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Tethyan suturing in Southeast Asia: Zircon U-Pb and Hf-O isotopic constraints from Myanmar ophiolites

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ABSTRACT

Ophiolites that crop out in Southeast Asia represent the relics of the Tethys Ocean, which existed between the continents of Gondwana and Laurasia during much of the Mesozoic. Two ophiolite belts in Myanmar, i.e., the Eastern Belt and the Western Belt, have been conventionally regarded as parts of a single suture connecting with the Yarlung-Tsangpo suture in the Tibetan Plateau and displaced by the dextral Sagaing fault. Here we present for the first time a combined analysis of zircon secondary ion mass spectrometry U-Pb ages and Hf-O isotopes of two Myanmar ophiolites, the Kalaymyo ophiolite from the Western Belt and the Myitkyina ophiolite from the Eastern Belt. Our results show that the Kalaymyo ophiolite has an Early Cretaceous age (ca. 127 Ma), coeval with Neo-Tethyan ophiolites along the Yarlung-Tsangpo suture. In contrast, the Myitkyina ophiolite was formed during the Middle Jurassic (ca. 173 Ma) and thus the Eastern Belt is the southern continuation of the Meso-Tethyan Bangong-Nujiang suture in the Tibetan Plateau. Consequently, we argue that the two Myanmar ophiolite belts belong to two different sutures of the Meso-Tethys and Neo-Tethys, and that the boundary between the Sibumasu and west Burma blocks is a Jurassic suture rather than a transcurrent shear zone.

INTRODUCTION

Southeast Asia comprises a giant jigsaw puzzle of continental terranes (e.g., Indochina, Sibumasu, and west Burma) that amalgamated during the Mesozoic after rifting and separation from Gondwana during the Paleozoic to Mesozoic. Rifting and suturing of these continental terranes were accompanied by the opening and closure of three successive Tethys oceans (i.e., the Paleo-Tethys, Meso-Tethys, and Neo-Tethys) since the Paleozoic (Metcalfe, 1996). Thus, the Tethyan evolution is essential to the geological history of Southeast Asia. Sutures of the Tethys oceans have been well established in the Tibetan Plateau (Fig. 1). The Paleo-Tethys suture is marked by the Carboniferous Longmu Co-Shuanghu belt (Zhai et al., 2013), which continues southeastward to the Bentong-Raub suture in Malaysia through the ophiolite belt east of Myanmar (Metcalfe, 1996). The Neo-Tethys suture is represented by the Yarlung-Tsangpo belt, which connects with the ophiolite belt along the eastern Indo-Burma Range (Mitchell, 1993). The Meso-Tethys suture is best exposed along the Bangong-Nujiang suture in central Tibet (Wang et al., 2016), but its occurrence in Southeast Asia remains unclear. For example, crucial ophiolites that crop out within Myanmar have not been well studied (Fig. DR1 in the GSA Data Repository[1]). In this paper we present zircon U-Pb ages and Hf-O isotopes of mafic and felsic dikes that intrude peridotites of the Kalaymyo and Myitkyina ophiolites. Our data provide critical new constraints not only on formation of the Myanmar ophiolites, but also on Tethyan suturing in Southeast Asia, which is essential to our understanding of opening and closure of the Tethys Ocean that played a key role in global plate tectonics during the Mesozoic.

