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Petrogenesis of the Early Cretaceous Laguila bimodal intrusive rocks from the Tethyan Himalaya: Implications for the break-up of Eastern Gondwana

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ABSTRACT

The Kerguelen mantle plume triggered the rift of Eastern Gondwana to open the eastern Indian Ocean, with the formation of ~132 Ma Comei–Bunbury large igneous province (LIP). The Comei area is located in the eastern Tethyan Himalaya, paleogeographically belonging to Greater India. The Laguila bimodal intrusive rocks from the Comei area consist of mafic (gabbro-diabase) and felsic rocks (quartz monzonite-granodiorite). This paper presents detailed LA-ICP-MS zircon U-Pb chronology, major and trace elements, and Sr-Nd-Pb isotope geochemistry of the Laguila bimodal intrusive rocks, in order to constrain the early activity of the Kerguelen mantle plume. LA-ICP-MS zircon U-Pb dating shows that the Laguila intrusive rocks were emplaced in the Early Cretaceous (~134–130 Ma). The Laguila mafic rocks are enriched in LREE, LILE and HFSE, similar to those of oceanic island basalts (OIB). Their $^{87}Sr/^{86}Sr_i$ (0.7054 to 0.7066), $^{143}Nd/^{144}Nd$ (T) (0.512548 to 0.512619) and $(^{206}Pb/^{204}Pb)_t$ ratios (18.492 to 18.859) are comparable with those basalts derived by the Kerguelen hot spot. Elemental and isotopic data suggest that they were likely derived by partial melting of the Kerguelen plume source in the spinel–garnet transition zone (~60–80 km). The Laguila felsic rocks share most of the geochemical features of A-type granite and show different $^{87}Sr/^{86}Sr_i$ (0.7171 to 0.7204), $^{143}Nd/^{144}Nd$ (T) (0.511874 to 0.511956) and $(^{206}Pb/^{204}Pb)_t$ ratios (19.087 to 19.274) from those of the mafic rocks. They were likely derived by partial melting of crustal rocks at a shallow depth (<30 km) triggered by underplating of the coeval basaltic magmas. The Laguila intrusive rocks were emplaced in a rift setting during the breakup of eastern Gondwana, associated with the Kerguelen plume activity.

We calculated the magmatic volume of Comei–Bunbury basalts and the result is ~1.1×10^4 km^3. The small volume is not reconciled with those typical models for the initial magmatic eruption of mantle plume. It was possible that the thick lithosphere (>150 km) underneath Greater India prevented the Kerguelen plume from large-scale melting because of the high pressure when the latter impinged onto the former at ~132 Ma. The shallow source (~60–80 km) of the Laguila mafic rocks indicate that they originated likely from a series of "diapirs" or "fingers" rising from the head of the Kerguelen plume, which penetrated into the thick lithospheric mantle of Eastern Gondwana at enough shallow depth for melting.

1. Introduction

Although only ca. 5% of volcanoes are related to mantle plumes, they play an integral part in the Earth's evolution (Frisch et al., 2011; Rogers and Santosh, 2002). For example, mantle plumes generally initiate continental breakup with doming and cracking, and subsequently drive plate movement (e.g. Li Z.X. et al., 1999; Morgan, 1972). Their resulting hot spots are responsible for large igneous provinces (LIP), consisting of dominantly mafic rocks and alkaline rocks, with areal extents of >100,000 km^2 (Bryan and Ernst, 2008; Coffin and Eldholm, 1994). Due to the enormous magmatic loss, the head of the plume cools rapidly and the magmatic activity ceases. However, volcanoes on some hot spots such as the Kerguelen hot spot intermittently erupted for more than 100 million years (Frisch et al., 2011).

