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Transformation from Permian to Quaternary bauxite in southwestern South China Block driven by superimposed orogeny: A case study from Sanhe ore deposit

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A B S T R A C T

Permian karstic bauxite and its Quaternary derivative, in western Guangxi, southwestern, South China Block, possess a total tonnage greater than 0.5 billion tons. The primary late Permian karstic bauxite formed in reduced environment in the background of Tethyan accretionary orogenesis. And as one consequence of Cenozoic convergence of the Indian and Eurasia continents, the primary orebody was uplifted, eroded and re-sedimented within Quaternary laterite. The geochemical variation and its controls during the ore transformation from Permian to Quaternary remain poorly understood. Quaternary ore blocks comprise an inner zone of fresh ore, and then it gradually transited through a middle zone to a margin with extensive weathering. One such bauxite block was selected and further subdivided into twenty-three samples for geochemical and mineralogical analysis. The inner and middle zones contain similar mineralogical compositions, dominated by diaspore and amesite, with minor illite, anatase, goethite, pyrite, zircon, and rutile. The margin is composed of diaspore, with small amounts of amesite, boehmite, illite, goethite, anatase, kaolinite, zircon, rutile, and barite. Bauxite in all three zones is composed of mainly Al, Si, Fe, and Ti, and high contents of Zr, Cr, Li, F, S, Zn, V, Sr, Nb, Ba, and REE. Variations in Fe^{2+} and Fe^{3+} between the three zones were observed. The elements Si, Al, Fe^{2+}, Mg, Ba, Cr, F, Li, Ni, Zn, and REE decrease from the core of the ore block outwards, corresponding to an increase in S and Fe^{3+}. Depletions in Si, Al, Fe^{2+}, Mg, Ba, and Cr were caused by the dissolution of amesite. Most of the Al and Si in amesite were lost during the weathering, and minor retained to form kaolinite. Depletions in Li, Ni, and Zn resulted from changes in the depositional environment between the late Permian and Quaternary. Dissolution of REE-bearing fluorocarbonates resulted in depletions of REE and F. The enrichment of Fe^{3+} and S was related to the precipitation of goethite, hematite, and barite in an oxidizing environment, while local enrichment of Ce resulted from the redox change of $Ce^{3+} \rightarrow Ce^{4+}$ under the same condition. This shows that the chemical composition of laterite enwrapping the bauxite also took part in Quaternary bauxite transformation. This study shows that the elements migrations during bauxite transformation were influenced by multiple independent factors except for the elemental attributes.

1. Introduction

Karstic bauxite, i.e., with the carbonate as substrate, is abundant in western Guangxi, southwestern South China Block (SCB). These bauxite deposits comprise two subtypes deposited in late Permian and Quaternary (Deng et al., 2010; Yu et al., 2014). The formation of late Permian karstic bauxite was controlled by the Permian Tethyan accretionary orogenesis (Deng et al., 2010; Zhong et al., 2013). In the background of Cenozoic Indian-Eurasian continental collision, the Permian bauxite was uplifted and exposed to receive further weathering and rework, and transformed into Quaternary ore in the karstic depressions (Liu et al., 2010).

Although both types of bauxite belong to karstic, they were characterized by different mineralogical and geochemical compositions due to the different formation conditions (Liu et al., 2012; Zhang et al., 2015). The Permian bauxite deposited under reduced and alkaline conditions, and the ore was dominated by diaspore,

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amesite, chamosite, pyrite, and anatase; whereas the Quaternary bauxite formed in an oxidized and acidic environment and was mainly composed of diaspore, kaolinite, goethite, hematite, and anatase. Aluminum, Si, Fe^{2+}, Mg, and Ti are the dominant chemical components in the Permian bauxite, and Al, Si, Fe^{3+}, and Ti in the Quaternary bauxite (Zhang et al., 2015). The strikingly mineralogical and geochemical differences between the two types of bauxite mainly resulted from the change of ore-forming condition between Permain and Quaternary (Wang et al., 2010; Liu et al., 2012, 2016). The mineralogical changes during the ore transformation have been studied (e.g., Liu et al., 2012, 2016); however, the elemental behavior in this process remains poorly understood.

The behavior of elements during weathering and bauxitization is complex (Nesbitt, 1979; Braun et al., 1993, 1998; Mordberg, 1996, 1997; Mordberg et al., 2001; Beyala et al., 2009; Feng, 2010; Wang et al., 2010; Du et al., 2012; Liu et al., 2013, 2016; Yusoff et al., 2013). The methods utilized for studying these trends include electron microprobe analysis (EPMA), mass balance calculations, correlation analysis, cluster analysis, and the construction of vertical curves for elements (Mordberg, 1996; Mongelli, 1997; Schwarz and Germann, 1999; Mordberg et al., 2001; Calagari and Abedini, 2007; Mameli et al., 2007; Karadağ et al., 2009; Zarasvandi et al., 2010; Liu et al., 2013). The two key points in mass balance calculations are the composition of parent rocks, and the identification and application of the correct immobile element in the equations.

