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Editorial

Intra-Oceanic Subduction Termination and Reinitiation of the Eastern Neo-Tethys in Myanmar

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Subduction initiation and termination represent the birth and death of a subduction zone and are inevitable elements of terrestrial plate tectonics. Increasing evidence demonstrates that subduction zone processes did not operate continuously and might involve multiple initiation and termination stages (Stern, 2004), characterized by sustained subduction-zone death and rebirth. Many geological and numerical studies focus on subduction initiation processes/mechanisms (see reviews in Yang, 2022); however, subduction termination is often studied numerically at continental margins (Gerya, 2022). How subduction termination proceeds in intra-oceanic settings remains enigmatic due to lacking geological records.

1 SUBDUCTION TERMINATION AND REINITIATION IN MYANMAR TETHYS

Myanmar, the eastern prolongation of the Himalayan orogenic system (Figure 1a), includes four tectonic units from east to west: the Indo-Burma Range, the West Burma Block, the Mogok metamorphic belt, and the Shan Plateau (Mitchell et al., 2012). Three north-south tending ophiolite belts occur along the boundaries between these units (the western and eastern ophiolite belts, referring to WOB and EOB), or within the West Burma Block (the central ophiolite belt, COB) (Htay et al., 2017) (Figure 1a). These ophiolite belts were confirmed to record the Neo-Tethyan subduction processes. The EOB (Myitkyina ophiolite belt) was formed during the Middle Jurassic (176–166 Ma; Figure 1b; Xu et al., 2017; Liu et al., 2016a, b; Yang et al., 2012) and represented a suture zone along the southern Eurasian (Sibumasu) margin (Liu et al., 2016a). Paleogeographic and petrological studies indicate that the West Burma Block was a Cretaceous intra-Tethyan arc (Licht et al., 2020; Westerweel et al., 2019). The WOB (Nagaland-Manipur-Kalaymyo ophiolite belt) along the western boundary of the West Burma Block has crustal rocks formed in the Early Cretaceous (127–115 Ma; Figure 1b; Singh et al., 2017; Zhang et al., 2017; Liu et al., 2016a) and thus likely represents an intra-oceanic suture zone of the eastern Neo-Tethys. The COB (Indawgyi ophiolite belt) has both the Jurassic (ca. 169 Ma, Searle et al., 2023) and Early Cretaceous (ca. 120 Ma, Zhang et al., 2024) gabbroic crusts (Figure 1b). However, high-pressure rocks (blueschists and eclogites) occur both in the WOB and COB but are absent in the EOB (Rajkakati et al., 2019; Htay et al., 2017; Searle et al., 2017). In addition, the West Burma arc volcanics are dominated by tholeiitic basalts and basaltic andesites with depleted to slightly enriched Sr-Nd isotope signatures (Zhang et al., 2022; Li et al., 2020), different from the magmatic arc rocks along the EOB that show more enriched isotopic compositions (Zhang et al., 2018; Xu et al., 2017; Yang et al., 2012). Therefore, the COB might have once connected with the WOB before the strike-slip movement of the Sagaing fault (Zhang et al., 2024). In this regard, the eastern Neo-Tethys has two subduction-zone systems: an eastern zone at the southern Sibumasu margin and a western one within the Neo-Tethys Ocean. This double subduction system of the eastern Neo-Tethys was confirmed by seismic observations that show two parallel, east-dipping, high-velocity slab remnants beneath the West Burma Block and Shan Plateau (Figure 1c) (Yang et al., 2022).

The western, intra-oceanic subduction zone preserves rare pre-Cretaceous records. The ca. 189–185 Ma Nagaland eclogites in the WOB show peak conditions of 2.5–2.8 GPa and ~650 °C with a low apparent peak thermal gradient of ~7–8 °C/km (Rajkakati et al., 2019), corresponding to cold subduction of the eastern Neo-Tethys. Myanmar jadeitite, a typical high-pressure and low-temperature (1.0–1.5 GPa, 350–500 °C) metamorphic rock in the north COB (Jade Mines, Figure 1a), documents oceanic slab-derived fluids at forearc depths (Chen et al., 2018). Although its formation age is debated, metamorphic zircon U-Pb ages of 158–147 Ma (Qiu et al., 2009; Shi et al., 2009, 2008) suggest that jadeititic fluids had already been derived from the subducted Neo-Tethyan slab during the Jurassic. The $^{40}Ar/^{39}Ar$ age (ca. 152 Ma) of glaucophane from a blueschist in Jade Mines (Shi et al., 2014) also confirms the Jurassic subduction. The oldest magmatic age in the COB is recorded in a gabbro sample from Indawgyi, dated at ca. 169 Ma (Searle et al., 2023). Due to lacking geochemical data, it is hard to conclude that this gabbro represents a Jurassic arc remnant or oceanic crust. However, the presence of Jurassic oceanic eclogites, blueschist, and jadeitites at least implies that