The Kerguelen LIP, one of Earth's largest flood basalt provinces, was believed to be the result of Kerguelen mantle plume activity which played a crucial role in rifting the Eastern Gondwana and opening the eastern Indian Ocean (Coffin et al., 2002; Srivastava and Sinha, 2004; Storey, 1995). The mantle plume activity produced massive magmatic rocks from ca. 130 Ma to present, including Bunbury (Australia), Rajmahal-Bengal-Sylhet (India), lamprophyres and lamproites of the conjugate Indian and Antarctic margins, southern Kerguelen Plateau,

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Elan Bank, Central Kerguelen Plateau, Broken Ridge, Ninetyeast Ridge, Skiff Bank, Northern Kerguelen Plateau, Kerguelen Archipelago, Heard and McDonald Islands (Fig. 1; Coffin et al., 2002; Ray et al., 2005; Srivastava et al., 2005; Srivastava and Sinha, 2007; Chalapathi Rao et al., 2014). These Cretaceous and Cenozoic igneous rocks have been widely dispersed from their original emplacement sites due to the changing motions of the Antarctic, Australian and Indian plates since ~130 Ma (Fig. 1; Müller et al., 1993).

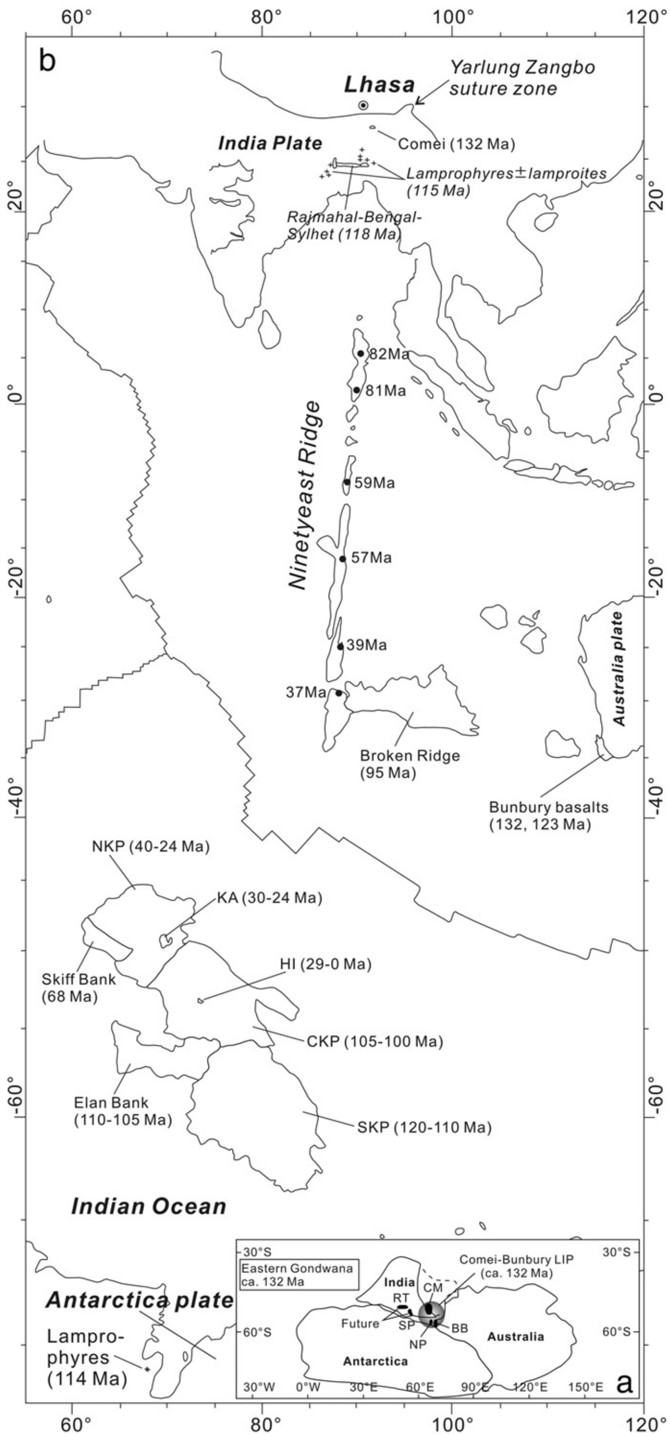

Fig. 1. (a) Generalized plate tectonic reconstruction of Eastern Gondwana at ~132 Ma (modified after Schettino and Scotese, 2001); (b) The Kerguelen hot spot–related basalt provinces in the Indian Ocean region (modified after Coffin et al. (2002) and Zhu et al. (2007)).

