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Mixed volcanogenic–lithogenic sources for Permian bauxite deposits in southwestern Youjiang Basin, South China, and their metallogenic significance

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ABSTRACT

Bauxite deposits at the base of the Upper Permian Heshan Formation in the Youjiang Basin, South China, contain zircons with dominant age peaks at 263–262 Ma. During the Middle to Late Permian, the Youjiang Basin consisted of a number of isolated and attached carbonate platforms separated by inter-platform troughs. The bauxite deposits are limited to the isolated carbonate platform facies and are not present on attached carbonate platforms and inter-platform troughs. Discriminant plots based on the trace element composition of the zircons indicate a combination of within-plate/anorogenic and arc-related/orogenic sources. Geochemical and isotopic data suggest that the metallogenic materials of the bauxite deposit came from felsic volcanic rocks of the Emeishan Large Igneous Provence (ELIP) in South China and from the Truong Son volcanic arc located between the South China and Indochina cratons. The northwestern and southeastern parts of the Youjiang Basin received larger amounts of ELIP detritus and volcanic arc detritus, respectively. Coarser siliciclastic material in proximal attached carbonate platform and inter-platform trough settings was delivered by rivers, but finer siliciclastics that accumulated on distally located carbonate platforms in isolated deep-water areas was probably transported by wind.

1. Introduction

Bauxites are products of subaerial chemical weathering with residual enrichment of Al, Fe and Ti (D'Argenio and Mindszenty, 1995). Bauxitization usually entails disintegration of clay minerals in laterite soils and release of Al ions and silicic acid into solution (Eq. (1)), followed by reprecipitation of the aluminum as Al-oxyhydroxides (Eq. (2)):

$$Al_2Si_2O_5(OH)_4(\text{kaolinite}) + 6H^+ = 2Al^{3+} + 2H_4SiO_4(aq) + H_2O \quad (1)$$

$$Al^{3+} + 2H_2O = AlO(OH)(\text{boehmite}) + 3H^+ \quad (2)$$

Prolonged chemical weathering of this type can enrich the Al-oxyhydroxides to ore grade. Climate has long been considered a major factor in the formation of bauxites, with warm and humid conditions favoring bauxitization (Price et al., 1997). The composition of parent rocks is also an important factor, with aluminum-rich parent rocks (Al >10%) favoring bauxite formation (Bogatyrev et al., 2009). Tectonic factors may also play a role in bauxitization, i.e., most large bauxite deposits are located on stable platforms because a lack of epeirogenic motions provides sufficient time for deep chemical weathering (Bárdossy, 1982; Bogatyrev et al., 2009). As intensive weathering is integral to bauxite formation, the original chemistry of the sediments is commonly strongly altered by the weathering process, causing challenges for geochemically based provenance studies. However, heavy minerals such as zircon are relatively resistant to weathering alteration and, thus, are especially useful for bauxite provenance studies (Bárdossy, 1982). A number of recent studies have made use of detrital zircon U–Pb ages as a fundamental tool in determining sediment provenance (Deng et al., 2010; Boni et al., 2012; Mongelli et al., 2016).

Two kinds of bauxite deposits exist in western Guangxi Province, South China. A paleokarst bauxite deposit (Mediterranean-type) dated to 262–256 Ma is present at the base of the Upper Permian Heshan Formation (Deng et al., 2010; Hou et al., 2014), and an epigenetic (Salento-type) bauxite deposit of Quaternary age developed from the Permian deposit (Yu et al., 2014). Detailed mineralogical (Liu et al., 2012; Yu et al., 2014) and geochemical studies (Wang et al., 2010; Wei et al., 2013; Yu et al., 2014) of the deposits have shown that the bauxite ore is composed of aluminum minerals (boehmite and diaspore), iron

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minerals (hematite or pyrite), clay minerals (kaolinite, illite, and chlorite) and some minor minerals (e.g., zircon, anatase, and rutile) with average Al, Si, and Fe contents of 30–50%, 5–25%, 10–20%, respectively.

