_3) are the major mineral components in the bauxite ores, anatase (TiO_2), quartz (SiO_2) and calcite (CaCO_3) are minor accessories. Geochemical investigations reveal that the Al_2O_3 (24.31-26.46 %), Fe_2O_3 (38.33-44.03 %), SiO_2 (8.76-12.27 %) are the major geochemical compositions in the bauxite ores. The Guigang bauxite belongs to the rich iron Salento-type bauxite with low alumina silica ratio. Semi-quantitative XRD results show that diaspore (25.2-56.3 %), gibbsite (0-33.6 %), hematite (4.0-26.2 %), goethite (0-24.4 %), ferroydrite (0-12.1 %) and calcite (0-21.6 %) vary widely in their abundance, quartz (2.6-3.2 %) and anatase (2.8-3.5 %)

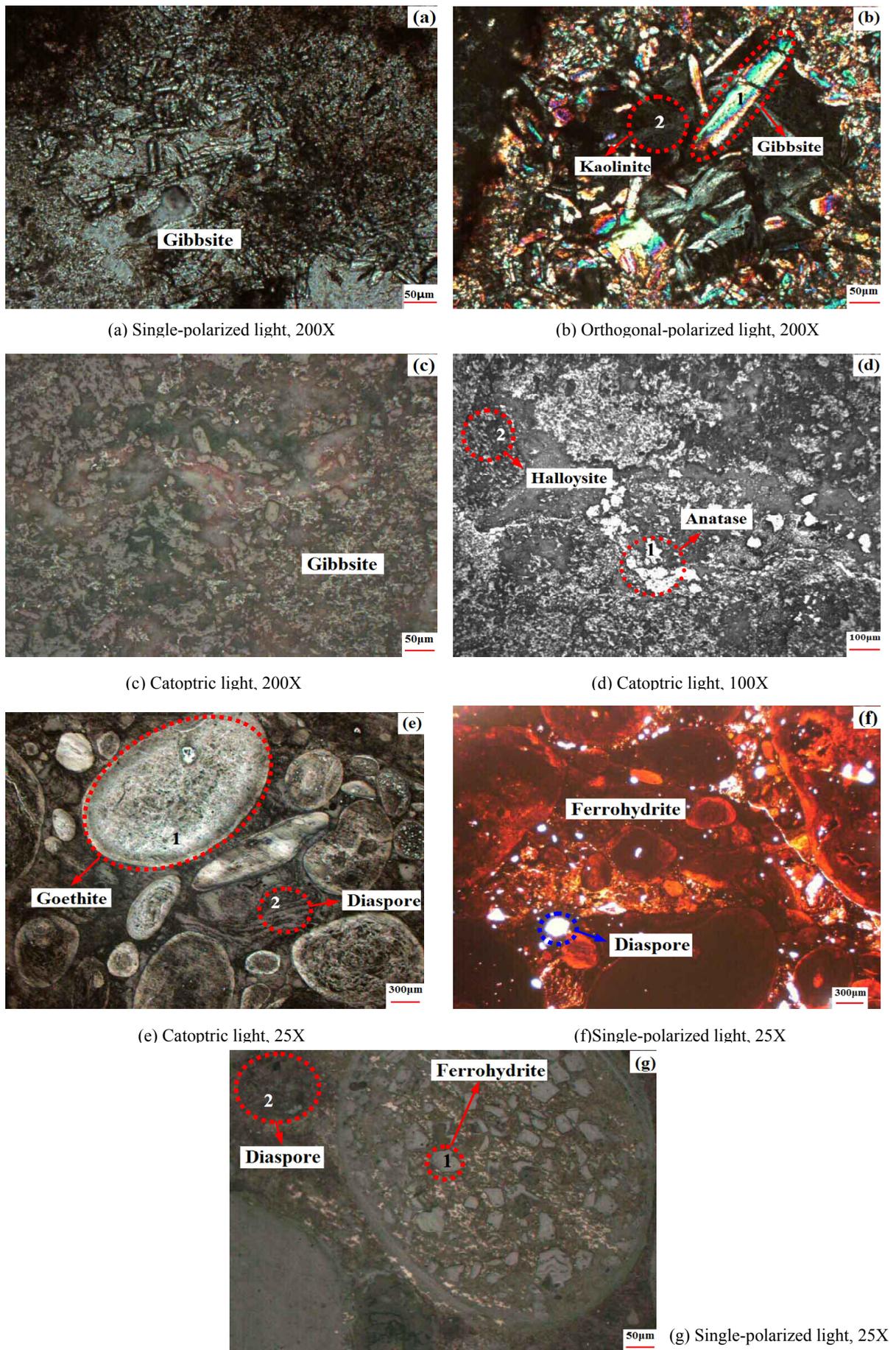


Fig. 5 Microphotographs of Guigang bauxite samples.

