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ADVANCING EARTH AND SPACE SCIENCE

Tectonics

RESEARCH ARTICLE
10.1029/2018TC005099

Key Points:
- Forty years of structural mapping and stored archives in the Semail ophiolite and its continental environment
- Break with the controversial models concerning the origin and emplacement of Semail ophiolite, using a multidisciplinary approach
- Open a new model to further investigations and activate a feedback concerning the ridge-trench collision system at an active margin

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Citation:
Boudier, F., & Nicolas, A. (2018). Synchronous seafloor spreading and subduction at the paleo-convergent margin of Semail and Arabia. *Tectonics*, *37*, 2961–2982. https://doi.org/10.1029/2018TC005099

Received 13 APR 2018
Accepted 8 AUG 2018
Accepted article online 17 AUG 2018
Published online 9 SEP 2018

Synchronous Seafloor Spreading and Subduction at the Paleo-Convergent Margin of Semail and Arabia

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Abstract The Semail ophiolite is the largest and best-exposed ophiolite, having preserved intact record of a precollision system related to Neotethyan Ocean closure. Breaking with the alternative models of ophiolite exhumation and emplacement, this paper builds on integrating the joined contribution of tectonic evolution of the continental margin in the premise of the ophiolite obduction. Connecting the along-strike segmentation of the ophiolite recorded in the lithospheric flow structure, and recent high-precision dating, results in a 3-D model of evolution of the ophiolite and its continental margin during Jurassic-Cretaceous time. Among the relevant characteristics newly accounted, (1) the contamination of the ophiolite by fluids and magmas of continental origin; (2) the discrimination of different types of metamorphics associated to the ophiolite, and conventionally classified metamorphic soles; (3) the instability of the Arabian margin during the Late Jurassic-Cretaceous times; (4) the new precise ages relating to overlapping of spreading and detachment; and (5) the inferred vergence of Neotethyan closure during late Mesozoic are stressed. The complex stem revealed may relate to processes associated with spreading center subduction at ridge-trench-transform (RTT) triple junction, as documented along a convergent margin. The Semail ophiolite emplacement on the Arabia continental margin would result from a temporary Arabian platform-directed subduction zone that consumed the southern Tethyan plate during Late Jurassic-Cretaceous time.

Plain Language Summary The Semail ophiolite is the largest and best-exposed ophiolite, having preserved intact record of a precollision system related to Neotethyan Ocean closure. Breaking with the alternative models of ophiolite exhumation and emplacement, this paper builds on the integration of the joined contribution of tectonic evolution of the continental margin in the premise of the ophiolite obduction, and the along-strike segmentation of the ophiolite recorded in the lithospheric flow structure. These elements are integrated in a 3-D model of genesis of the ophiolite by detachment along a ridge-trench collision system, resulting from a temporary continent-oriented subduction.

1. Introduction

Due to its obduction on the continental margin of Arabia, the Semail ophiolite has been preserved from major orogenic events related to Late Cretaceous Neotethyan Ocean closure. Offering its extended exposure (600 km × 150 km) of oceanic lithosphere, the Semail ophiolite has collected the highest geological interest and promoted a largest number of contributions, being considered the ophiolite reference. Initiated with the earliest papers (Coleman & Hopson, 1981; Pearce et al., 1981), a considerable controversy regarding the assumed origin of the Semail ophiolite, whether the ophiolite was formed in a mid-ocean ridge or at a supra-subduction zone setting, has motivated a large number of contributions, pointing to the ambiguous question of origin of ophiolites.

Structural and thermal evidence suggest that the obduction was initiated close to an active spreading center (Coleman & Hopson, 1981; Ishikawa et al., 2002; Nicolas, 1989). The ophiolite was little deformed during and after emplacement, preserving the internal structure of a fast-spreading ridge accretion (see Nicolas et al., 2000a). Also, for its continuous gabbro section, the Semail ophiolite is considered as an analogue for present-day intermediate to fast-spreading ridges (e.g., Boudier et al., 1996; Kelemen et al., 1997; Peters et al., 1991).