In this study, one single bauxite block sample consisting of a fresh Permian core and a weathered Quaternary margin was collected from the Sanhe bauxite deposit. The sample was sliced into 23 parts and their mineralogical and geochemical compositions were analyzed individually. Based on these data, the elemental behaviors during Quaternary weathering are studied by means of mass balance calculations, cluster analysis, and mineral composition comparison. Then the transformation process from Permian to Quaternary bauxite in the background of superimposed orogeny was established.

2. Geological setting

Several sub-parallel Tethyan sutures occur in the Sanjiang Orogenic Belt, west of the South China Block (SCB) (Fig. 1a). These structures formed as a result of the Permo-Triassic accretion of the South China, Indochina, Simao, and Eastern Qiangtang blocks. Later, large-scale shearing and crustal uplift resulted from oblique continental collision between the Indian and Eurasian plates during the Cenozoic (Mo et al., 1994; Metcalfe, 2013; Cocks and Torsvik, 2013; Deng et al., 2015a). Both tectonic events were recorded on the western margin of the SCB in terms of tectonic, igneous, topographic, and metallogenic processes.

Western Guangxi is located in the southwestern part of the Youjiang Basin, on the southern margin of the SCB (Deng et al., 2011; Yang et al., 2012a,b). The formation of the Youjiang Basin resulted from the tectonic extension that initiated in the Devonian by rifting of Cambrian–Ordovician strata of the SCB (Du et al., 2009; Yang et al., 2012a,b; Deng et al., 2015a,b). Permian to Early Triassic sedimentation within the basin was dominated by marine clastic rocks, volcaniclastics, and isolated carbonate platforms, on which bauxite horizons developed (Yang et al., 2012a,b; Liu et al., 2016). Permian–Triassic volcanic rocks occur along the SSW margin of the Basin and are believed to be related to closure of the branch Tethyan Ocean during the Paleo-Tethys Orogeny (Wu et al., 2000, 2002; Yang et al., 2012a; Deng et al., 2014a,b). Permian Paleo-Tethys accretion along the southwestern SCB resulted in the exposure of carbonate platforms, which were subsequently weathered, forming abundant ferric clays and wide karstic depressions. At 260 Ma, the Emeishan basalts erupted and filled the karstic depressions; these basalt sequences experienced strong biological chemical and physical weathering, forming giant bauxite deposits. The Permian bauxitization was terminated by a late Permian transgression, resulting in the submergence of Western Guangxi. During the Middle–Late Triassic, clastic detritus was deposited in the Youjiang Basin, representing the final stage of its evolution (Du et al., 2009) and closure of the Paleo-Tethys (Wu et al., 1999; Cai and Zhang, 2009). Later, in the Cenozoic, the initiation of India–Asia convergence resulted in uplift of the Tibetan Plateau and lateral extrusion of the Sanjiang area. Western Guangxi experienced significant uplift and strong weathering during this period (Wang et al., 2011). The Permian bauxite was exposed, fragmented, oxidized, eroded, and redeposited into karstic depressions, forming the Quaternary bauxite (Liu et al., 2012; Yu et al., 2014). This reworking process caused changes in the mineralogical and geochemical features of the bauxite (Liu et al., 2012; Zhang et al., 2015).

3. Sampling and analytical methods

3.1. Study area and sampling

The Sanhe bauxite deposit is located in the western part of the Western Guangxi bauxite belt (Fig. 1a). The stratigraphic

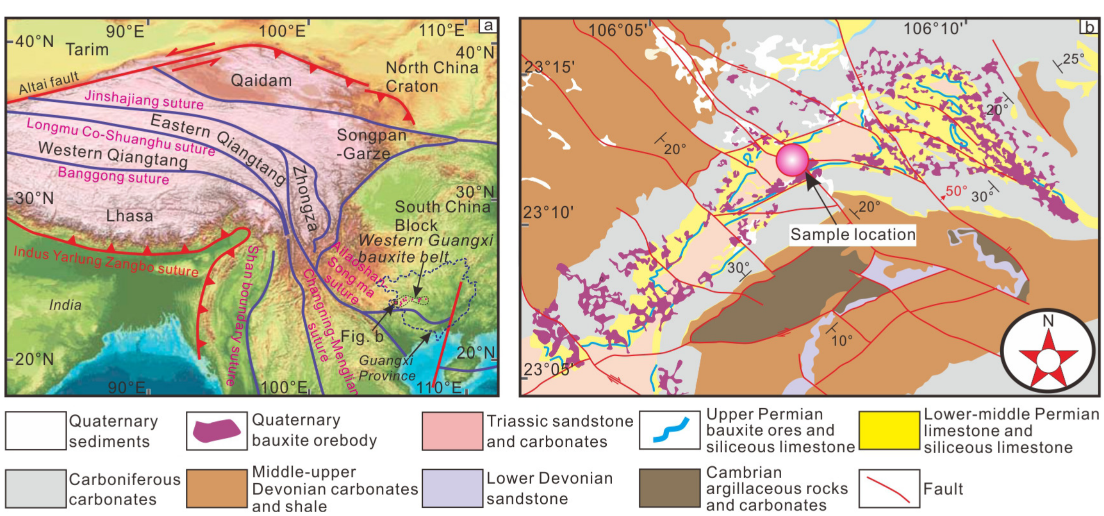

Fig. 1. Geological map showing (a) the location of the Sanhe bauxite deposit (modified from Deng et al., 2014b), and (b) local geology and sampling locations.