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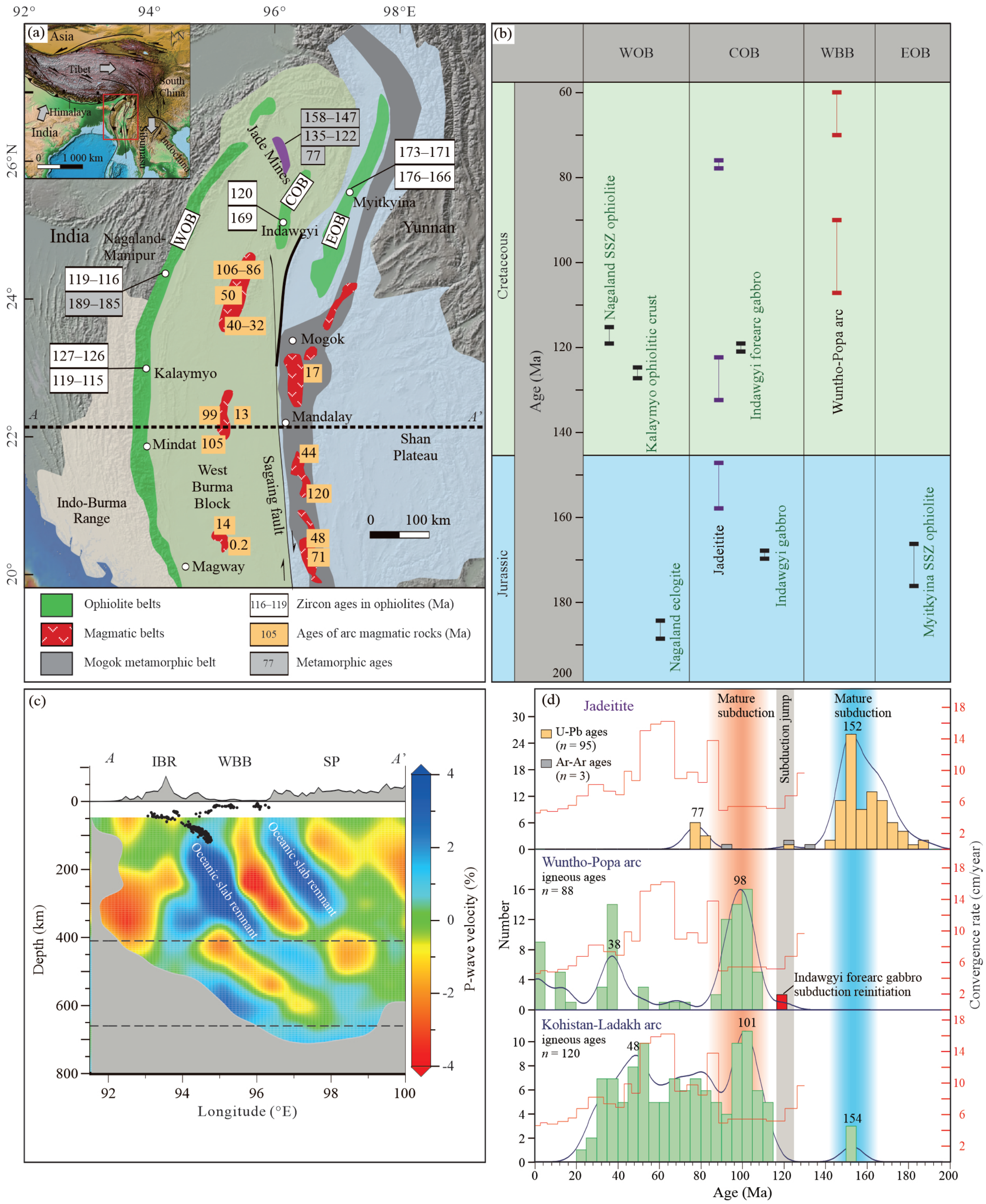