On the geochemical ground, most of the Semail ophiolite volcanic sequence is composed of mid-ocean ridge-type lavas, but in the northern part of the ophiolite, they are topped by trace element-depleted, low-Ti tholeiitic volcanics interpreted as the first stages of island arc volcanism (Alabaster et al., 1982; Lippard et al., 1986; Pearce et al., 1981). This arc component led to the concept of origin of the Semail ophiolite at an oceanic ridge in a suprasubduction back-arc context. Growing recognition of an arc geochemical signature in most exposed ophiolites has promoted the model of suprasubduction origin of ophiolites (e.g., Agard et al., 2007).

A third possible origin of ophiolites at a ridge-trench collision system has been envisaged (Dewey & Bird, 1971; Sturm et al., 2000), based on hybrid signatures of volcanics discovered at southern Chile Ridge (Karsten et al., 1996; Klein & Karsten, 1995), confirmed along the America-Pacific plate junction (Aguillon-Robles et al., 2001). Emplacement of ophiolite in such geodynamic context requires thrusting of a hot oceanic lithosphere slab onto the continental margin in the dynamics of a continent-directed subduction. This convergent margin model has been proposed for Semail on local ground (Gray, Miller, et al., 2004; Gregory et al., 1998; Nicolas & Boudier, 2017).

In the present paper, we explore, in a multidisciplinary approach, the complex history of Arabian shield margin junction with Neothethyan ocean, pointing to a certain number of petrostructural elements supporting a ridge-trench interaction, not accounted for in previous models of Semail ophiolite emplacement.

The complete 1/100,000 coverage of Oman and Emirates mountains by geological mapping (Bureau de Recherches Geologiques et Minières, 1986, 1992; Bishimetal Exploration Co, 1987; British Geological Survey, 2006; Nicolas et al., 2000b) represents a valuable support in this quest, in addition to original local structural mapping.

2. Ophiolite, Northern-Southern Evolution

2.1. Arc Parallel to a Segmented Spreading Axis

The Semail ophiolite lies in a NW to SE arcuate series of 13 massifs (Figure 1). The central and southeastern massifs are split around an *S*-shaped domal structure exposing the Arabian shield with Saih Hatat, Jebel Akhdar, ending in the Hawasina window. The sheeted dikes, marking the paleoridge trend parallel to the arc-shaped ophiolite (Figure 1a), with an additional orthogonal ridge strike appearing in the southern massifs. The segmentation is punctuated by mantle diapirs (Nicolas et al., 2000a), more common in the southern part of the ophiolite. The high-T ($T > 1{,}000$ °C) fabrics, interpreted as inherited from solid-state flow in asthenospheric conditions, characterize the dominant part of the exposed mantle (Figure 1a). The frozen asthenospheric mantle flow exhibits a general trend orthogonal to the spreading axis, a situation inferred to be typical of fast spreading dynamics (Nicolas, 1989). The homogeneous kinematics of asthenospheric mantle flow along the Semail belt, joined with the continuous trend of sheeted dike, militate for a unique spreading axis of origin of the Semail ophiolite,

2.2. Timing of Accretion

An extensive program of U/Pb dating on gabbro and trondjhemite throughout the Semail ophiolite (Rioux et al., 2012, 2013, 2016) has considerably complemented the set of dating concerning the Semail crustal accretion (Goodenough et al., 2010; Tilton et al., 1981; Warren et al., 2005) and cooling history of the ophiolite (Gnos & Peters, 1993; Hacker et al., 1996). Rioux and co-authors data rely on measurements from single zircon crystal repeated on sampling sites, providing data with intrasample variability between 0.1 and 0.3 Ma (Rioux et al., 2012). The age of accretion is constrained between 96.5 and 95.5 Ma, along-strike the Semail ophiolite (Rioux et al., 2013, 2016; Figure 1b).