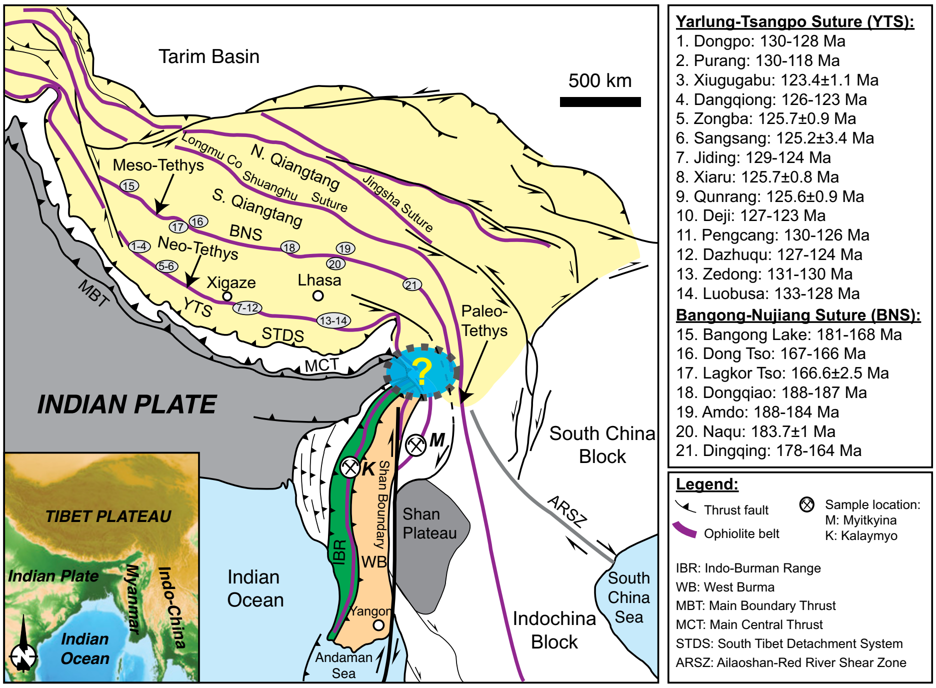

Figure 1. Ophiolite belts in the Tibetan Plateau and southeastern Asia. Ages of ophiolites along the Yarlung-Tsangpo and Bangong-Nujiang sutures are compiled in Table DR6 (see footnote 1).

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[1] GSA Data Repository item 2016093, Figures DR1–DR6 and Tables DR1–DR6, is available online at www.geosociety.org/pubs/ft2016.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

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OPHIOLITES IN MYANMAR

The major tectonic units of Myanmar are an eastern province in the Shan Plateau, which is part of the Sibumasu block, and a western province called the west Burma block. These two provinces are bound by discontinuous ophiolites that have been traditionally classified into the Western Belt and the Eastern Belt (Fig. 1; Fig. DR1). The Western Belt roughly follows the trend of the eastern Indo-Burma Range (IBR), and crops out best in the Chin Hills and Naga Hills. The Eastern Belt is east of the IBR and mainly occurs in northern Myanmar, and includes the Jade Mines and Tagaung-Myitkyina belts (Mitchell, 1993).

The Myitkyina ophiolite in the Eastern Belt has been dated by the zircon U-Pb method, yielding Jurassic ages of 176–166 Ma (Yang et al., 2012). For ophiolites in the Western Belt, zircon U-Pb ages are absent, and only K-Ar ages have been reported for a hornblende pegmatite intruding serpentinites in the Chin Hill ophiolite (158 ± 20 Ma; Mitchell, 1981) and a basalt juxtaposed with cherts in the Naga Hill ophiolite (148 ± 4 Ma; Sarkar et al., 1996). Moreover, Late Jurassic (i.e., Kimmeridgian–early Tithonian) radiolaria ages were obtained for cherts from the Naga Hill ophiolite (Baxter et al., 2011), broadly coeval to the Late Jurassic (i.e., middle–late Tithonian) radiolaria ages reported for cherts in the Myitkyina ophiolite (Maung et al., 2014). Samples in this study were collected from the Myitkyina ophiolite of the Eastern Belt and the Kalaymyo ophiolite of the Western Belt.

