

Unveiling of a trans-oceanic arc system diachronous initiation: Easternmost Neo-Tethyan intra-oceanic subduction record from Bornean peridotite

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Abstract

Reconstructing the initiation and evolution of intra-oceanic subduction is fundamental to understanding plate convergence, crustal growth and paleogeographic evolution. The easternmost Neo-Tethys remains a key gap in global reconstructions, as direct mantle evidence for subduction initiation has been lacking. Here we identify two geochemically distinct mantle suites (abyssal vs. fore-arc affinities) from the Meratus Complex in southeastern Borneo that record the initiation of an intra-oceanic subduction system. **Group 1** peridotites exhibit abyssal peridotite affinities, reflecting ~8–12% partial melting of depleted mid-ocean ridge mantle (DMM) followed by limited silicate melt-rock interaction. **Group 2** peridotites, by contrast, reflect a highly depleted fore-arc mantle origin and metasomatism by hydrous boninitic melts. Integrated with regional fore-arc basalts, adakite, and island arc suites, the Meratus assemblage preserves a complete sequence from subduction initiation to mature arc development, analogous to the Izu-Bonin-Mariana system. Synthesis of geochronological data across the Neo-Tethyan suture demonstrates that intra-oceanic subduction initiated diachronously—earlier in the east and progressively later westward—forming a > 8,000-km arc system by Late Cretaceous, with the Meratus Complex marking its easternmost terminus. These findings place constraints on the eastern extent of the Neo-Tethys with implications for models of Mesozoic global plate reorganization.

Introduction

Understanding how intra-oceanic subduction zones initiate and evolve is fundamental to decipher plate convergence, net crustal growth, and paleogeographic reconstruction (1–3). The Izu-Bonin-Mariana (IBM) arc provides the modern archetype: subduction onset generates fore-arc basalts (FAB), followed by boninites and ultimately low-K tholeiitic to calc-alkaline suites as the arc matures (4, 5). This geochemical progression—from MORB-like FAB through boninitic magmatism to mature arc lithologies—provides diagnostic constraints on the timing, polarity and accretionary dynamics of intra-oceanic subduction (4–6). Recognition of this sequence in ancient accretionary complexes therefore offers a robust framework for reconstructing the evolution of paleo-ocean basins (6), yet well-preserved mantle records of subduction initiation remain rare in orogenic belts worldwide.

During the Cretaceous to early Paleogene, multiple subduction systems developed within the Neo-Tethys, including a northward-dipping margin beneath southern Eurasia (7), and a separate intra-oceanic subduction system within the Neo-Tethys ocean (Fig. 1) (2). This system has been traced from southern Turkey to the Woyla arc in Sumatra, but its eastward extent and termination remains unconstrained (Fig. 1) (1, 8). The timing and polarity of Neo-Tethys intra-oceanic subduction also remain debated: most studies favour northward-dipping subduction during the Late Mesozoic (1, 2), although southward subduction has been documented in west Sumatra during the Early Cretaceous (1). A set of outstanding questions remain: where was the easternmost terminus of Neo-Tethys intra-oceanic subduction system, when did subduction initiate, and what geodynamic processes governed its evolution? Addressing these questions has been hindered by a lack of direct mantle evidence for subduction initiation in the easternmost segments of the suture.

The Meratus Complex in southeastern Borneo occupies a critical tectonic position at the inferred easternmost margin of the Neo-Tethys, comprises a Jurassic–Cretaceous subduction–accretion assemblage (Fig. 1) (9–13). Diverse lithologies record a long-lived northward subduction–accretion history of the Neo-Tethys oceanic plate (Fig. 2) (10–13). The absence of terrigenous sediments in the Pulau Laut mélange (Fig. 2c) has been interpreted as circumstantial evidence for an intra-oceanic setting (10). However, direct petrological evidence for a coeval intra-oceanic arc—and particularly for the subduction initiation stage, recorded in mantle peridotites—has remained elusive. The evolutionary pathway of this system from subduction onset to arc maturation therefore remains poorly constrained, and its position in the broader Neo-Tethyan framework remains speculative.

Mantle peridotites are sensitive recorders of melting and metasomatic processes, and their mineral and bulk compositions can distinguish mid-ocean ridge, fore-arc and subduction-related mantle environments (14, 15). Here we present new whole-rock and in-situ mineral geochemical data for peridotites from the Meratus Complex to test for diagnostic geochemical signatures of intra-oceanic subduction initiation. We identify two geochemically distinct mantle suites—abyssal and fore-arc affinities—that record the inception and progressive evolution of an intra-oceanic subduction system. When integrated with published data on regional volcanic and plutonic rocks, our findings demonstrate that the Meratus Complex preserves a complete tectono-magmatic sequence from subduction initiation to mature arc development. Compilation of geochronological data across the entire Neo-Tethyan suture further reveals that intra-oceanic subduction initiated diachronously—earlier in the east and progressively later westward—with the Meratus Complex marking the easternmost terminus of this > 8,000 km arc system. These results place first-order constraints on the eastern extent of the Neo-Tethys and reveal basin-width control on subduction duration timing, with broad implications for models of Mesozoic global plate reorganization.

Results and discussion

Sample description and petrography

A total of 11 samples were collected at two locations in the Meratus Complex: SK-1 and SK-4 (Fig. 2b and Supplementary Fig. S1). Based on clinopyroxene (Cpx) contents, mineral and whole-rock geochemical characteristics, the Meratus peridotites can be divided into two groups (Supplementary Table 1).

The **Group 1** peridotites that consist of serpentinized wehrlite and single specimen of serpentinite (SK-1.1) with light to dark green colors (Supplementary Fig. S1). The serpentinized wehrlite (samples SK-1.2, SK-1.6, SK-1.7) is composed of 50–60 vol% olivine, 15–20 vol% Cpx, 15–20 vol% serpentine, 2–5 vol% orthopyroxene (Opx), and < 2 vol% Cr-spinel (Supplementary Fig. S2), whereas the serpentinite SK-1.1 is dominated by serpentine (> 90 vol%), containing only minor amounts of Cr-spinel and magnetite with porphyroclastic textures (Supplementary Fig. S2).

The **Group 2** peridotites include serpentized harzburgite and serpentinite with dark green to black color (Supplementary Fig. S1). Among these rocks, samples SK-1.3, SK-1.4, and SK-4.4 are serpentinites. The serpentized harzburgite (samples SK-4.1, SK-4.2, SK-4.3, SK-4.5) consists of 40–50 vol% olivine, 20–30 vol% serpentine, 15–25 vol% Opx, 1–3 vol% Cpx, and < 2 vol% Cr-spinel (Supplementary Fig. S2). Sample SK-4.2 contains minor amphibole (Supplementary Fig. S2I). The serpentinite (SK-1.3, SK-1.4, SK-4.4) has a similar composition to that of Group 1 serpentinite (Supplementary Fig. S2).

Whole-rock geochemistry

Whole-rock major and trace elements data for the Meratus peridotites are shown in Supplementary Table 1. Both groups of peridotites exhibit relatively high loss on ignition (LOI), ranging from 6.0–17.8 wt% and 9.7–17.0 wt%, respectively (Supplementary Table 1). Given the high LOI values of most peridotites, the major element oxide contents were recalculated to anhydrous base at 100 wt%. Consequently, the Group 1 peridotites contain MgO, Al₂O₃, and CaO contents of 41.0–42.3 wt%, 1.4–2.4 wt%, and 2.0–2.8 wt%, respectively, while the Group 2 peridotites yield higher MgO contents (43.4–51.1 wt%) but lower Al₂O₃ (0.4–1.1 wt%) and CaO (0.2–1.3 wt%) values (Fig. 3a, b).