Figure 1. (a) Geological sketch map of Myanmar showing major units and ages of ophiolite, magmatic arc, and high-pressure metamorphic rocks. WOB. Western ophiolite belt; COB. central ophiolite belt; EOB. eastern ophiolite belt; the thick dashed line *AA'* marks the location of the cross section presented in (c). (b) Age framework of three ophiolite belts and arc magmatism in the West Burma Block (WBB), see text for details. (c) Tomographic model of P-wave velocity modified after Yang et al. (2022). IBR. Indo-Burma Range; SP. Shan Plateau. (d) Age distribution of the Myanmar jadeitites (only metamorphic ages, Qi et al., 2014, 2013; Yui et al., 2013; Qiu et al., 2009; Shi et al., 2008), Wuntho-Popa arc in the WBB (Zhang et al., 2022; Licht et al., 2020), Indawgyi forearc gabbro (Zhang et al., 2024), and Kohistan-Ladakh arc (Jagoutz et al., 2019). The convergence rate of India-Asia (van Hinsbergen et al., 2011) is shown as the red line curve.

the intra-oceanic Neo-Tethyan subduction readily entered a mature stage at that time (Figures 1d, 2a). Such a mature subduction of the Neo-Tethyan slab would continuously release fluids into the mantle wedge and might generate a Jurassic island arc (Figure 2a), although further geological arguments are needed. However, the Manipur gabbros and plagiogranites in the WOB supra-subduction zone (SSZ) ophiolite (119–116 Ma, Aitchison et al., 2019; Singh et al., 2017), the Kalaymyo amphibolitefacies metamorphic sole (119–115 Ma, Zhang et al., 2017; Liu et al., 2016a) in the WOB, and the Indawgyi forearc gabbro in the COB (ca. 120 Ma, Zhang et al., 2024) all reflect the intra-oceanic Neo-Tethyan subduction system re-initiated during the Early Cretaceous. Thus, this subduction zone must be inhibited and restarted again in the Early Cretaceous. The intra-oceanic subduction termination could explain the magmatic lull of the Wuntho-Popa arc and the Kohistan-Ladakh arc and the sharp decrease of the India-Asia convergence rate during 130–120 Ma (Figure 1d). The precise timing of the subduction termination is hard to determine; however, the rarely preserved zircon U-Pb ages of ca. 122 Ma (Shi et al., 2008) and the jadeite $^{40}Ar/^{39}Ar$ age of ca. 124 Ma (Qi et al., 2013) in jadeitites suggest that slab-derived fluids were still active at that time. Therefore, the time lag from subduction termination to reinitiation in the eastern Neo-Tethys appears to be less than 2–4 Myr.

2 DYNAMIC MECHANISM

Within an intra-oceanic subduction system, subduction termination requires a loss of slab pull (e.g., oceanic slab breakoff) or a thick, buoyant block (oceanic plateau or microcontinent) clogged at the convergent margin that would mitigate the ongoing subduction. The following sections will discuss these potential mechanisms responsible for the Neo-Tethyan subduction termination and reinitiation.

2.1 Shallow Slab Breakoff?

Slab breakoff is a common subduction zone process and could occur within the oceanic lithosphere (Duretz et al., 2011), continent-ocean transition zone (Magni et al., 2017), or continental lithosphere (Freeburn et al., 2017). As the Myanmar jadeitites and the Cretaceous Wuntho-Popa arc rocks show depleted Sr-Nd-Hf isotope signatures (Lee et al., 2016; Wang et al., 2014; Shi et al., 2009), no evidence supports the recycling of isotopically enriched continental materials beneath the West Burma Block during the Early Cretaceous. Thus, the latter two cases related to continental crust subduction are not considered here. The intra-oceanic subduction termination requires shallow breakoff to remove the negative buoyancy of the subducting Neo-Tethyan slab; otherwise, the rest slab after deep breakoff would be continuously subducted due to the oceanic crustal eclogitization. The rest oceanic slab subject to shallow breakoff might have rebounded and finally stopped to be subducted or shifted to a slow flat subduction (van Hinsbergen et al., 2015). Then, the oceanic subduction restarted at pre-existing weak zones with a far-field pushing force, such as a contemporary mantle plume (van Hinsbergen et al., 2021) or spreading ridge (Zhu et al., 2023). However, based on the following arguments, this scenario is unlikely to occur at 130–120 Ma. (1) Shallow slab breakoff can trigger significant magmatism (Freeburn et al., 2017) and high-temperature metamorphism (Zhang et al., 2019) at convergent margins, both of which are not observed in the Indo-Burma Range and West Burma Block (Figure 1d). (2) Shallow breakoff commonly involves a weak, young slab and fast plastic yielding (Duretz et al., 2011; Andrews and Bellen, 2009), leading to hot subduction that cannot generate low-temperature/high-pressure jadeitites in the forearc region (Chen et al., 2018).

