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Late Cenozoic volcanism in central Myanmar: Geochemical characteristics and geodynamic significance

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ABSTRACT

Late Cenozoic volcanism occurred in the central Myanmar basin, a region that is marked by the existence of the dextral Sagaing fault linking the eastern Himalayan Syntaxis to the north and the Andaman Sea to the south. Here we report new geochemical data of volcanic rocks from Monywa, Mt. Popa and Singu areas erupting in two distinct stages, i.e., mid-Miocene and Quaternary, respectively. While calc-alkaline rocks showing arc-like geochemical features are abundant, an apparent change in magma composition is observed between these two stages. The mid-Miocene rocks are mainly dominated by intermediate compositions ($SiO_2 = 53$-61 wt.%) and typical of high-K calc-alkaline nature. They exhibit uniform Sr and Nd isotopic ratios ($I_{Sr} \approx$ ~0.705; $\varepsilon_{Nd}(T) = +2.7$ to $+1.6$), suggesting a juvenile mantle origin related to the subduction of Indian oceanic lithosphere beneath this part of Asia. The Quaternary rocks consist mainly of basalts that, however, show variations in geochemical features. Three suites in this stage are observed: (1) calc-alkaline suite (basalts and basaltic andesites from Monywa and Mt. Popa: $SiO_2 = 48$–56 wt.%; $I_{Sr} = 0.704$ to 0.705; $\varepsilon_{Nd}(T) = +3.1$ to $+2.1$), originating from partial melting of a "remnant" juvenile mantle wedge, (2) alkali basalt suite I (basanites from Monywa: $SiO_2 \approx 45$ wt.%; $MgO = 10$–12 wt.%; $K_2O \approx 2.0$ wt.%; $I_{Sr} = 0.704$ to 0.705; $\varepsilon_{Nd}(T) \approx +3.6$), interpreted as the product of small-degree melting from an amphibole lherzolite in the lithospheric mantle, and (3) alkali basalt suite II (trachybasalts from Singu: $SiO_2 \approx 51$ wt.%; $K_2O = 2.6$–3.5 wt.%; $I_{Sr} \approx 0.706$; $\varepsilon_{Nd}(T) = +1.6$ to $+0.9$), interpreted as the product of partial melting from the asthenosphere. All processes of magma generation were related to the India–Asia collision that caused regional plate reorganization, a transition from oblique subduction to dextral movement in the Miocene, and subsequent "rollback" of the subducted Indian oceanic lithosphere in the Quaternary. Therefore, the arc volcanism ceased at ca. 15 Ma and, after a >10-m.y. magmatic gap in the region, volcanism revived in the Quaternary with heterogeneous compositions owing to rise of the geotherm resulting from asthenospheric upwelling that caused small-degree melting of different domains in pre-Miocene subduction-enriched lithospheric mantle and the asthenosphere beneath central Myanmar.

1. Introduction

The collision of India with Asia commenced at approximately 55–50 Ma (Chung et al., 2005; Dewey et al., 1989; Hodges, 2000; Klootwijk et al., 1992; Lee et al., 2012). Myanmar, located in the eastern margin of the India–Asia collision zone, is marked by the existence of the ~1200 km dextral Sagaing fault linking the eastern Himalayan Syntaxis (Namche Barwa) to the north and the Andaman Sea to the south. Thus, this region is unique as a transition between a compressional (Himalayan) and extensional (Andaman Sea) tectonic settings (Fig. 1). Furthermore, it is characterized by the exposures of (1) Cretaceous–Paleogene granitoids correlating northward to the Gangdese batholith (Barley and Pickard, 2003; Gardiner et al., 2015; Lin et al., in preparation; Mitchell, 1979; Mitchell et al., 2012), and (2) a series of Miocene–Quaternary volcanoes extending to those in the Andaman–Sunda (Sumatra)–Banda subduction system in southeast Asia (Hamilton, 1979; Hutchison, 1989; McCaffrey, 2009; Sheth et al., 2009). The former represents the pre- to syn-collisional products (Barley and Pickard, 2003; Mitchell, 1979) resulting from the subduction and subsequent breakoff of the Neo-Tethyan oceanic lithosphere/slab (Chung et al., 2005; Lee et al., 2009, 2012; Lin et al., in preparation). The latter is attributable to the ongoing subduction of the Indian–Australian Plate beneath the Eurasian Plate (Hamilton, 1979; McCaffrey, 2009; Sheth et al., 2009), and/or the transtensional environment caused by dextral motion along the Sagaing fault (Maury et al., 2004; Wang et al., 2007).