The Group 1 peridotites show slightly lower heavy rare earth elements (HREE) than the DMM, and depletion of medium and light rare earth elements relative to HREE, forming a spoon-shaped REE distribution patterns (Fig. 3c). The Group 2 peridotites exhibit a U-shaped patterns, with depletion of HREE relative to the Group 1 peridotites (Fig. 3c). Both groups of peridotites show enrichment in LILE and fluid-mobile elements (Rb, Pb, Sr, Li), while being depleted in HSFE (e.g., Nb, Ta, Ti; Fig. 3d).

Mineral chemistry

Major and trace elements data for minerals from the Meratus peridotites are presented in Supplementary Tables 2 and 3. The Cr-spinel from Group 2 peridotites exhibit high and variable Cr# values ($\text{Cr\#} = 100 \times [\text{Cr}/(\text{Cr} + \text{Al})]$) of ~ 39.5 to 80.7, but low Mg# values ($\text{Mg\#} = 100 \times [\text{Mg}/(\text{Mg} + \text{Fe}^{\text{T}})]$) of 37.9–59.8 (Fig. 4). The Group 1 peridotite olivine Fo values ($\text{Fo} = 100 \times [\text{Mg}/(\text{Mg} + \text{Fe}^{\text{T}})]$) of 88.5–90.9, while the Group 2 shows slightly higher Fo values (90.2–91.6; Fig. 4). Compared to the Cpx in the Group 1 peridotite ($\text{Mg\#} = 92.1–95.8$; Al₂O₃ = 0.93–5.67 wt%; TiO₂ = 0.07–0.30 wt%), the Cpx in the Group 2 exhibits higher Mg# values (93.4–95.3) and lower Al₂O₃ (0.13–2.62 wt%) and TiO₂ (0–0.11 wt%) contents (Fig. 4 and Supplementary Table 2). Finally, Opx in the Group 2 peridotites exhibits higher Mg# values (89.7–91.7), but lower Al₂O₃ (0.76–2.68 wt%), CaO (0.25–1.48 wt%), and TiO₂ (0–0.9 wt%) contents (Fig. 4 and Supplementary Table 2).

The Cpx in Group 1 peridotites is characterized by pronounced LREE depletion, with (Ce/Yb)_N ranging from 0.001 to 0.004, and a nearly flat medium-heavy REE distributions (Fig. 5a and Supplementary Table 3). In contrast, the Cpx in Group 2 peridotites shows rather moderate LREE depletion, with

(Ce/Yb)_N ranging from 0.015 to 0.090, and a nearly flat medium-heavy REE pattern, but overall with lower contents than that of the Group 1 peridotites (Fig. 5a and Supplementary Table 3). The Opx in Group 2 peridotites shows LREE depletion and HREE enrichment, exhibiting a left-leaning REE distribution pattern (Fig. 5b). The Cpx in Group 1 peridotites shows a silicate metasomatism trend with high Ti/Eu ratio, while Cpx in the other Group 2 peridotites has the highest Ti/Eu ratio (Fig. 5c).

Petrogenesis and tectonic affinity of the two peridotite suites

Constraining the petrogenesis of peridotites in accretionary complexes provides key insights into the evolutionary history of fossil oceans. Both peridotites groups exhibit high Mg# values, Ni, and Cr contents, consistent with residual mantle rocks rather than cumulate peridotites (16). Three lines of evidence support an abyssal peridotite affinity for Group 1: (1) Relatively fertile bulk compositions, with whole-rock Al₂O₃ and CaO contents matching typical abyssal peridotites (Fig. 3a, b); (2) HREE-enriched whole-rock REE patterns with subtle fractionation, comparable to abyssal peridotites (Fig. 3c); (3) High Al₂O₃ and TiO₂ contents in Cpx (Fig. 4) and low olivine Fo values (Supplementary Table 2), consistent with abyssal peridotites. By contrast, the Group 2 peridotites exhibit refractory characteristics: (1) Low whole-rock Al₂O₃, CaO, and HREE contents (Fig. 3); (2) High spinel Cr# and Mg#, high olivine Fo values, and low Al, Na, Ca, and Ti contents in Cpx and Opx (Fig. 4), diagnostic of—highly depleted fore-arc peridotites.

The strong correlation between La–Nb and (Gd/Lu)_N–Th suggest that the both peridotite groups experienced melt–rock reaction (Supplementary Fig. S3) (17). Group 1 peridotites record limited modification by low-degree silicate melts, as indicated by their low whole-rock Ca/Al and high whole-rock and cpx Ti/Eu ratios (Fig. 5c) (18, 19). In contrast, Group 2 peridotites exhibit stronger metasomatism by hydrous boninitic melts, reflected by elevated whole-rock and cpx Ti/Eu ratios, U-shaped REE patterns, and high Cr# spinels coupled with low TiO₂ contents (Fig. 3c and Fig. 5d) (20, 21).

Considering that silicate melt metasomatism can increase bulk-rock Al₂O₃ contents, the Al₂O₃ compositions of Group 1 and Group 2 peridotites suggest minimum melting degrees of 10–18% and 20–30%, respectively (Supplementary Fig. S4a) (22). These estimates are consistent with fractional melting modelling based on different melting modes and partition coefficients, which yields 6–10% melting for Group 1 and 18–30% for Group 2 peridotites (Supplementary Fig. S4b) (23). Furthermore, non-modal fractional melting modelling of Cpx HREE contents (24–26), using DMM compositions (27) and parameters listed in Supplementary Table 4, gives comparable estimates of ~ 8–12% and ~ 20–30% melting for Group 1 and Group 2 peridotites, respectively (Fig. 5a, b). Collectively, these results indicate that Group 2 peridotites experienced substantially higher degrees of partial melting than Group 1 peridotites.

We therefore conclude that Group 1 peridotites represent DMM-like residues after 8–12% melt extraction and limited interaction with LREE-enriched silicate melts, whereas Group 2 peridotites record highly

depleted fore-arc mantle residues formed by 20–30% melting and subsequent metasomatism by boninitic melts.

The Meratus Complex as a fossil IBM-type intra-oceanic fore-arc system

Modern intra-oceanic subduction systems, such as the IBM arc, demonstrate that ophiolitic mantle sections formed during subduction initiation commonly contain both abyssal and fore-arc peridotites (28, 29). The Meratus Complex preserves an analogous association, with Group 1 and Group 2 peridotites representing abyssal and fore-arc mantle components, respectively. Group 1 peridotites were incorporated into the fore-arc during the initial stages of subduction, whereas Group 2 peridotites formed through boninitic melt-related metasomatism within the fore-arc mantle wedge (14, 28, 30). The Meratus peridotites thus formed in a fore-arc setting above an intra-oceanic subduction zone (Fig. 6b) (31).

Four lines of evidence demonstrate that the Meratus Complex records a nearly complete evolutionary sequence from subduction initiation to mature intra-oceanic arc development: (1) MORB–arc transitional basalts with FAB-like geochemical affinities mark the earliest stage of subduction initiation (Supplementary Fig. S5) (12); (2) Group 2 peridotites record boninitic melt metasomatism, characteristic of the fore-arc mantle during early arc formation; (3) Early Cretaceous (~ 143 Ma) plagiogranites with high Sr/Y and Al₂O₃ contents (13) exhibit adakitic signatures, consistent with melting of subducted oceanic crust under eclogite-facies conditions (32); (4) tholeiitic to calc-alkaline basalts and intermediate–felsic rocks with LILE enrichment and HFSE depletion, represent mature island arc magmatism (12).