SAMPLES AND METHODS

Analytical methods and results are given in Tables DR1–DR6. Three samples, including two rodingites and a plagioclase amphibolite, from the Kalaymyo ophiolite were dated (Fig. DR2). The rodingites (13MD16 and 13MD17) occur as irregular pods within serpentinites, and the amphibolite (13MD42) was collected from the amphibolitic metamorphic sole beneath the Webula ultramafic massif. The rodingites are characterized by high CaO (22–24 wt%) and low alkali ($Na_2O + K_2O < 0.2$ wt%) contents (Fig. DR3a). Sample 13MD16 has a relatively flat rare earth element (REE) pattern and is depleted in most large ion lithophile elements (LILE; Figs. DR3b and DR3c). It displays a positive Sr anomaly and negative Eu, Ti, and K anomalies. Sample 13MD17 has a light (L) REE–enriched pattern, and displays positive Eu, Zr, and Hf anomalies and a negative Sr anomaly. In comparison, the amphibolite (13MD42) has a flat REE pattern with slight depletion in LREEs. It is strongly enriched in LILEs and displays an apparent positive K anomaly.

Dated samples from the Myitkyina ophiolite (Fig. DR2) include two diorites (13MD345 and 13MD351) and a gabbro (13MD345). The diorites, compositionally similar to oceanic plagiogranites (Coleman and Peterman, 1975), contain 57–60 wt% SiO_2, 1.3–7.7 wt% Na_2O, and 0.6–0.7 wt% K_2O (Fig. DR3a). They are enriched in LREEs and LILEs, with positive Eu and Sr anomalies (Figs. DR3b and DR3c). The gabbro contains 46.05 wt% SiO_2 and 6.72 wt% MgO. It displays an REE pattern similar to that of the diorites, but has much lower REE contents than the latter. It shows a negative Ti anomaly and positive anomalies in Zr, Hf, and Sr.

ZIRCON DATA

Zircons from two Kalaymyo rodingites show obvious oscillatory zoning (Fig. DR4); they contain 24–232 ppm U and 3–93 ppm Th, with Th/U ratios of 0.14–0.45 (Fig. DR5). Two rodingites, 13MD16 and 13MD17, have similar ages of 126.6 ± 1.0 Ma and 125.8 ± 1.7 Ma, respectively (Fig. 2A). They have highly depleted Hf isotopes, with $\varepsilon_{Hf}(t)$ values of +18.4 to +18.9 (Fig. 2B), and identical $\delta^{18}O$ values of 5.66‰–5.72‰, similar to the mantle values (i.e., 5.3‰ ± 0.6‰; Valley, 2003). Zircons from the Kalaymyo amphibolite (13MD42) show a round shape and weak sector zoning. They have high U (74–523 ppm) and low Th (2–12 ppm) contents and very low Th/U ratios of <0.05. Compared to the rodingites, the amphibolite has younger age of 114.7 ± 1.4 Ma (Fig. 2A), remarkably higher zircon $\delta^{18}O$ values (8.11‰ ± 0.27‰), and slightly lower $\varepsilon_{Hf}(t)$ values (+14.2 ± 2.4).

Zircons from the Myitkyina gabbro and diorites display obvious oscillatory zoning (Fig. DR4). They have variable U (32–1210 ppm) and Th (9–470 ppm) contents, but a limited range of Th/U (0.23–0.76; Fig. DR5). Three samples have identical U-Pb ages within error (Fig. 2A), i.e., 172.8 ± 2.2 Ma (13MD345), 171.6 ± 1.5 Ma (13MD351), and 173.0 ± 1.5 Ma (13MD360). They have mantle-like $\delta^{18}O$ values of 4.8‰–5.1‰ and $\varepsilon_{Hf}(t)$ values of +16.7 to +17.9 that are similarly depleted as the Kalaymyo rodingites (Fig. 2B).

DISCUSSION

Age of the Myitkyina Ophiolite

Both gabbroic and felsic intrusions are common in peridotites of the Myitkyina ophiolite. The Myitkyina diorites with K_2O contents <1 wt% are compositionally similar to oceanic plagiogranites (Coleman and Peterman, 1975). Plagiogranites are frequent targets for dating ages of the ophiolites, and their genesis has been ascribed primarily to either extreme fractional crystallization of basaltic melts (Coleman and Peterman, 1975; Kakar et al., 2012) or melting of hydrated mafic crust (Koepke et al., 2004). The TiO_2 contents of Myitkyina plagiogranites (<1 wt%) are lower than the minimum values obtained from all experiments on tholeiitic mid-oceanic ridge basalt (MORB) differentiation (Koepke et al., 2004), indicating their formation probably through melting of hydrated mafic rocks.