2.3. Metamorphic Soles and Internal Shear Zones in Oman Ophiolite, Oceanic Detachment

The oceanic detachment of the ophiolite is recorded in the basal peridotite and in the metamorphic soles spread-along at the base of the ophiolite nappe (Figure 2a). In the Oman part of the ophiolite, the metamorphic soles have their typical attributes, up to hundred meters thickness, inverse thermal gradient, and structurally parallel to the basal peridotite. The steep thermal gradient characteristic of metamorphic soles, $>$1,000 °C/km in the upper contact to 100 °C/km at the base (Hacker & Mosenfelder, 1996) could result largely from large-scale multiple thrust accompanying cooling (Ghent & Stout, 1981), evidenced also by uncommon inclusion of granulitic rocks in amphibolite facies layers (Cowan et al., 2014).

Thermobarometric calculations on metamorphic soles from Oman have been carried on in the best-exposed sites (Figure 2a), at Mahlah of the Wadi Tayin massif, and Sumeini of the Fizh massif. In Wadi Tayin, Ghent and Stout (1981) assume temperature in the range of 880–915 °C based on garnet-clinopyroxene equilibrium and pressure estimated only from phase diagram to 2–5 kbar. Cowan et al. (2014) calculate *P*/*T* conditions 11 to

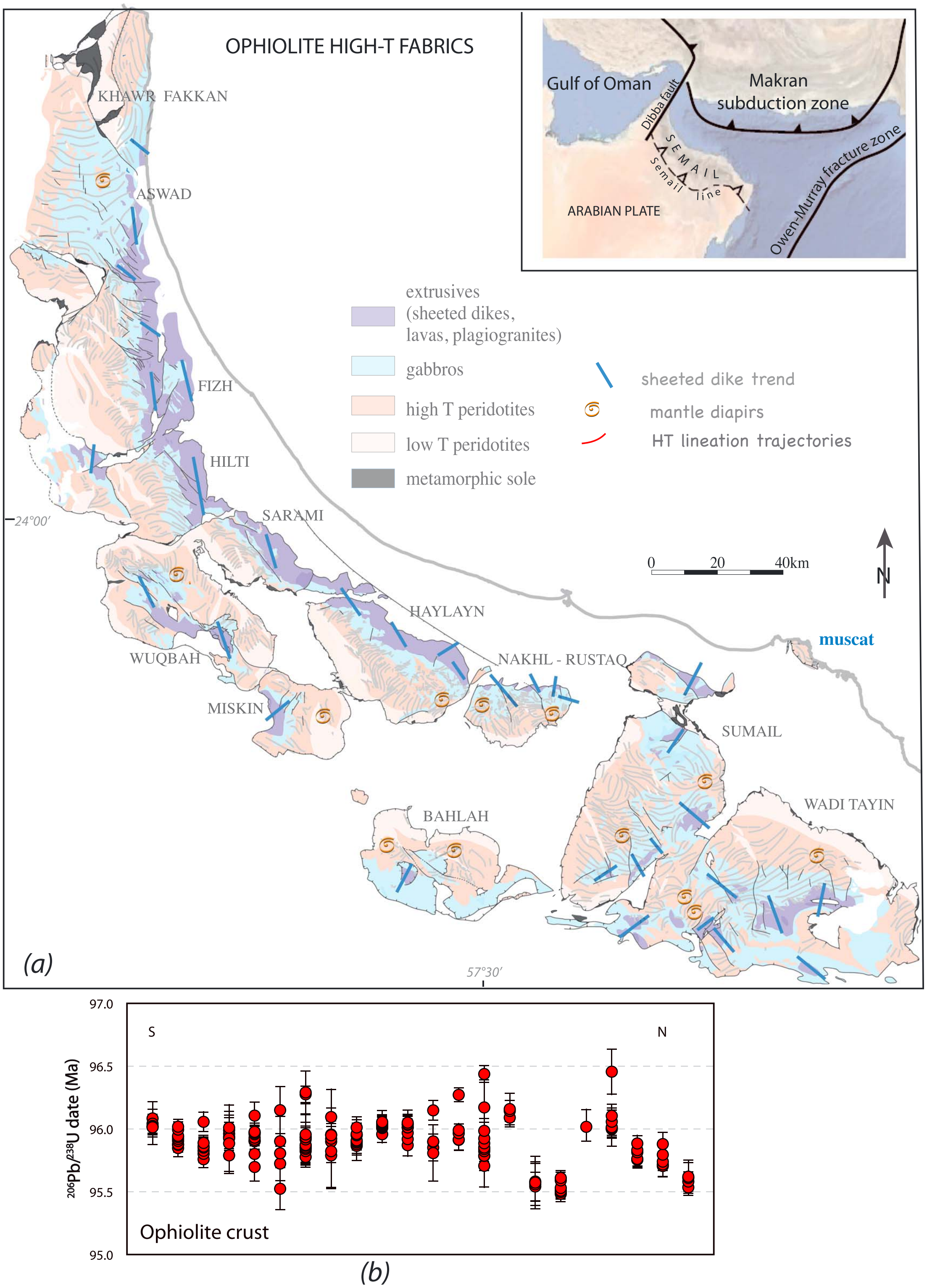

Figure 1. Structural map of Semail ophiolite. (a) Fabrics of ridge accretion ($T > 1000$ °C), including averaged orientation of sheeted dike complex, asthenospheric mantle diapirs, and mantle flow lines (after Nicolas et al., 2000b). Insert, Semail ophiolite present geodynamic situation, lying on the Arabia margin, bounded to the south by the Semail line, limit of nappe thrust. To the north, the present plate limit is the active Makran subduction. (b) U-Pb ages of accretion along-strike the Semail ophiolite, from high-precision $^{206}Pb/^{238}U$ geochronology on single grain zircon from upper level gabbros including tonalites, trondhjemites, and quartz diorites, just below the sheeted dikes (Rioux et al., 2016). Clusters of data are for a single sample, with error bar for each single zircon analysis (Rioux et al., 2012).