Together, these features demonstrate progressive evolution of the Meratus Complex from subduction initiation to a mature intra-oceanic arc. The combined occurrence of FAB, boninitic melt-metasomatized forearc peridotites, subduction-related plagiogranites (adakites), and island arc tholeiitic to calc-alkaline magmas establishes the Meratus Complex as a relatively well-preserved fossil IBM-type intra-oceanic arc system (4, 5).

Tectono-magmatic evolution of the Meratus subduction system

The diverse lithological assemblages and geochemical signatures of the Meratus Complex indicate formation through subduction–accretion processes in the eastern Neo-Tethys (Fig. 6 and Supplementary Table 5) (12, 33). However, the timing and evolution of Mesozoic subduction in this region remain debated. Integrating our new findings with previous work (10, 12, 13, 33), we propose a revised tectono-magmatic model for the easternmost Neo-Tethyan subduction system (Fig. 6a and 6b).

The eastern Neo-Tethys likely opened during the Late Triassic–Early Jurassic following the breakup and northward drift of the Cimmerian ribbon continent (34), as indicated by Pt–Os age of 198 ± 8 Ma for

Meratus chromite and the oldest radiolarian ages of ~ 180 Ma from associated cherts (Fig. 6c) (10, 35). Intra-oceanic subduction was initiated before 143 Ma (Fig. 6c), constrained by 143 ± 1 Ma adakitic plagiogranites formed by partial melting of subducted oceanic crust at eclogite facies (13). Following initiation, slab-derived fluids metasomatized the mantle wedge and triggered partial melting, forming FAB (Fig. 6) (4, 5). Progressive subduction enhanced fluid flux and mantle melting, producing boninitic melts that interacted with fore-arc peridotites (Fig. 6b). Continued arc evolution generated arc tholeiitic basalts and low-K to high-K calc-alkaline magmas (Fig. 6).

Fore-arc basins developed during intra-oceanic subduction and accumulated sediments mainly derived from the adjacent intra-oceanic arc system (36). In the Meratus Complex, the basaltic–andesitic lavas and tuff breccias of the Haruyan Formation and Pitanak Group record submarine volcanism, as indicated by chert fragments containing abyssal fauna and radiolarians (10, 33). Such submarine volcanic deposits are commonly associated with immature island arcs (36). The absence of coarse-grained terrigenous sediments in the Pulau Laut mélange further suggests limited continental input and a position distant from the continental margin (Fig. 6b) (10, 33).

Implications for the Neo-Tethys intra-oceanic subduction system

Analogous abyssal–forearc peridotite associations are documented in Neo-Tethyan ophiolites from Turkey, Iran, and the Yarlung Zangbo suture zone (Fig. 1) (37–41), and are widely interpreted as remnants of intra-oceanic subduction systems, indicating that such subduction was widespread throughout the Neo-Tethys Ocean (2, 8).

We compiled geochronological data for subduction-related rocks (FAB, boninites, plagiogranites, island-arc tholeiites, calc-alkaline suites and metamorphic soles) along the Neo-Tethyan suture zone to constrain the onset and duration of intra-oceanic subduction (Fig. 7 and Supplementary Table 6). In the western Neo-Tethys, intra-oceanic subduction was active during the mid-Cretaceous (Fig. 7): the Bursa Ophiolite in Turkey (Fig. 1) records 90 ± 1 Ma FAB, IAT (Fig. 7), with depleted mantle metasomatized by boninitic melts (42, 43); Zagros ophiolites preserve mid-Cretaceous (105–93 Ma) FAB, subduction-related plagiogranites, IAT, and boninites (44); and the Oman Ophiolite documents a transition from MORB-like V1 magmatism (~ 96 Ma) to subduction-related V2 plagiogranites and granitoids (~ 95 Ma) (45, 46).

In the eastern Neo-Tethys, intra-oceanic subduction initiated significantly earlier. The Kohistan arc in Pakistan preserves a magmatic history from the Middle–Late Jurassic to the Cretaceous (155–76 Ma) (Figs. 1 and 6) (47, 48). In Tibet, the Yarlung Zangbo Ophiolite records FAB, boninites, and calc-alkaline suites dated at 156–123 Ma (Figs. 1 and 6) (49, 50). West Myanmar yields FAB and IAT dated at 120–90 Ma have been reported (Figs. 1 and 6) (8, 51). Subduction-related plagiogranites of ~ 90 Ma occur in the Andaman ophiolite (Figs. 1 and 6) (52). The Woyla arc of Sumatra formed between 102 and 87 Ma (53), whereas subduction-related plagiogranites dated at ~ 143 Ma have been documented in the Meratus Complex of southeastern Borneo (Figs. 1 and 6) (13). Integrating these datasets, we show that intra-

oceanic subduction within the Neo-Tethys initiated diachronously during the Late Mesozoic: subduction onset was earliest in eastern segments and became progressively younger westward (Fig. 7 and Supplementary Table 6). By the Late Cretaceous (~ 90 Ma), the system was fully developed along the entire length of the ocean basin, forming an > 8,000-km intra-oceanic arc extending from Turkey in the west to the Meratus Complex in southeastern Borneo at its easternmost terminus (Fig. 8).

The duration of arc magmatism also varies systematically along strike. Eastern segments record substantially longer-lived arc activity than western segments (Fig. 7 and Supplementary Table 6). The Kohistan arc in Pakistan has the longest recorded duration (~ 79 Myr) (Fig. 7), whereas arc systems in the Oman, Iran and Turkey record shorter durations of ~ 0.8–15.2 Myr (Fig. 7). This spatial pattern supports the hypothesis that the Neo-Tethys Ocean was narrower in its western segment (Turkey, Iran, Oman) and wider in the east (Kohistan, Tibet, Myanmar), with the Meratus Complex representing the easternmost terminus of this broad ocean basin (Figs. 7 and 8). The diachronous initiation pattern probably reflects far-field forces associated with global plate reorganization during mid-Cretaceous breakup of Gondwana (54), modified by pre-existing variations in ocean basin width and lithospheric strength along strike. The earlier initiation in the wider eastern basin is consistent with subduction nucleation in older, colder and denser oceanic lithosphere, whereas the narrower western basin may have required stronger far-field forcing to initiate subduction.

Methods

Whole-rock major and trace elements

Whole-rock major and trace elements analyses were conducted at Guizhou Tongwei Testing Technology Co., Ltd., in China. After removal of weathered surfaces, samples were crushed, and small rock chips were then pulverized into powder using an agate mortar to a grain size of < 200 mesh. The samples were thoroughly mixed with a fluxing agent ($\text{Li}_2\text{B}_4\text{O}_7 + \text{LiBO}_2$) by grinding. Glass fusion discs were prepared using a high-temperature gas automatic fusion machine, followed by the determination of major element compositions via X-ray fluorescence of ARL Perform' X 4200 spectrometry using procedures as described in Norrish and Hutton (1969). Trace element concentrations including rare earth elements (REE) were determined using a Thermo Fisher iCAP RQ inductively coupled plasma mass spectrometer. The uncertainty of major elements analyses was generally within 1%, and the analytical precision of most trace elements was better than 5%.

Mineral major elements

Mineral major elements compositions were obtained by Electron Probe MicroAnalysis (EPMA) using JEOL JXA-iHP200F microprobe with a 5-channel spectrometer at the Institute of Mineral Resources, Chinese Academy of Geological Sciences (CAGS), Beijing, China. Samples were coated with a carbon film approximately 20 nm thick before testing. Detailed EPMA analysis procedures are described in Yang et al. (2022). The operating conditions were as follows: an accelerating voltage of 15 kV, a beam current

of 10 nA, and a beam current of 2 μm . Natural minerals or synthetic oxides were used as standards and all the raw data collected were ZAF corrected.