However, the analyzed Myitkyina plagiogranites and gabbro have similar REE patterns and identical zircon U-Pb ages within error. Moreover, zircons of plagiogranites have highly depleted Hf isotopes and mantle-like oxygen isotopes (Fig. 2B), providing no indication of involvement of altered rocks or seawater in their formation (Grimes et al., 2013). This argues

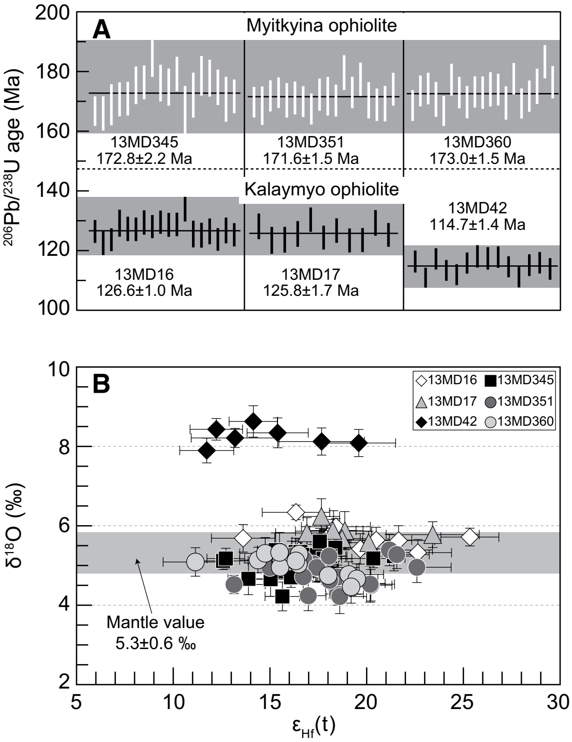

Figure 2. A: Zircon $^{206}Pb/^{238}U$ ages of Myanmar ophiolites. B: Hf-O isotopes. Mantle values are from Valley (2003).

against their formation via melting of hydrated mafic rocks and favors the process of extreme fractionation of basaltic melts that occurred during the ophiolite genesis. Our zircon U-Pb ages (ca. 173–171 Ma) are similar to ages previously reported for different lithologies (e.g., andesitic basalt, leucogabbro, and plagiogranite) of the Myitkyina ophiolite, i.e., 176–166 Ma (Yang et al., 2012), and slightly older than the radiolaria age (i.e., Late Jurassic) of cherts (Maung et al., 2014). Therefore, the Myitkyina ophiolite was formed during the Middle Jurassic.

Age of the Kalaymyo Ophiolite

Rodingites can be transformed from either mafic or felsic rocks via interaction with high-Ca and low-Si fluids released during serpentinization of peridotites. Two Kalaymyo rodingites occur as irregular pods within serpentinites and share similar features of high CaO and low Na_2O contents. Nevertheless, they have different SiO_2 contents and display distinct REE patterns, suggesting their formation from different protoliths. Rodingite 13MD17 displays an enriched REE pattern similar to that of the Myitkyina diorites, and thus was probably transformed from a dioritic protolith. Another rodingite, 13MD16, with a flat REE pattern and a remarkable negative Eu anomaly, could be produced from a mafic protolith.