The provenance of the western Guangxi bauxite deposits remains in dispute. Based on petrographic and geochemical similarities, Wei et al. (2013) proposed that the Heshan Formation bauxite has an affinity with carbonates of the underlying Maokou Formation. However, numerous zircons in the bauxite deposit have yielded an age cluster at 263–256 Ma, suggesting an origin related to the Emeishan Large Igneous Provence (ELIP) (Deng et al., 2010), which is known to have been active at 260 ± 3 Ma (Shellnutt, 2014). In this case, the likely source of the material would have been pyroclastic ash fall following ELIP eruptions. An alternative hypothesis was advanced by Hou et al. (2014), who inferred an arc-related origin on the basis of zircon U–Pb dating and geochemical discriminant diagrams.

In this paper, we present new whole-rock and zircon geochemical and U–Pb geochronological data on the Upper Permian bauxite deposit of the Heshan Formation in western Guangxi Province, South China, supplemented with previously published elemental and zircon U–Pb ages and geochemical data from lower Upper Permian strata within the Youjiang Basin. The results of our study document a mixed provenance for the bauxite deposit, with metallogenic material derived both from felsic rocks of the ELIP to the north and from the magmatic arc between the South China and the Indochina cratons to the south (note: all coordinates given as Late Permian paleo-coordinates). The northwestern and southeastern parts of the Youjiang Basin were dominated by ELIP and volcanic arc inputs, respectively, with a zone of approximately equal mixing through the center of the basin.

2. Geological background

The study area is located in the West Guangxi Province, SW China. Paleogeographically, it belongs to the southwestern quadrant of the Youjiang Basin, which is also known as the Nanpanjiang Basin in some studies (e.g., Lehrmann et al., 2006). As a passive continental margin basin, the Youjiang Basin extended across the modern southwestern part of the South China Craton (Fig. 1A–B). The Youjiang Basin evolved as a distinct feature in the Devonian Period during rifting of the South China Craton away from the northeastern margin of Gondwana. Permian strata are well-developed in the study area, with thicknesses to 2000 m (Fig. 1C). By the Permian, the Youjiang Basin had deepened, producing three kinds of paleogeographic facies: (1) isolated carbonate platforms within the basin (e.g., Leye, Fusui, Pingguo, Debao and Jingxi platforms), (2) attached carbonate platforms around the margins of the basin (e.g., Laibin Platform), and (3) inter-platform troughs (e.g., Sidazhai, Napo, and Banai troughs). On the carbonate platforms, the Middle Permian Maokou Formation is represented by massive cherty limestone and the Upper Permian Heshan Formation by bauxite and black shale in the lower part shifting to bioclastic limestone upward. The correlative units in the inter-platform troughs are the Middle Permian Sidazhai Formation, which consist of thin bioclastic limestone with chert nodules and thin chert layers, and the Upper Permian Linghao and Wuchiaping formations, which consist of radiolarian chert and siliciclastic sediments with interbedded volcaniclastic layers (Fig. 2).

A regional unconformity exists between Middle and Upper Permian strata in the Youjiang Basin and adjacent areas (Fig. 2). This unconformity reflects a major global sea-level drop at the Guadalupian–Lopingian boundary (GLB) (Kofukuda et al., 2014), which was reinforced in South China by regional crustal doming linked to ELIP emplacement (He et al., 2010a). On the isolated carbonate platforms, the base of the Upper Permian Heshan Formation consists of a 0.5- to 10-m-thick gray or red bauxite deposit that formed in part through weathering of the underlying Middle Permian Maokou Formation. This deposit accumulated on a paleokarst surface that developed on the top of the Maokou Formation, the relief on which controls the thickness of the bauxite deposit (Deng et al., 2010; Wei et al., 2013; Yu et al., 2014). On the attached