Cpx and Opx trace elements

Trace elements compositions of pyroxenes were analyzed by laser ablation-inductively coupled plasma mass spectrometry (LA-ICP-MS), employing an Element XR High-Resolution-ICP-MS instrument coupled with a 193 nm ArF excimer laser system at the Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, China. Analyses were performed with a laser fluence of 5 or 6 J/cm^2 , a repetition rate of 5 Hz, and a beam diameter of 60 or 80, or 90 μm . Silicon (^{29}Si) and ARM-3 (57) were used as internal standards and external standards, respectively, and BIR-1 was selected as a secondary standard to monitor the accuracy of the analyses. The raw data were reduced by the GLITTER software (58). For most trace elements (> 0.005 ppm), the accuracy was better than $\pm 10\%$ (1 RSD).

Declarations

Data availability

The data required to produce all figures and tables are available in the supplementary data files.

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Author contributions

Conceptualization: D.G., S.L., and J.Ž.; Investigation: S.L. and I.S.; Visualization: D.G., S.L., J.Ž., and L.Q.; Writing—original draft: D.G.; Writing—review and editing: S.L., J.Ž., L.A., and L.Q.; Funding acquisition: S.L.

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Figures

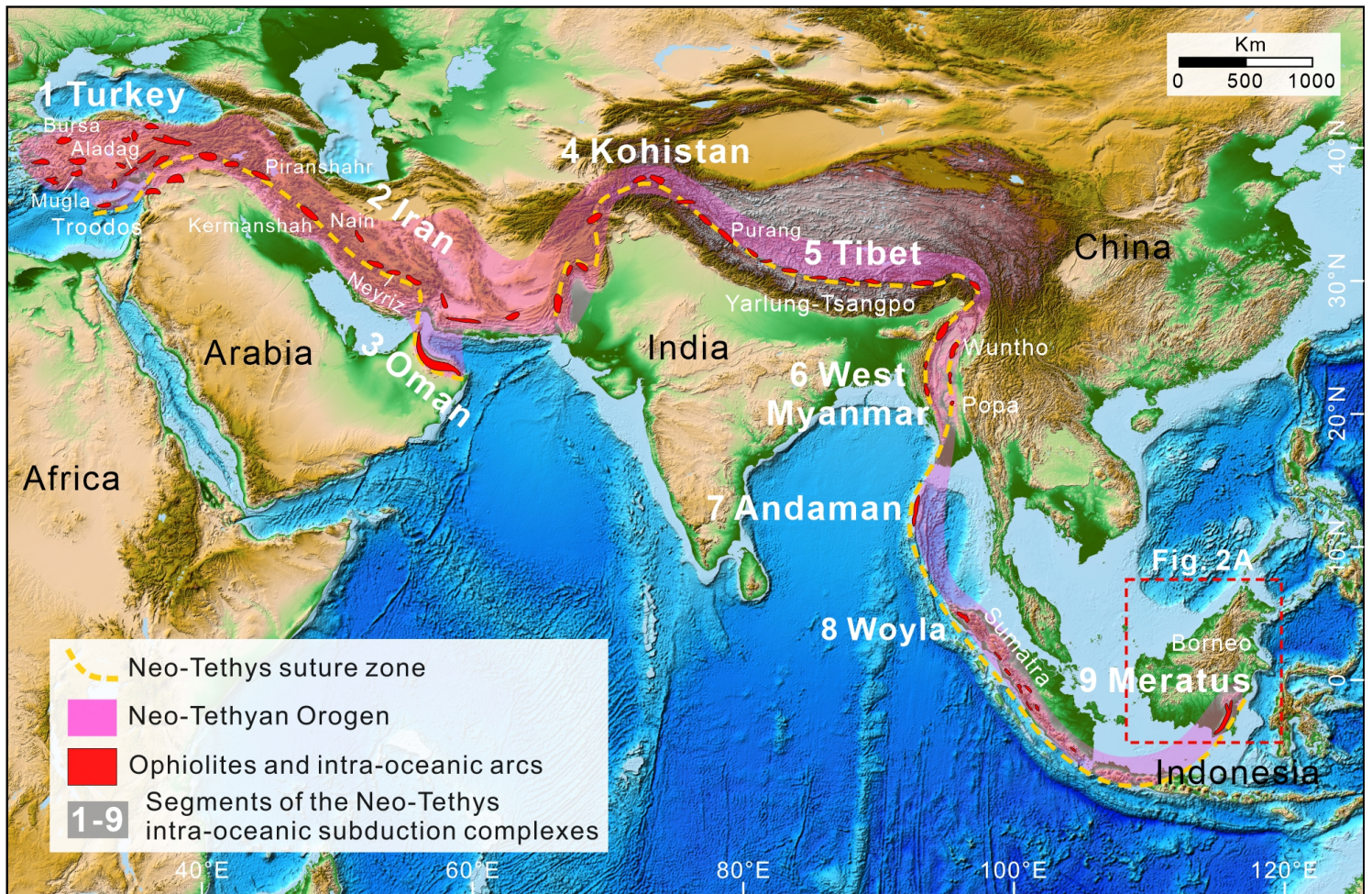


Figure 1

Spatial distribution of ophiolites and intra-oceanic arcs along the Neo-Tethys suture zone.

Spatial distribution of ophiolites and intra-oceanic arcs (with the main segments marked 1–9) from west to east along the Neo-Tethys suture zone (modified from ref. 8,59), the Meratus Complex (southeast Borneo) formed at its easternmost termination.