Hydrothermal zircons precipitated from the fluids during rodingization show features distinct from magmatic zircons. They are typically round or ovoid, and exhibit surface etching or pitting (Hoskin and Schaltegger, 2003). They commonly display spongy or stringer textures due to a high frequency of fluid inclusions (Rubin et al., 1989). They also contain high common Pb and have low Th/U ratios (i.e., <0.07) due to the low partition coefficient of Th in fluids (Rubatto, 2002). Nevertheless, zircons of the Kalaymyo rodingites display euhedral and tabular shapes, with no obvious fluid inclusions (Fig. DR4). Their Th/U ratios (0.14–0.41) are higher than the typical values of hydrothermal zircons. They have mantle-like $\delta^{18}O$ values and highly depleted Hf isotopes, with $\varepsilon_{Hf}(t)$ values ~+18. All these features support that zircons of the Kalaymyo rodingites are of magmatic origin rather than hydrothermal origin. Almost all analytical spots of these two rodingites plot on the U-Pb concordia (Fig. DR6), indicating that the U-Pb isotope system of zircon was not significantly disturbed by rodingitization. Zircon U-Pb ages of rodingites thus represent the crystallization ages of their protoliths intruding the mantle peridotites, and suggest that the Kalaymyo ophiolite was formed during the Early Cretaceous, i.e., ca. 125 ± 2 Ma. This age is younger than the K-Ar ages previously reported for a hornblende pegmatite intruding serpentinites in the Chin Hill ophiolite (i.e., 158 ± 20 Ma; Mitchell, 1981) and an ophiolitic basalt juxtaposed with cherts in the Naga Hill ophiolite (i.e., 148 ± 4 Ma; Sarkar et al., 1996). It is also clearly younger than the Late Jurassic (i.e., Kimmeridgian–early Tithonian) radiolaria ages reported for cherts from the Naga Hill ophiolite (Baxter et al., 2011).

Plagioclase amphibolites underlying the ultramafic massif of the Kalaymyo ophiolite represent the subophiolitic metamorphic sole that is commonly formed at the inception of intraoceanic subduction (Wakabayashi and Dilek, 2000). The Kalaymyo amphibolite displays a flat REE pattern and is slightly depleted in LREEs. Zircons from this sample are of metamorphic origin, as they have low Th contents and low Th/U ratios of ~0.03. They have depleted Hf isotopes [$\varepsilon_{Hf}(t)$ of ~+14], and $\delta^{18}O$ values of 8.11‰ ± 0.27‰, remarkably higher than the mantle values (Fig. 2B). These features indicate that zircons in the plagioclase amphibolite were formed during metamorphism of a MORB-like protolith that had undergone low-temperature alteration. They record a ca. 115 Ma metamorphic event that we attribute to ophiolite emplacement; i.e., the Kalaymyo ophiolite was emplaced ~10 m.y. later after its formation. Such a temporal relationship of the ophiolite-sole pair is consistent with the observations from global ophiolites (Wakabayashi and Dilek, 2000).

Relationship to the Tibetan Sutures

It is debated whether two ophiolite belts within Myanmar belong to a single suture, and their relationship with sutures in the Tibetan Plateau is not clear (Mitchell, 1993; Sengör et al., 1988). Zircon U-Pb ages of the Kalaymyo and Myitkyina ophiolites suggest that the Eastern Belt in Myanmar was formed in the Middle Jurassic, whereas the Western Belt was generated during the Early Cretaceous. Such a temporal framework suggests that these two belts represent two different sutures (Sengör et al., 1988), and does not favor the proposal that both belts belong to a single suture connecting the Yarlung-Tsangpo suture (YTS) in the Tibetan Plateau (Mitchell, 1993; Yang et al., 2012). This conclusion is supported by studies of mantle peridotites from two belts that indicate a mid-ocean ridge setting of the Kalyamyo ophiolite and a suprasubduction zone affinity of the Myitkyina ophiolite (Chuan-Zhou Liu's unpublished data).

The Jurassic Myitkyina ophiolite has been regarded as the eastern continuation of the YTS (Yang et al., 2012), as similar ages have been reported for ophiolites that crop out at the eastern segment of the YTS (Zhong et al., 2006). Previous studies have shown that ophiolites found at both the western and central segments of the YTS were formed during the Early Cretaceous (Fig. 3; Table DR6), whereas ophiolites in the eastern segment (e.g., Luobusa) have relatively older ages of Middle to Late Jurassic (Zhong et al., 2006). Recently, more precise U-Pb ages of ca. 134–128 Ma have been obtained for both zircons and titanites in different lithologies (e.g., gabbros and plagiogranites) that crop out in the Luobusa (Zhang et al., 2016) and Zedong ophiolites (Table DR6). This suggests that the ophiolites found along the entire YTS formed during Early Cretaceous, and are coeval with the Kalaymyo ophiolite. Therefore, the YTS connects with the Western Belt in Myanmar, and represents fragments of the Neo-Tethys Ocean lithosphere.