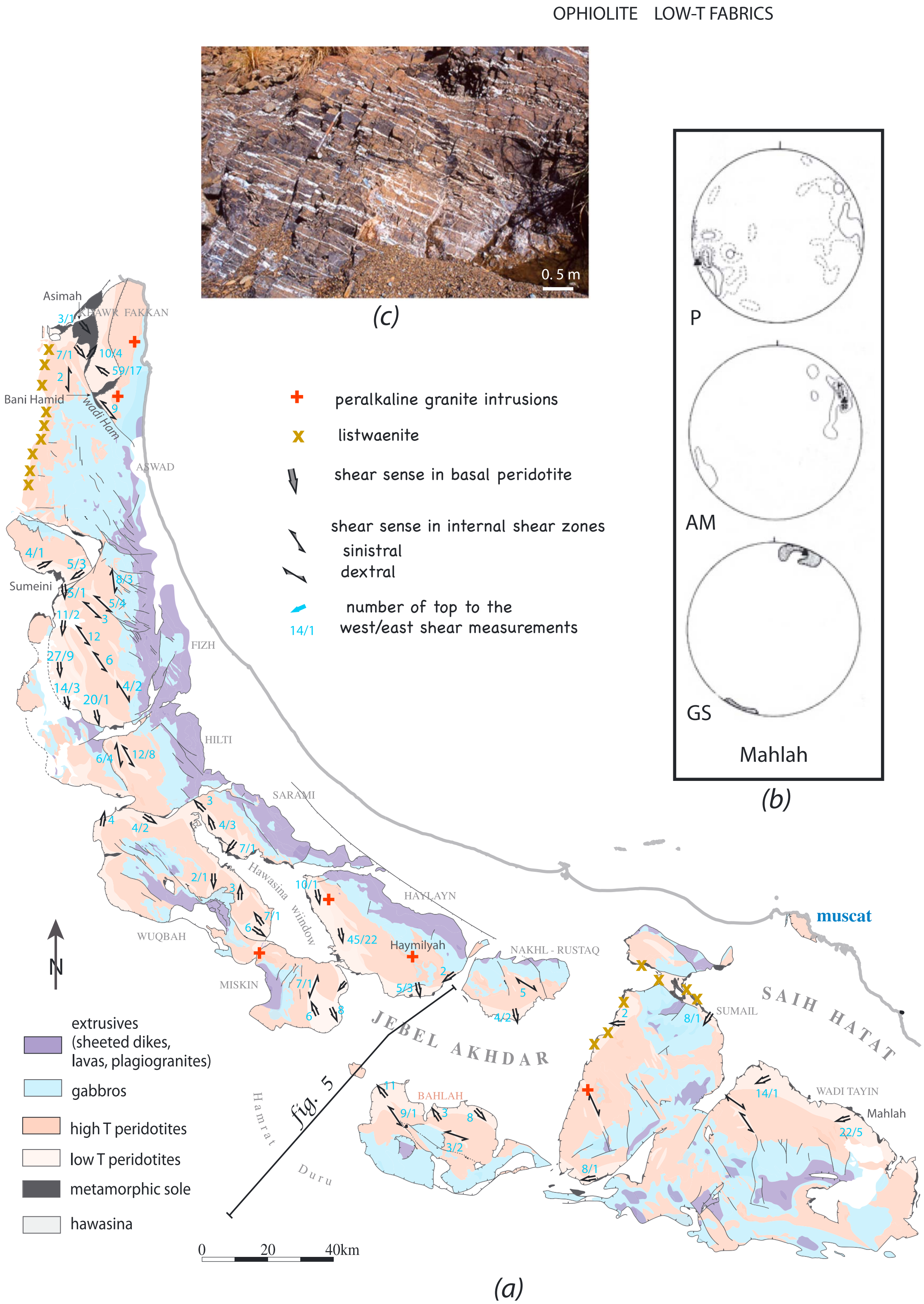

Figure 2. (a) Lithospheric structures (1000 > T > 800 °C) related to oceanic detachment, recorded in basal peridotite and in internal shear zones (pale pink design; after Nicolas et al., 2000b). Sense of shear is compiled from individual measurements of angular relation of olivine crystallographic fabrics and flow structures, foliation, and lineation (Nicolas, 1989). Numbers are ratio of opposite measurements. (b) Stereographic plot (lower hemisphere) of flow direction in peridotite (P), amphibolite (AM), and greenschists (GS) in metamorphic sole of Mahlah (Wadi Tayin massif). Contours are 2% dashed line, 4% solid line, 10% spaced dots, and 20% close dots (after Boudier & Coleman, 1981). (c) Internal mylonitic harzburgite injected by gabbroic diking, in shear zone of Wadi Bulaydah (Miskin massif).

13 kbar at 770–900 °C in Wadi Tayin and Sumeini windows, based on multiequilibrium thermobarometry, biased by the absence of unaltered plagioclase. Temperatures at limit of granulite facies combined with calculated depth of 35 km are difficult to integrate in the frame of an oceanic detachment, considering the thickness of the lithospheric plates exposed (maximum 15 km), and of the low-angle thrust recorded in the basal peridotite (Nicolas et al., 2000b).

Kinematics of detachment is deduced from the kinematic analysis in low-T porphyroclastic-mylonitic peridotite exposed continuously at the base of the ophiolite and along internal shear zones. Structural mapping (Figures 1a and 2a) documents the progressive transition from asthenospheric flow in mantle peridotite to localized solid-state flow at decreasing temperature in the basal shear zones. Detailed petrostructural study at Mahlah (Boudier & Coleman, 1981) has documented a consistency of solid-state mantle flow recorded in the basal peridotite at "low-T" mantle flow $<$950 °C, correlated with activation of the "high-T" $>$ 700 °C slip system in quartzite from the metamorphic sole (Figure 2b). Inferred from mapping at the scale of the Oman ophiolite (Nicolas et al., 2000a), the sense of detachment thrust compiled (Figure 2a) is somewhat ambiguous, dominantly oriented parallel to the paleo-ridge axis, and toward southeast in the northern and central Oman ophiolite, but westerly oriented in the southern Sumail and Wadi Tayin massifs, and rotating from E-W to NE-SW trend at decreasing temperature (Figure 2b).