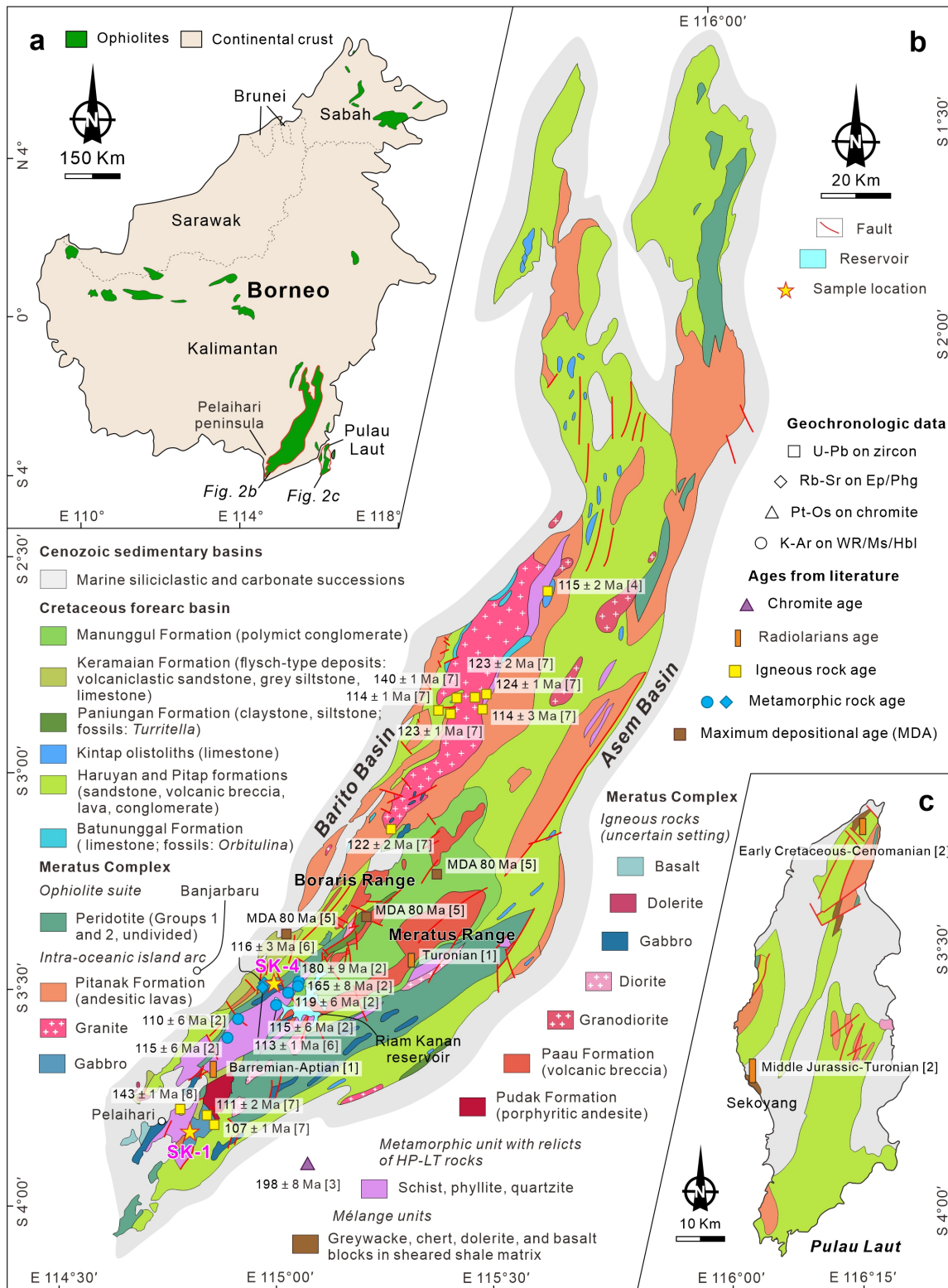


Figure 2

Ophiolite distribution and geological maps of Meratus Complex and Pulau Laut, Southeast Borneo.

(a) Spatial distribution of ophiolites in Borneo, the Meratus Complex is the largest one in the southeast (modified from ref. 12,60).

(b) Geological map for Meratus Complex in southeast Borneo showing the published radiometric ages and sampling locations SK-1 and SK-4.

(c) Geological map of Pulau Laut showing the radiolarian ages of chert blocks in the mélangé.

Data source: [1]–ref. 9; [2]–ref. 10; [3]–ref. 35; [4]–ref. 61; [5]–ref. 62; [6]–ref. 11; [7]–ref. 12; [8]–ref. 13.
 Abbreviations: Ms = muscovite; Hbl = hornblende; Ep = epidote; Phg = phengite; WR = whole-rock.

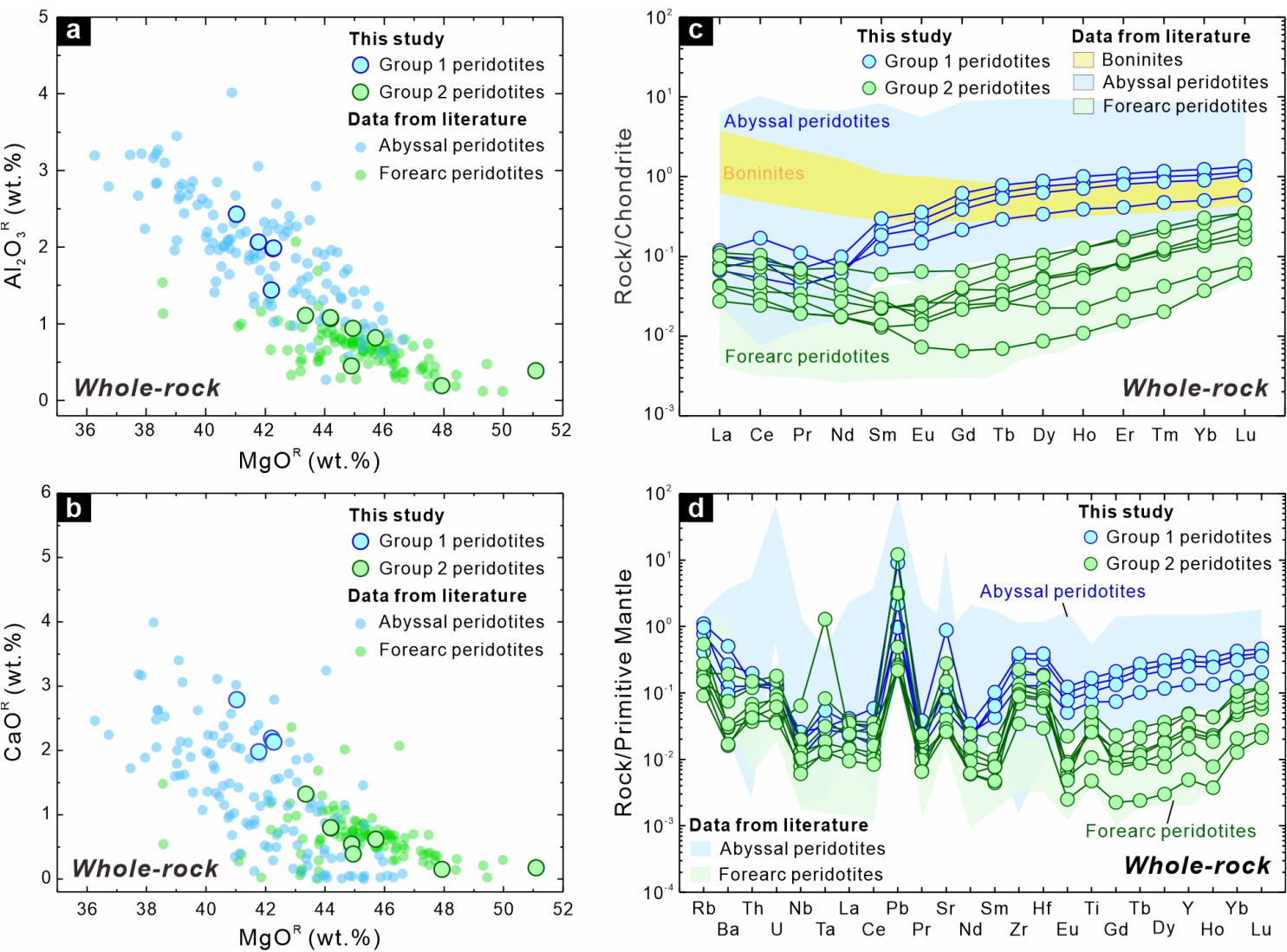


Figure 3

Whole-rock geochemical features of two group peridotites.

Plots of whole-rock $\text{Al}_2\text{O}_3^{\text{R}}$ vs. MgO^{R} (a) and CaO^{R} vs. MgO^{R} (b) contents of the Meratus peridotites.

REE and extended trace elements patterns (c and d, respectively) of the Meratus peridotites normalized to chondrite and primitive mantle, respectively.

R represents whole-rock compositions (including the literature data) that were normalized to 100% anhydrous base. The values of chondrite and primitive mantle are from ref. 63. Boninite field is drawn from ref. 20. Mineral abbreviations: Cpx = clinopyroxene; Opx = orthopyroxene.