2.2 Oceanic Plateau Accretion?

The subduction termination and reinitiation of the eastern Neo-Tethys may be explained by oceanic plateau-induced subduction jump, a process numerically proved to occur at continental margins (Riel et al., 2023; Yan et al., 2021) or within intra-oceanic settings (Sun et al., 2023). A weak, thick oceanic plateau may accrete to the trench, resulting in the cessation of subduction and generating a new subduction zone behind the plateau (Sun et al., 2023). The intra-oceanic subduction jump induced by oceanic plateau accretion is well documented in the Mussau Trench in the western Pacific, which was generated by the collision of the Caroline Plateau with the Yap Trench (Cloetingh et al., 2021). In that case, the time lag between termination and initiation is less than 1 Ma (Zahirovic et al., 2014), broadly comparable with that of the eastern Neo-Tethys in Myanmar. Ocean island basalts (OIBs), typical crustal rocks of oceanic plateaus, indeed have been found in the Manipur ophiolite in the WOB (Khogenkumar et al., 2016), but their formation age is unclear. Furthermore, this subduction jump model requires a mantle plume located between the north margin of Greater India (~30° S, Morley et al., 2020) and the West Burma Block (~5°S, Westerweel et al., 2019) during (or before) the Early Cretaceous. At that time, however, the paleo-positions of mantle plumes in the southern hemisphere (~32° S–55° S) lied within Gondwana and triggered the breakup of India from Antarctica-Australia (Torsvik, 2019), which cannot form an oceanic plateau in the eastern Neo-Tethys. A recent numerical study on intra-oceanic subduction jump required a plateau width of up to 500 km (Sun et al., 2023). This size may be impossible for the Myanmar case because only scarce OIB-type mafic rocks have been found in the WOB. Future work can test this model's validity through discovering Early Cretaceous–Jurassic OIBs and revealing other factors that govern plateau-induced subduction jumps.

2.3 Microcontinent Triggers Intra-Oceanic Subduction Jump

Subduction jump in the eastern Neo-Tethys is more likely triggered by microcontinent collision. Numerical studies often test this type of subduction jump at continental margins (Yan et al., 2024; Zhong and Li, 2020), which repeatedly occurred in the Tethyan realm. Microcontinent collided with the trench or a pre-existing intra-oceanic arc may also inhibit the ongoing oceanic subduction and generate a new subduction zone at the neighboring passive margin (Figures 2b–2c). The microcontinent relics can be seen from the Pane Chaung Formation and Kanpetlet schists in the Indo-Burma Range, underlying ophiolitic mantle rocks (Yao et al., 2017; Sevastjanova et al., 2016). The Pane Chaung Formation and Kanpetlet schists occasionally outcrop in Kalay, Mindat, and Magway (Yao et al., 2017; Zhang et al., 2017), and tectonically contact to the west of the Kalaymyo ophiolite (Yao et al., 2017), indicating that they may belong to other continental fragments, not West Burma Block. The Pane Chaung Formation comprises turbiditic sandstone and shale with rare limestone (Mitchell et al., 2010). The detrital zircons from the turbidites and *Halobia* fossils in the Pane Chaung Formation are distinct from similar aged strata in Indochina and Sibumasu, but comparable to NW Australia or Great India (Yao et al., 2017). In addition, the Pane Chaung Formation is sealed