Large internal shear zones, at low-angle to the paleo-ridge axis (Figure 2a), marked by low-T porphyroclastic to mylonitic textures developed in lithospheric condition, extend at the scale of given massifs (Boudier et al., 1988). The abundant gabbro diking associated (Figure 2c) exemplifies the feedback between flow localization and melt transfer in these mid-T shear zones. They are largely developed in the northern Oman belt, and dominantly sinistral, less present in the central and southern massifs and concurrently dextral or sinistral (Figure 2a).

2.4. Metamorphic Windows in the Emirate Part of the Ophiolite

Metamorphic windows in the Emirate part of the ophiolite, namely, Asimah and Bani Hamid (Figure 3a), point to somewhat different characters compared to the metamorphic soles from Oman exposures. Both inliers expose relatively large metamorphic domains at the limit between Khor Fakkan and Aswad massifs, along the large Wadi Ham shear zone.

The Asimah window (Figure 3b) exposes on an ~10-km distance an accretionary prism formed by greenschist rocks including metacherts, metacarbonates, and metavolcanics. The structure is progressively flattening westward passing to high-grade amphibolites interlayered with mylonitic peridotite. Inside the Asimah inlier, metachert grade eastward to metavolcanics, bordered by alkalic metabasalt and metacarbonatites (Ziegler et al., 1991) dated Early Cretaceous (British Geological Survey, 2006). The metamorphic sediments and volcanics forming this main inlier record consistent inverse thrusting eastward (British Geological Survey, 2006), developed in greenschist metamorphic condition. On the eastern border, the Asimah greenschist rocks abut on the harzburgite section of Khor Fakkan massif along a steep thrust contact (Figure 3c). Shear planes in marginal harzburgite are marked by chlorite and talc, product of orthopyroxene hydration at greenschist conditions. Actually, the internal structure of the accretion prism, greenschist facies foliation and internal thrust contacts, are parallel to this mantle sheared contact. The southern part of the Asimah inlier ends in a narrowing exposure bordered on both side by high-grade amphibolite.

Exhaustive multicomponent equilibrium calculations of *P*/*T* condition of the high-grade metamorphism at the western margin of Asimah window (Gnos, 1998) provide a large sample variability, with maximum temperatures 770 to ~900 °C. Pressures calculated using the barometer of Mäder et al. (1994) applied to plagioclase-absent reactions provide values 11.6 to 12.1 kbar at peak temperatures (Gnos, 1998). The discovery of kyanite in the narrowing end of Masafi correlates with pressure ~6 to 10.5 kbar on alumino-silicate phase equilibria (Gnos, 1998), based, respectively, on maximum temperature 700 to 820 °C calculated at this site. The polymetamorphic evolution of the greenschist facies rocks points to peak conditions 450–500 °C and 5 kbar (Bucher, 1991) based on phase equilibria.

The Bani Hamid (or Shis) granulitic assemblage occur in an ~2-km-thick inlier, open in the Khor Fakkan harzburgitic mantle (Figure 3a). The inlier trends parallel to the mantle flow plane, and its southern end is rotated into parallelism with the Wadi Ham shear zone. The Bani Hamid metamorphic rocks define a southern extension of a block boundary that separates an eastern peridotite part displaying high-temperature fabrics, from a