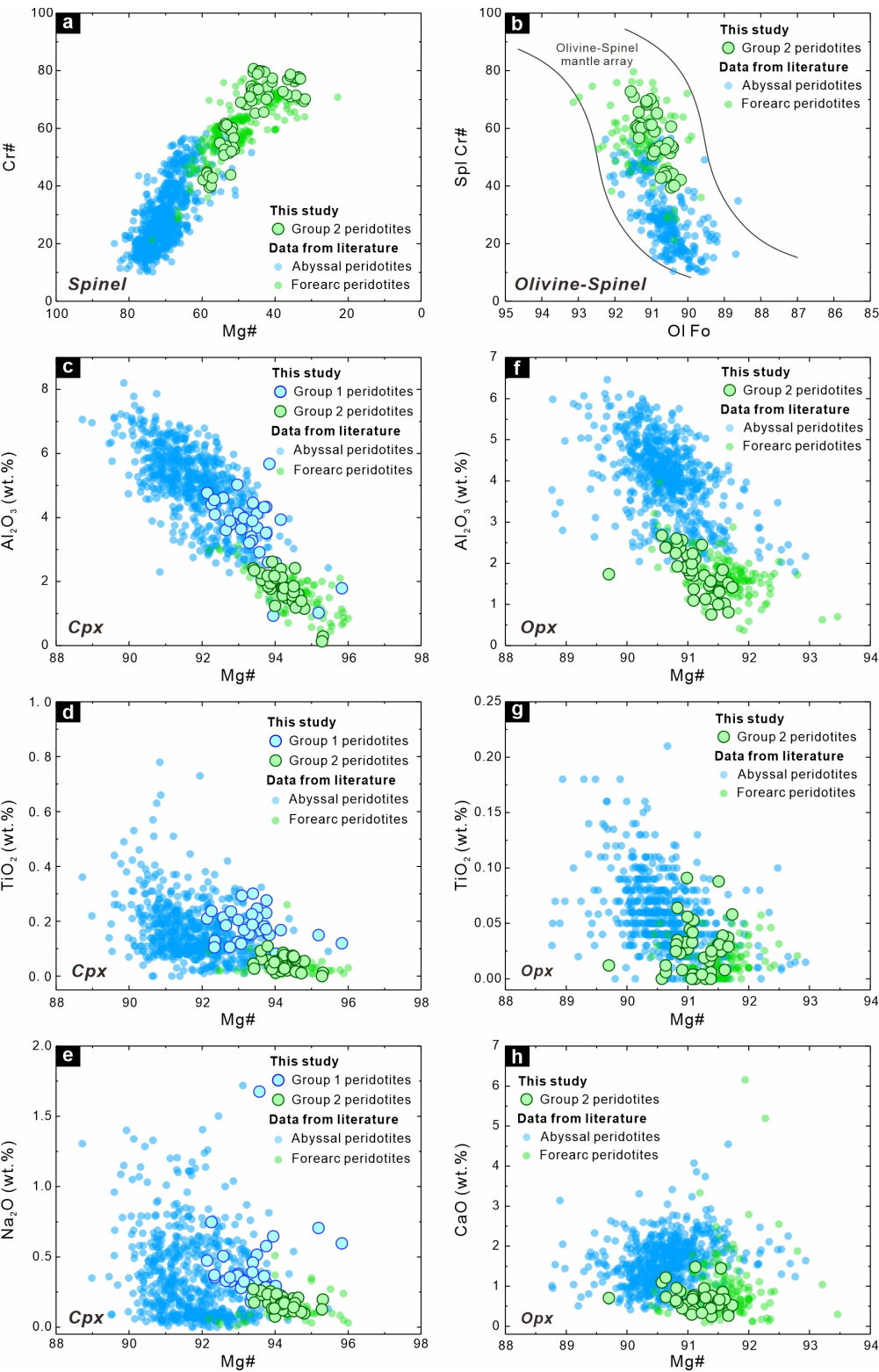


Figure 4

Mineral geochemical features of two group peridotites.

(a) Spinel Cr# vs. Mg# and (b) spinel Cr# vs. olivine Fo diagrams.

(c-e) Al_2O_3 , TiO_2 , and Na_2O vs. Mg# of clinopyroxene and orthopyroxene (g-h) are shown.

The olivine-spinel mantle array from ref. 64.

Data sources: fore-arc peridotites (14,65,66,67,68) and abyssal peridotites (25,68). Mineral abbreviations: Cpx = clinopyroxene; Opx = orthopyroxene.

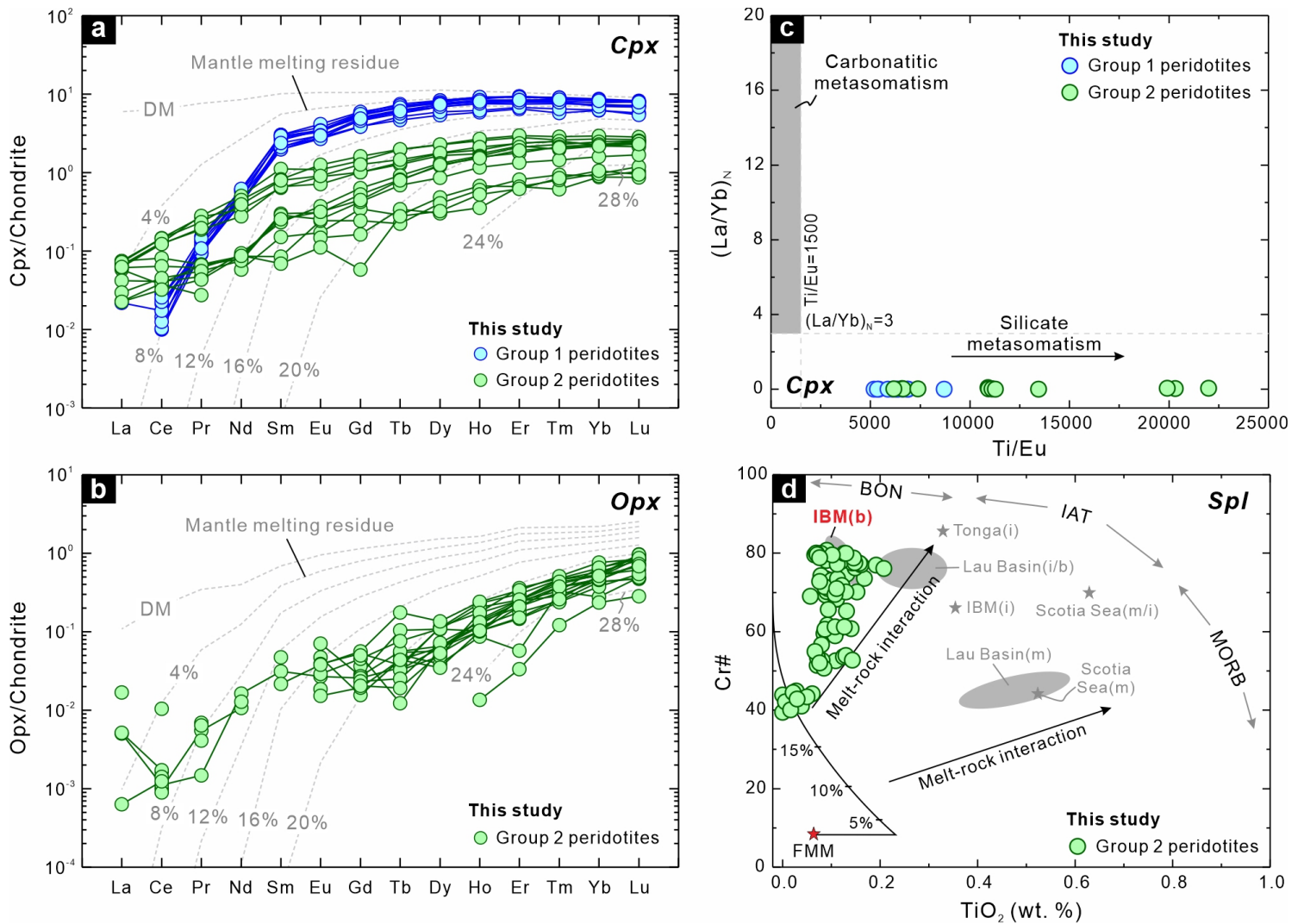


Figure 5

Geochemical features of clinopyroxene, orthopyroxene, and spinel in Meratus peridotites.