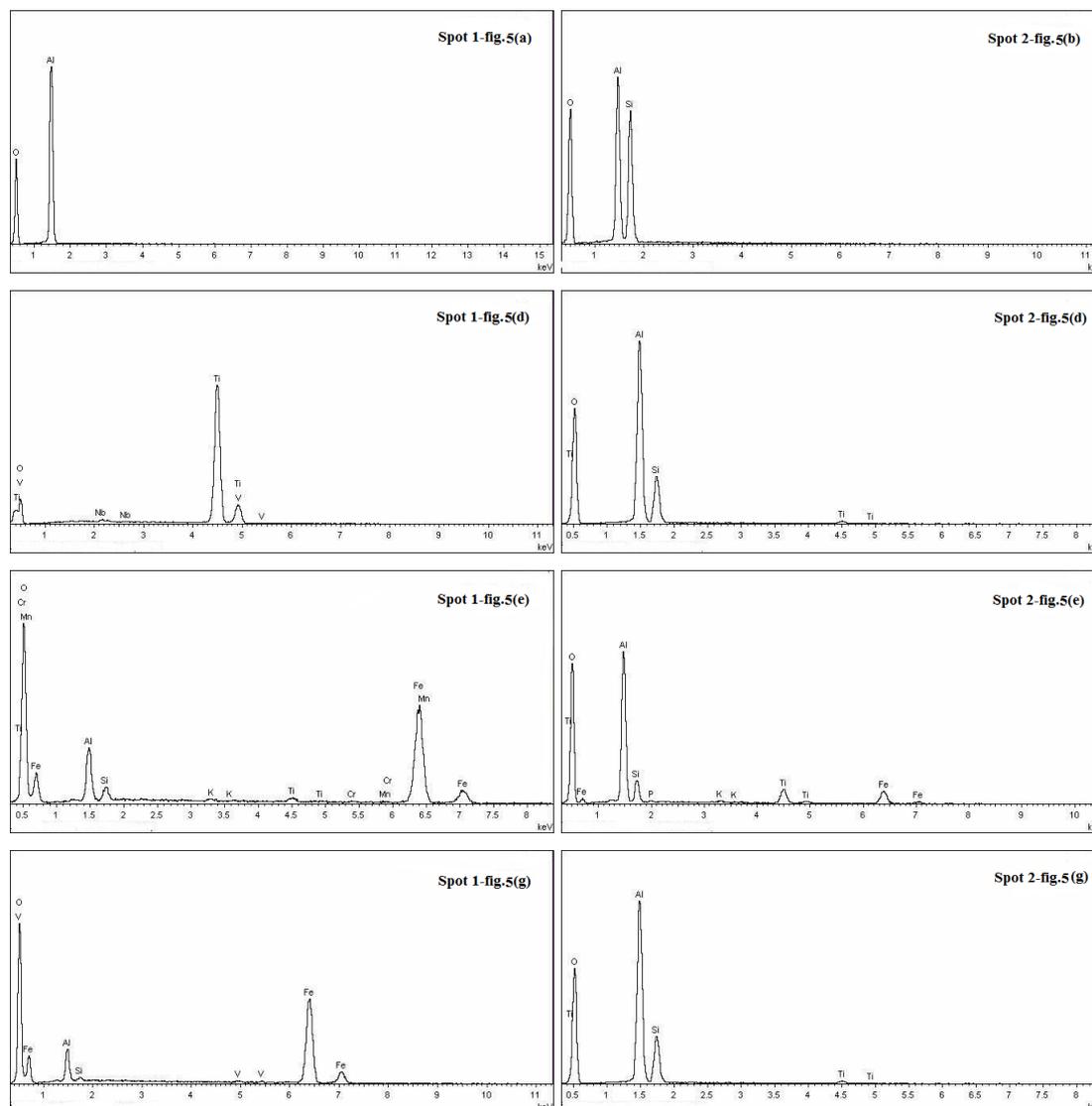


Fig. 6 EDS spectrums of the Guigang bauxite samples.

Table 3 The analysis results of SEM-EDS.

| Test points | Test results (wt. %) | | | | | | | | | Mineral names and chemical structural formula | |
|-------------|----------------------|-------|-------|--------|-------|------|-------|----------|---|--|--|
| | P | Al | Si | K | Ti | Mn | Fe | Ni | O | | |
| Fig.5(b)-1 | | 52.93 | | | | | | | | 47.07 | Gibbsite / $\text{Al}(\text{OH})_3$ |
| Fig.5(b)-2 | | 23.16 | 26.29 | | | | | | | 50.55 | Kaolinite / $\text{Al}_4[\text{Si}_4\text{O}_{10}](\text{OH})_8$ |
| Fig.5(d)-1 | | | | V:0.65 | 58.38 | | | Nb: 1.02 | | 39.95 | Anatase / TiO_2 |
| Fig.5(d)-2 | | 35.31 | 14.58 | | 1.25 | | | | | 48.86 | Halloysite / $\text{Al}_4(\text{H}_2\text{O})_4[\text{Si}_4\text{O}_{10}](\text{OH})_8$ |
| Fig.5(e)-1 | | 10.46 | 2.63 | 0.34 | 1.1 | 0.49 | 55.31 | Cr: 0.42 | | 29.27 | Goethite / FeOOH |
| Fig.5(e)-2 | 0.41 | 31.23 | 6.48 | 0.45 | 6.62 | | 11.36 | | | 43.45 | Diaspore / AlOOH |
| Fig.5(g)-1 | | 8.27 | 0.88 | | | | 63.27 | V:0.62 | | 26.97 | Ferrohydrite / $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ |
| Fig.5(g)-2 | 0.19 | 31.73 | 6.76 | 0.24 | 6.53 | | 9.25 | | | 43.67 | Diaspore / AlOOH |

abundance are relatively consistent. SEM+EDS analyses show that most of the diaspores are cryptocrystalline with a small particle size and mainly coexists with ferrosiderite. Kaolinite is the major clay mineral in the Quaternary bauxite and mainly coexists with gibbsite and anatase, which may have formed partially at the expense of gibbsite. Ferrosiderite and goethite are the major iron oxide in the Quaternary bauxite and they were formed during the Quaternary weathering.

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