Limited chronological data show that volcanic centers in the central Myanmar are of Quaternary ages (Bertrand et al., 1998; Maury et al., 2004). Lee et al. (2010), however, conducted a geochronological study to conclude that the magmas from Monywa, Mt. Popa and Singu, central

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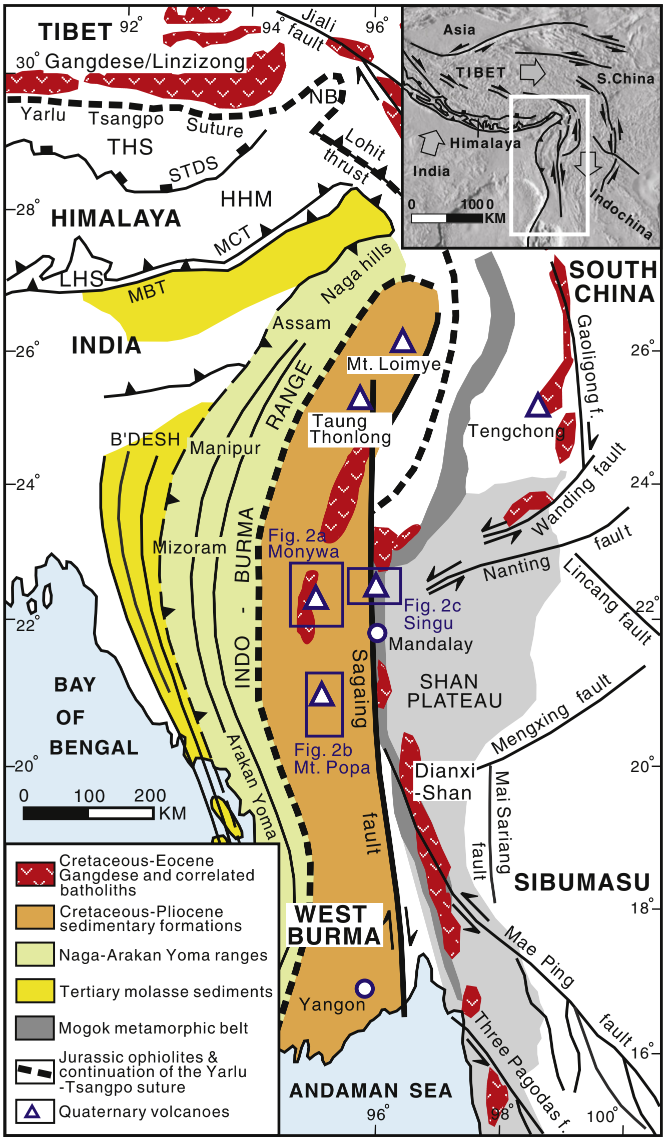

Fig. 1. Simplified geologic map (modified from Mitchell et al., 2007; Searle et al., 2007; Yang, 2008) showing the main volcanoes in Myanmar and related areas. Inset denotes the principal terrane boundaries and Cenozoic tectonic extrusion in East Asia related to the India–Asia collision. NB = Namche Barwa Syntaxis. THS = Tethyan Himalayan sequences. HHM = High Himalayan metamorphic rocks. LHS = Lesser Himalayan metasedimentary series. STDS = South Tibet detachment system. MCT = main central thrust. MBT = main boundary thrust.

Myanmar erupting in two stages at the mid-Miocene and the Quaternary. This paper documents geochemical data for volcanic rocks in the same areas, and all results can include (1) reporting new major and trace element and Sr–Nd isotopic data, and (2) distinguishing the geochemical characteristics of the volcanic rocks between Miocene and Quaternary stages. Using this new dataset, we examine the petrogenesis and tectonomagmatic implications to better understand the tectonic evolution in the eastern margin of the India–Asia collision region.