Chondrite-normalized (63) REE patterns of (a) Cpx and (b) Opx from the Meratus peridotite.

(c) Plot of $(\text{La/Yb})_N$ vs. Ti/Eu for clinopyroxene from Meratus peridotites that is used for discrimination of silicate vs. carbonatitic metasomatism (19,69).

(d) Plot of Cr# vs. TiO_2 for spinel from the Meratus Peridotites (31).

The modelled curves of partial melting degrees refer to that of ref. 25 using the depleted MORB mantle (27) as a starting composition. The melting mineral modes and partition coefficients were used from ref. 26. Primitive mantle from ref. 63. Abbreviations: Cpx = clinopyroxene; Opx = orthopyroxene; FMM = fertile MORB mantle; IBM = Izu-Bonin-Mariana; BON = boninite; IAT = island-arc tholeiite; MORB = mid-oceanic-ridge basalt. (b), (i), and (m) represent boninite, island-arc tholeiite, and MORB, respectively.

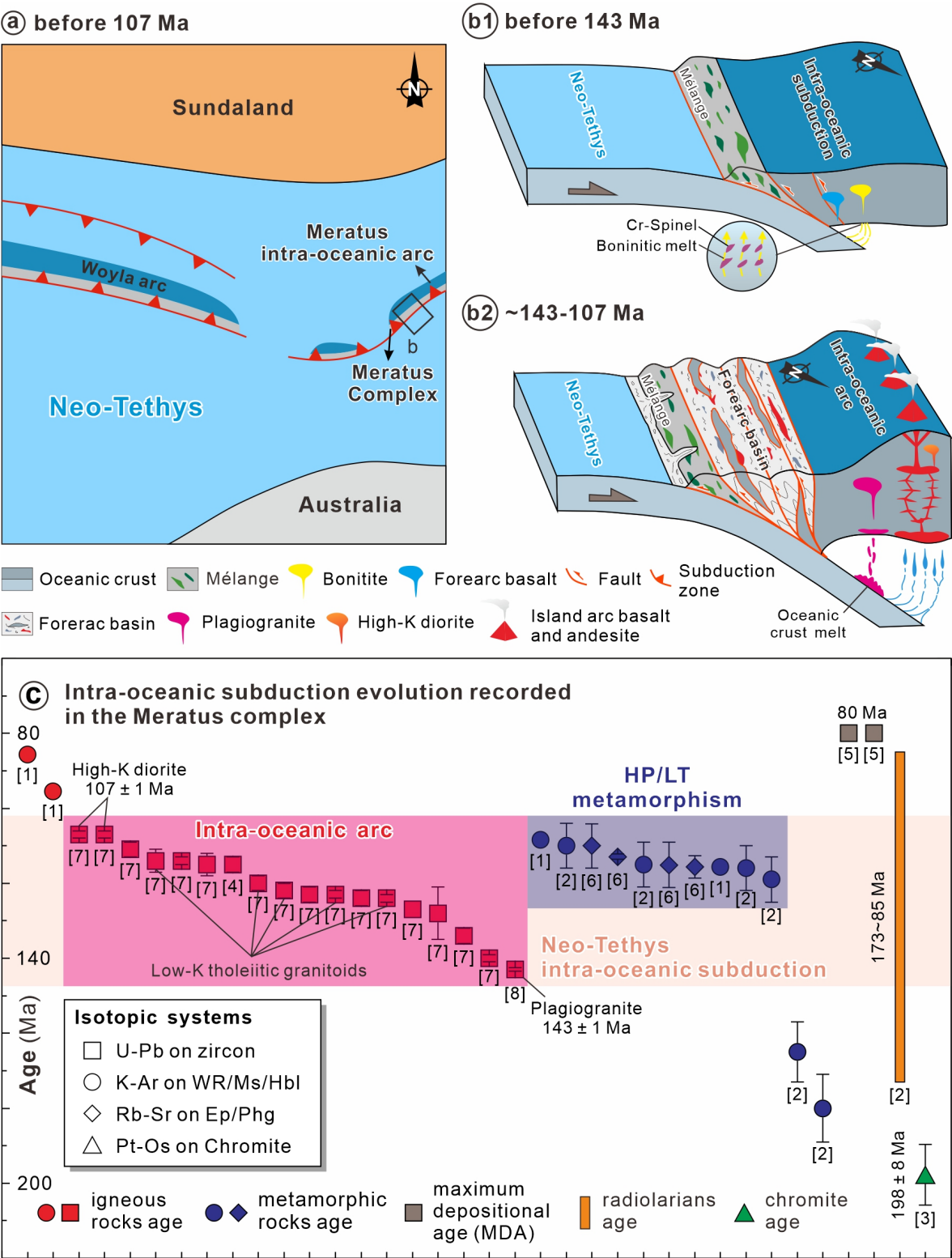


Figure 6

Geodynamic evolution for the easternmost Neo-Tethys (Meratus Complex) during the Late Mesozoic.

- (a) Simplified paleogeographic reconstruction of the easternmost Neo-Tethys (1).
- (b) Schematic model for subduction initiation (b1) to mature intra-oceanic arc (b2) evolution as recorded in the Meratus Complex of the southeast Borneo based on published data and new geochemical data on peridotites presented in this study.
- (c) Summary of timing of tectonic, magmatic, and metamorphic events recorded in the studied Meratus Complex; see text for discussion. Abbreviations: HP/LT = high pressure/low temperature; WR = whole-rock; MOR = mid-oceanic-ridge. Mineral abbreviations: Ms = muscovite; Hbl = hornblende; Ep = epidote; Phg = phengite.

The data source is the same as that in Fig. 2.