However, the Jurassic age of the Myitkyina ophiolite is similar to ophiolites along the Bangong-Nujian suture (Fig. 3). This suggests that the Eastern Belt in Myanmar represents the southern continuation of the Bangong-Nujian suture, which corresponds to the suture of the Meso-Tethys that opened in the middle Permian as the Cimmerian continental silvers separated from northern Gondwana (Metcalfe, 1996). The southward continuation of this belt in Myanmar remains unclear. A candidate is the cryptic suture, i.e., the so-called Medial suture zone west of the Shan Plateau (Mitchell et al., 2015).

BROADER IMPLICATIONS

Our results show that the Neo-Tethyan ophiolites crop out in a prolonged suture >3000 km extending from southern Tibet to western Myanmar (Fig. 1), within which all ophiolites were formed broadly coevally ca. 130–120 Ma in the

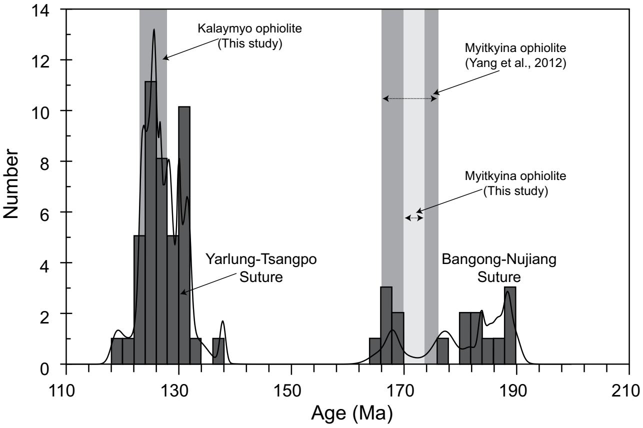

Figure 3. Comparison of zircon U-Pb ages of ophiolites in Tibetan Plateau and Myanmar.

Early Cretaceous (Fig. 3). Ophiolites with a limited range of ages are not unique in the Neo-Tethyan suture, as ophiolites found along the North American Cordillera have Middle Jurassic ages of ca. 168–161 Ma (Hopson et al., 2008). However, the Neo-Tethyan ophiolites in Tibet and Myanmar are remarkably older than other Neo-Tethyan ophiolites exposed to the west in Muslim Bagh, Pakistan (ca. 85 Ma; Kakar et al., 2012) and to the east in the Andaman Islands (ca. 95 Ma; Pedersen et al., 2010). The reason for the difference remains unclear and further studies are needed.

Moreover, our results clarify the controversy regarding the timing when west Burma rifted from Gondwana and collided later with Sibumasu. A popular view is that the west Burma block has a Cathaysian affinity (Thura Oo et al., 2002) and was accreted to south China as part of Indochina, followed by strike-slip emplacement on the western margin of the Sibumasu block during the Triassic (Barber and Crow, 2009). In this model, the boundary between Sibumasu and west Burma has been interpreted as a major transcurrent shear zone. Our study does not support this argument, but suggests the existence of a Jurassic suture represented by the Myitkyina ophiolite between the Sibumasu and west Burma blocks. These two blocks, in our view, were separated by the Meso-Tethys Ocean until west Burma accreted onto the western margin of Sibumasu; this must have occurred after the Middle Jurassic. This is consistent with the alternative model that west Burma was separated from Gondwana along with opening of the Neo-Tethys Ocean in the Late Triassic, and eventually accreted to the western margin of Sibumasu in the Cretaceous (Metcalfe, 1996).

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