2. Geological background and samples

Myanmar is divided into two structural provinces by the Sagaing fault. The eastern part, which belongs to the Sibumasu terrane consists of the Shan Plateau, the Mogok metamorphic belt and the Shan Scarps, whereas the western part, which belongs to the West Burma terrane comprises the Indo-Burma Range and the Wuntho–Popa magmatic arc system overlying Cretaceous–Pliocene strata (Fig. 1; Mitchell et al., 2007, 2012). The Wuntho–Popa magmatic arc system includes largely Late Cretaceous to Tertiary granodioritic batholiths, and minor Late Cretaceous to Quaternary volcanic rocks (Mitchell et al., 2012; United Nations, 1978). There are five volcanoes in the magmatic arc including Mt. Loimye, Taung Thonlong, Singu, Monywa and Popa from north to south (Bender, 1983; Searle et al., 2007). Three of the volcanic centers, i.e., Monywa, Mt. Popa and Singu, are located in the central part of Myanmar. Two out of the three studied volcanic areas, Monywa and Mt. Popa, are located within the central basin while the third one of Singu is located to the east and crosscut by the Sagaing fault (Fig. 1). The age data for shear rocks in the Sagaing fault delineate a duration of major dextral motion around ~20–15 Ma (Bertrand et al., 1999, 2001; Lee et al., 2003), and this right-lateral faulting is generally accepted to be related to the opening of the Andaman Sea beginning around ~15–10 Ma (Fig. 1; Curray et al., 1982; Lee et al., 2003). All sample localities in this study are presented in Fig. 2 and Table 1.

One andesite (SC034) of the volcanic rocks in Monywa erupted in the mid-Miocene with an age of ~14 Ma (Mitchell et al., 2012; Fig. 2a; Table 1). In contrast, the Quaternary population in Monywa (Table 1) is basaltic to basaltic andesitic compositions. An important feature of the deposits is the extraordinary abundance of ultramafic to gabbroic cumulates including olivine pyroxenites and amphibole-bearing pyroxenites, troctolites and gabbros (Maury et al., 2004; Fig. 2a). Volcanic rocks in Mt. Popa, however, have been subdivided into two groups geographically (Chhibber, 1934; Maury et al. 2004; Stephenson and Marshall, 1984). The old group of volcanics which covers an area to the south of the Mt. Popa volcano and erupted in the mid-Miocene (Table 1) includes dacitic and rhyolitic pumice flows, andesitic flows and dacitic domes and flows (Fig. 2b). Their ages are in good accordance with those of mid-Miocene Monywa rocks. The young group of volcanics which erupted in the northern area of Mt. Popa in the Quaternary (Table 1) includes basaltic to basaltic andesitic lava flows, a pyroclastic cone made of basaltic to basaltic andesitic pyroclastics and the basaltic Popa neck (Figs. 2b and 3a–c). The singu area, offset by the Sagaing fault (Bertrand et al., 1998), is made of a thick pile of basaltic flows (Figs. 2c and 3d) which erupted in the Quaternary and overlie Mio- to Pliocene sandstones as well as the Pliocene to Quaternary Irrawaddy formaiton (Bender, 1983; Caroff et al., 2000; Chhibber, 1934; Maury et al., 2004).

In this study, a total amount of forty-three volcanic samples were collected from Monywa, Mt. Popa and Singu areas, and they are generally fresh and show either porphyritic or aphyric textures. Here the basalts and basaltic andesites display porphyritic textures with up to ~20% phenocrysts including clinopyroxene and plagioclase. Their groundmass contains microcrysts of plagioclase, clinopyroxene, Fe–Ti oxides and olivine (Figs. 4a to d). The andesites contain ~5% plagioclase together with microphenocrysts of clinopyroxene, hornblende, biotite, apatite and opaque phases (Figs. 4e and f). Six among these samples had been subjected to whole-rock Ar–Ar and in-situ zircon U–Pb isotopic determinations by Mitchell et al. (2012) and Lee (2015) unpublished data (Table 1). The dating results indicate that the volcanic rocks in central Myanmar resulted from two stages of eruption in the mid-Miocene (ca. 14 Ma) and the Quaternary (after 1 Ma).

3. Analytical methods

Powdered samples of the studied rocks were analyzed for major elements using a Rigaku® RIX 2000 X-ray fluorescence (XRF) spectrometer at Department of Geosciences, National Taiwan University. Analytical uncertainties are generally better than 5% for all elements. Loss on ignition (LOI) was analyzed by routine procedures. Trace elements were measured using an Agilent® 7500cx inductively coupled plasma-mass spectrometer (ICP-MS) in the same department. The measurements show a stability range within ~5% variation. Accuracy and precision are generally better than 3%. Analytical details for major and trace element analyses are the same as in Lee et al. (2012) and Lin et al. (2012).