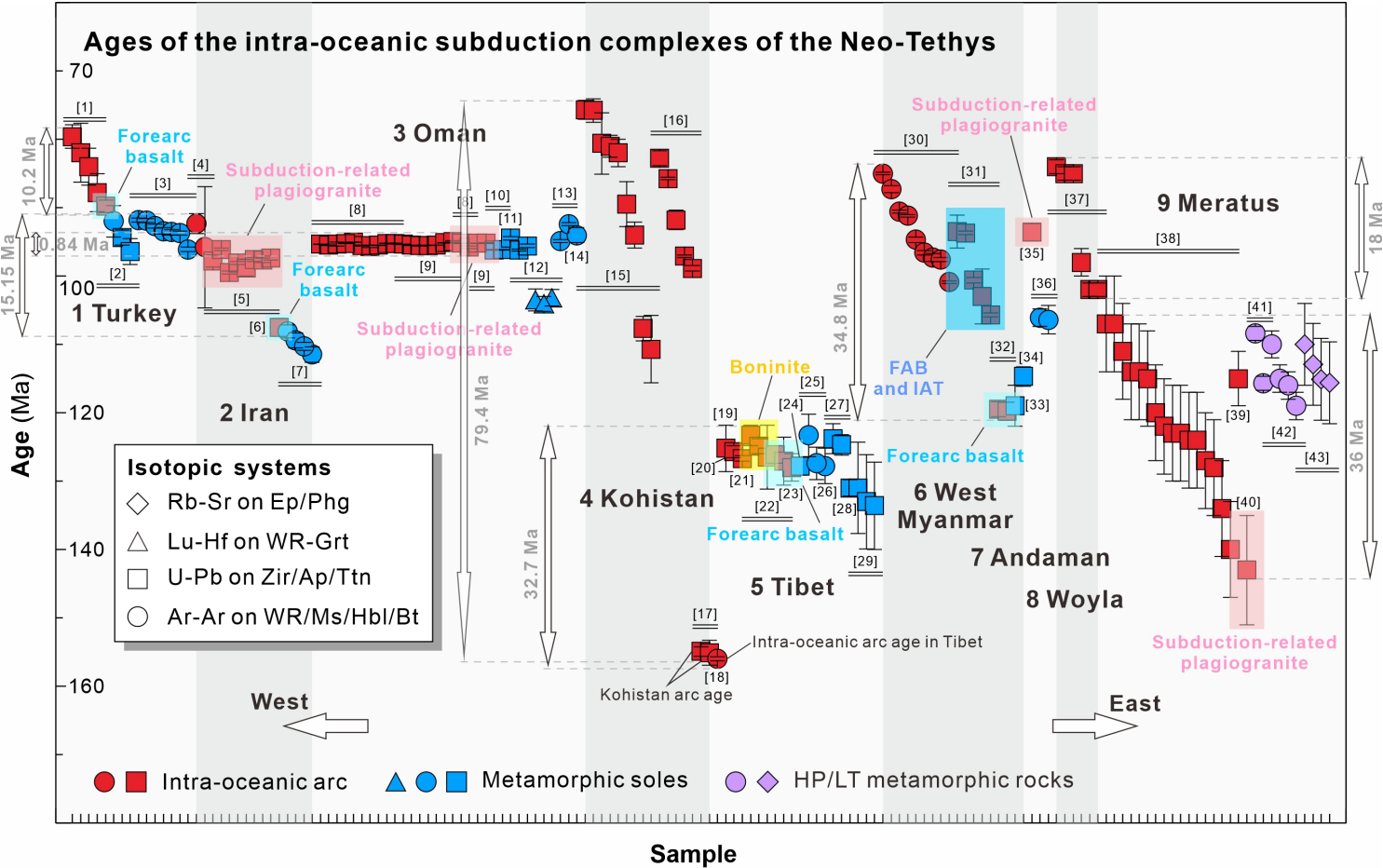


Figure 7

Evolution of intra-oceanic arcs within the Neo-Tethys ocean basin.

A compilation of available geochronological information on arc magmatic rocks, HP/LT metamorphic rocks, and ophiolite metamorphic soles in 9 main segments of the Neo-Tethys suture zone (see Fig. 1 for location).

Data of the sampling localities, ages, and references are presented in Supplementary Table 6. Abbreviations: HP/LT = high pressure/low temperature; FAB = fore-arc basalt; IAT = island-arc tholeiite; WR = whole-rock; Ms = muscovite; Hbl = hornblende; Ep = epidote; Phg = phengite; Bt = biotite.

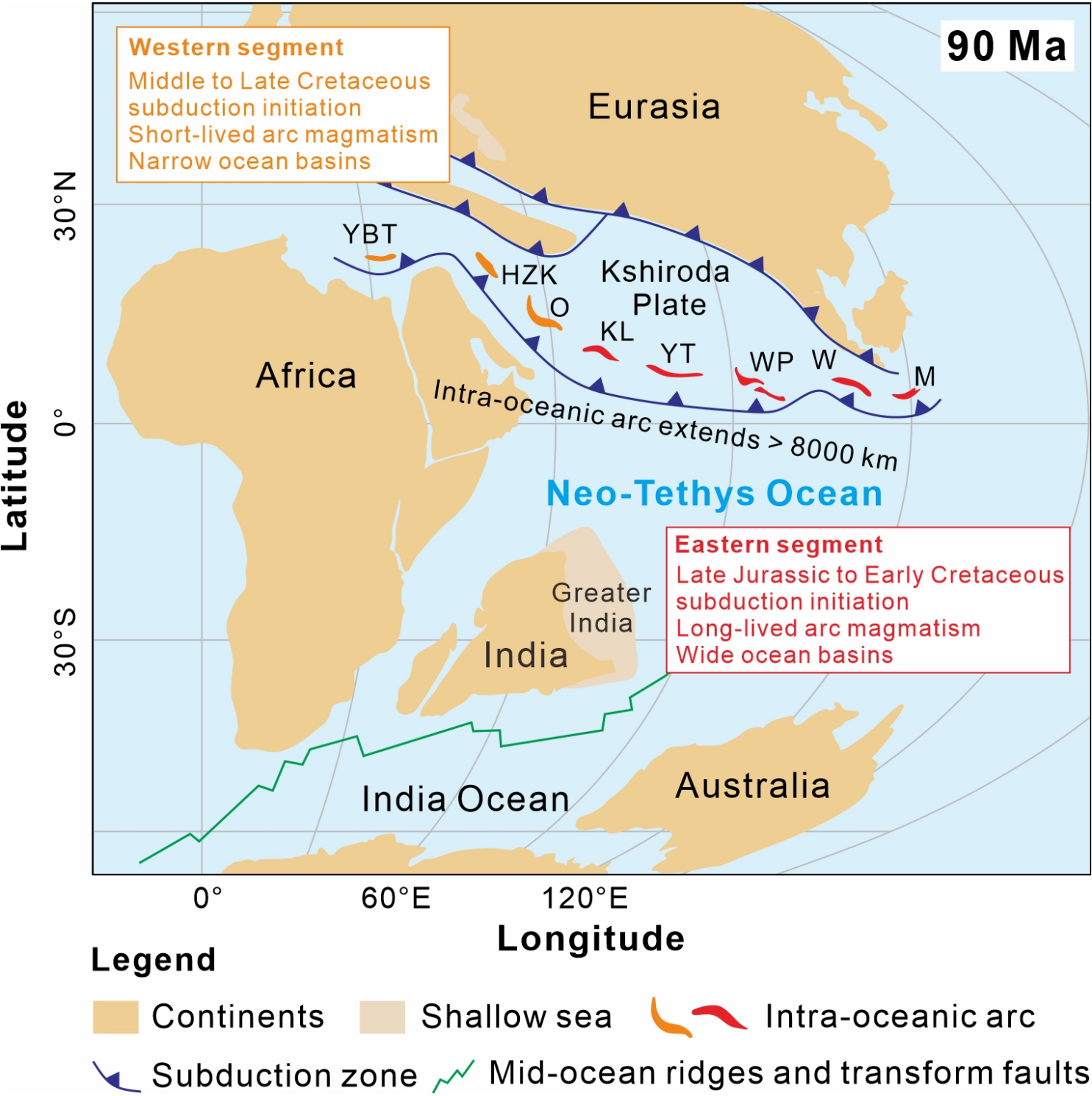


Figure 8

Cretaceous (~90 Ma) paleogeographic reconstruction of the Neo-Tethys ocean.

Cretaceous (~90 Ma) paleogeographic reconstruction showing the assumed ultra-long intra-oceanic subduction of the Neo-Tethys, with contrasting characteristics in the western and eastern segments (modified from ref. 2,8,34).

Abbreviations: YBT = Yuksekova-Bursa-Tauride; HZK = Hasanbag-Zagros-Khoy; O = Oman; KL = Kohistan-Ladakh; YT = Arc rocks within the Yarlung-Tsangpo suture; WP = Wuntho-Popa; W = Woyla; M = Meratus.

Supplementary Files

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