Recently, Zhu et al. (2007, 2008) have reported that some Early Cretaceous (~132 Ma) within-plate igneous rocks (dominant by basaltic lavas) are exposed in the Comei area from the eastern Tethyan Himalaya with an areal extent of ~40,000 km^2, paleogeographically belonging to the northeastern margin of Greater India. These magmatic rocks are coeval with the Bunbury Basalt (southwestern Australia) and sit near the southwestern margin of Australia on the tectonic reconstruction of Gondwana at ca. 132 Ma (Fig. 1a; Schettino and Scotese, 2001). Subsequently, a newly large igneous province was termed as Comei–Bunbury LIP and was also a product of the Kerguelen mantle plume activity (Zhu et al., 2009). However, only a few data for the Cretaceous magmatic rocks outcropped in the western Comei area have been reported by Zhu et al. (2005, 2007, 2008 and 2009). Further detailed studies should be conducted to verify the genetic relationship between the Comei igneous rocks and the early activity of the Kerguelen plume. The Laguila bimodal intrusive rocks, exposed in the eastern Comei area (Fig. 2), were firstly discovered and identified in our field investigation. Here, we present zircon U-Pb chronological, whole rock geochemical, and Sr-Nd-Pb isotopic data for these rocks, to further constraint the initial activity of the Kerguelen plume and the breakup of Eastern Gondwana.

2. Geological setting, field occurrence and petrography

The Tethyan Himalaya adjoins the Indus-Yarlung Zangbo Suture Zone in the north and the Greater Himalayan crystalline complex in the south, paleogeographically belonging to "Greater India" (Zhu et al., 2008, 2013). The regional strata include Precambrian metamorphic rocks and Paleozoic to Cenozoic sedimentary rocks. Extensive basaltic lavas and minor felsic volcanic rocks are exposed in the Jurassic-Cretaceous passive continental sequences such as the Lakang Formation and Sangxiu Formation, consisting mainly of sandstone, sandy shale, slate and muddy limestone (Nie et al., 2005; Wan et al., 2005; Zhu et al., 2007, 2008). The thickness of the basalts in these sequences range from several meters to ~600 m (Zhu et al., 2008). They show massive, amygdaloidal or pillow structures, with similar eruption ages of ~132 Ma (Zhu et al., 2009). The volcanic rocks of Sangxiu Formation include alkaline basalts and felsic volcanic rocks. The Sangxiu basalts are geochemically similar to OIB, while the Sangxiu felsic volcanic rocks share most geochemical features of A-type granites (Zhu et al., 2007). The formation of these igneous rocks owes to an interaction between the Kerguelen hot spot and the lithosphere of Greater India (Zhu et al., 2007).

The Laguila bimodal intrusive rocks are exposed in the eastern Comei area of the Tethyan Himalaya. They consist of mafic (gabbro–diabase) and felsic rocks (quartz monzonite–granodiorite) (Figs. 3, 4). These rocks intruded into the Jurassic volcanic–sedimentary sequence (Figs. 2, 3a–c). The felsic pluton occurs as a small stock and covers only an area of ~0.5 km^2 (Fig. 2c). Detailed LA-ICP-MS U-Pb zircon geochronology in this study (see below) indicates that they were emplaced during the Early Cretaceous (~134–130 Ma). The Laguila felsic rocks have a fine to medium-grained granitic texture and a massive structure, mainly containing plagioclase (20%–30%), quartz (25%–30%), K-feldspar (25%–30%), amphibole (<10%) and biotite (5%–10%) (Fig. 3d, g). The Laguila gabbros exhibit typical gabbroic texture and the diabases show typical diabasic texture. These mafic rocks have uniform compositions, comprised of plagioclase (40%–45%), clinopyroxene (45%–50%), olivine (~5%), ilmenite and magnetite (~5%) (Fig. 3 h, i).

3. Sampling and analytical methods

Nine samples were collected from the Laguila bimodal intrusive rocks (Fig. 2). The whole-rock geochemical and Sr-Nd-Pb isotopes were analyzed for all the samples. Prior to these analyses, samples were cut to remove altered surfaces and crushed to 200-mesh in an agate mill successively.