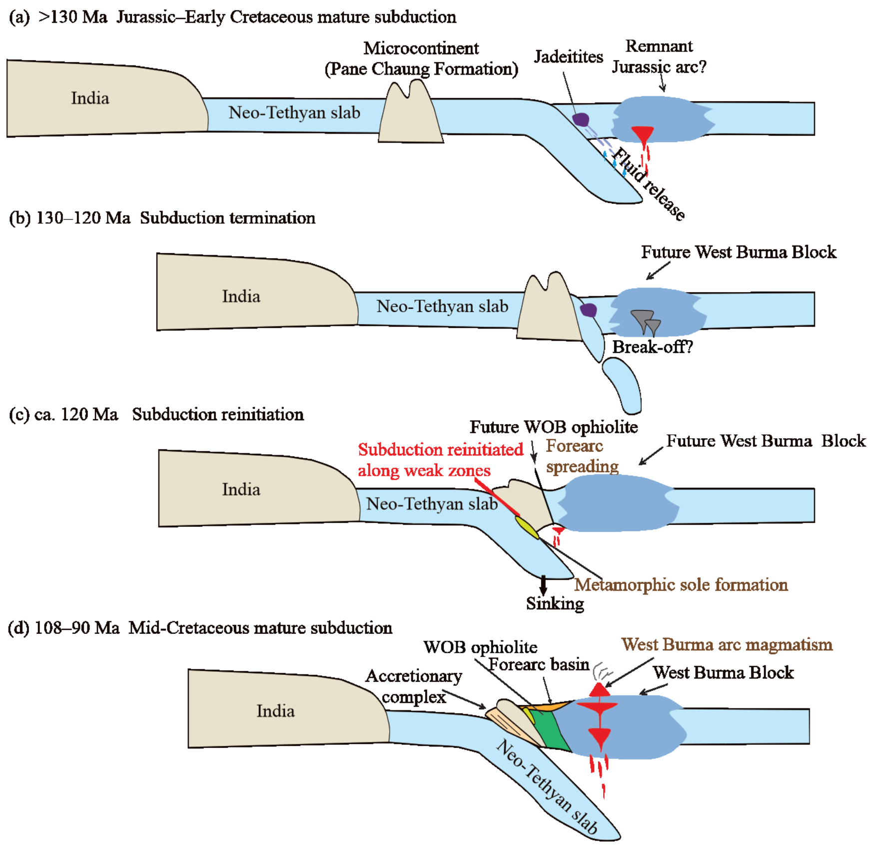

Figure 2. Tectonic model (not to scale) showing the intra-oceanic subduction processes of the eastern Neo-Tethys.

by Cretaceous unconformities, arguing against the origin of part of the Indian continental margin (Mitchell et al., 2010). All these results indicate that the Pane Chaung Formation was originally deposited and rifted as a microcontinent from the northern margin of Australia or India, and then collided with the West Burma Block (Morley et al., 2020). The collision time between this allochthonous microcontinent and the West Burma Block is still uncertain. It could likely be revealed by the metamorphism of the underlying Kanpetlet schists, which possibly occurred between the Jurassic and Mid-Cretaceous (Morley et al., 2020). We suggest that the Pane Chaung Formation met with the West Burma Block during the Early Cretaceous (ca. 120 Ma), leading to a subduction jump, the subsequent overriding plate extension and ophiolite emplacement. This scenario can explain (1) the presence of the Pane Chaung Formation in the footwall of ophiolites (Morley et al., 2020; Yao et al., 2017), (2) the emplacement of the WOB ophiolite at 119–115 Ma (Zhang et al., 2017; Liu et al., 2016a), and (3) the eastern Neo-Tethyan subduction termination and reinitiation (Figure 2). The fast convergence rate of India-Asia during 130–120 Ma (Figure 1d) would facilitate the quick transition (<4 Ma) from collision to subduction reinitiation (Yan et al., 2024), although further numerical simulations are needed for intra-oceanic settings. After the reinitiation, the Neo-Tethyan subduction would enter into a steady-state, mature stage that led to formation of the Mid-Cretaceous West Burma arc magmatism (Figure 2d).

3 BROAD IMPLICATIONS

This study proposes a new tectonic model that well explains a quick transition from subduction termination to reinitiation in the eastern Neo-Tethys in Myanmar, based on available geological data and modeling results. Our results also provide a new insight into the origin of intra-oceanic arcs. The intra-oceanic arcs along the western Pacific Ocean occasionally have refractory mantle peridotite with old Re-depletion model ages (Parkinson et al., 1998) and Precambrian crustal zircons in their basement (Buys et al., 2014; Tapster et al., 2014), interpreted to be microcontinents rifted from Australia or Asia which suffered extensive reworking by back-arc spreading and sustained arc magmatism (Wu et al., 2019). The microcontinent-induced subduction jump highlighted in this study can explain why these ancient continental materials occur in the intra-oceanic arcs and SSZ ophiolitic mantle. The microcontinents rifted from Australia would move northward and potentially collide with intra-oceanic arcs, forming new basements for the arcs. The emplacement of SSZ ophiolites and subsequent arc magmatism can potentially capture the continental materials. Any new model for forming intra-oceanic arcs and subduction jumps needs to consider the effect of microcontinent collision.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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