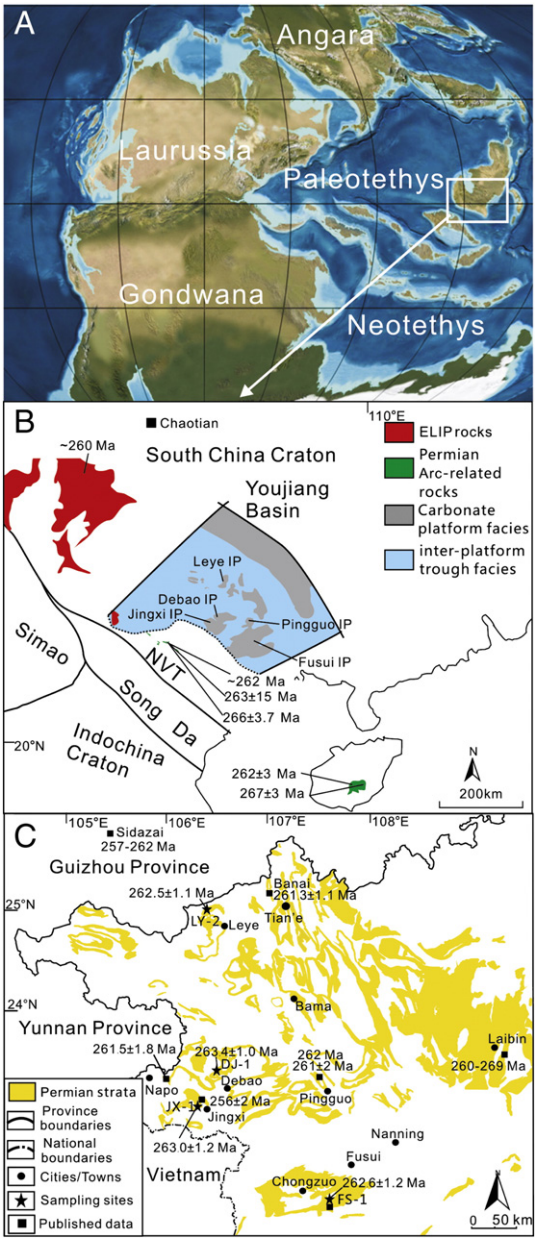

Fig. 1. (A) Paleogeography of the Tethys Ocean region during the late Middle Permian (~260 Ma). Base map courtesy of R. Blakey (http://jan.ucc.nau.edu/rcb6/). (B) Generalized tectonic domains of southwestern South China Craton and Middle–Late Permian paleogeography of the Youjiang Basin. IP = isolated carbonate platform; NVT = North Vietnam Terrane; ELIP = Emeishan Large Igneous Province. The ages of ELIP rocks are from Shellnutt (2014), and the ages of Permian arc-related rocks are from Halpin et al. (2016) and Li et al. (2006). (C) Permian strata in northwestern Guangxi (modified from BGMRGR, 1985) and ages of bauxite deposits and clastic rocks above the Middle–Upper Permian boundary. Data sources: Debao, Fusui, Jingxi and Leye isolated carbonate platform sections (this study), Pingguo isolated carbonate platform section (Deng et al., 2010; Hou et al., 2014), Chaotian (He et al., 2010a, 2010b), Napo (Huang et al., 2014), Banai (Yang et al., 2012), and Laibin (Zhong et al., 2013).

carbonate platforms, 0.2- to 4-m-thick claystone layers were deposited on the paleokarst surface of the Maokou Formation carbonates and were covered by Heshan (or Wuchiaping) Formation (He et al., 2010b; Zhong et al., 2013). In the inter-platform troughs, the Middle–Upper Permian boundary is marked by a lithologic transition, e.g., from limestone of the Middle Permian Sidazhai Formation to basalt and siliciclastic sediments of the Upper Permian Linghao Formation at Napo (Huang et al., 2014), or from brecciated limestone of the Middle Permian Sidazhai Formation to mudstone of the Upper Permian Linghao (=Wuchiaping) Formation at Banai and Sidazhai (Yang et al., 2012).