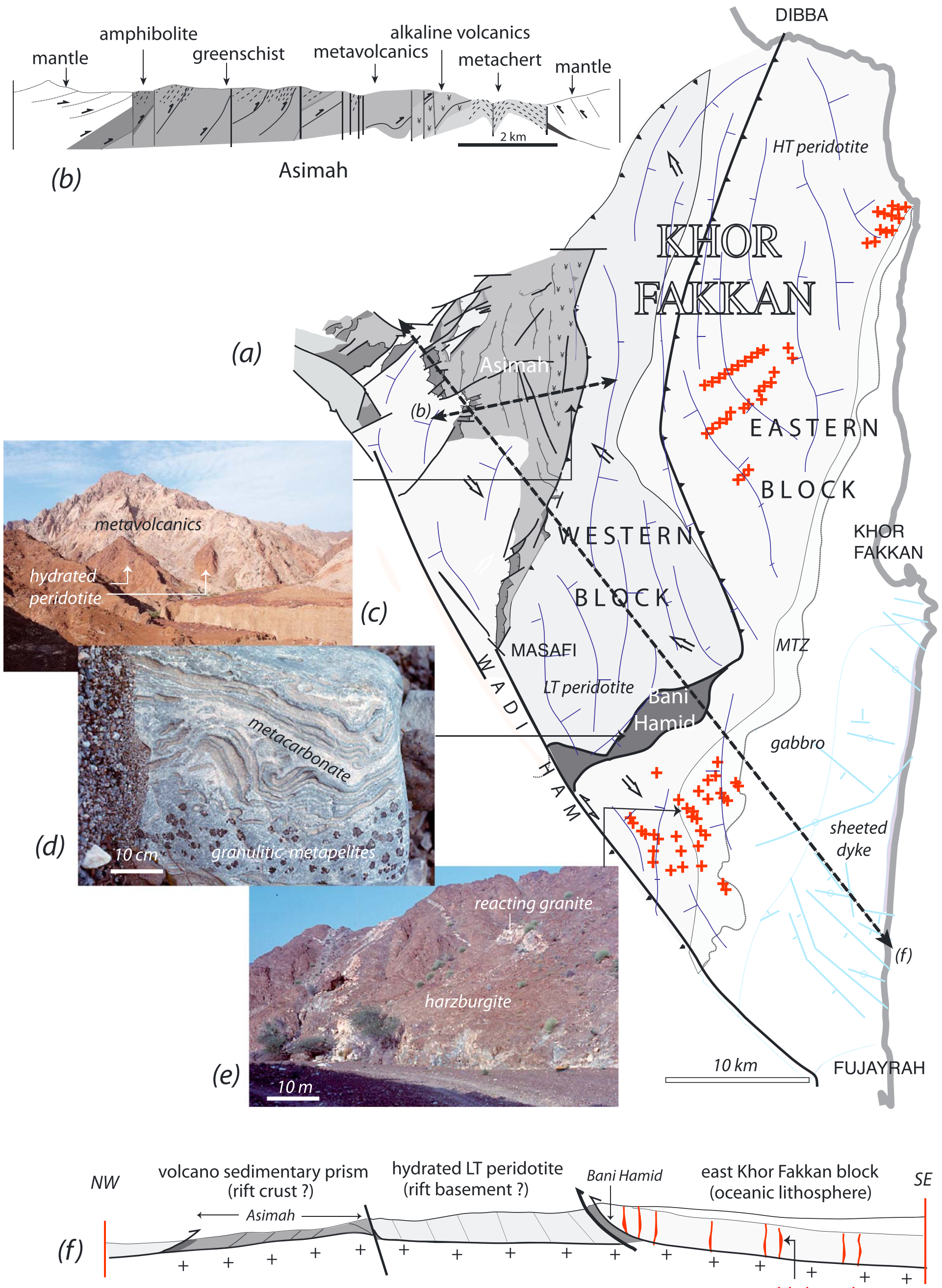

Figure 3. (a) Structural map of Khor Fakkan massif including metamorphic windows of Asimah and Bani Hamid after Gnos and Nicolas (1996), British Geological Survey (2006), and unpublished data. An east dipping structural limit separates eastern and western blocks in Khor Fakkan massif. The eastern domain is composed of normal oceanic lithosphere, but marked by multiple granitic intrusions (red crosses) invading the high-T mantle section. The granulitic Bani Hamid inlier marks the western limit of this domain (Gnos & Nicolas, 1996). The western block of Khor Fakkan massif is composed of hydrated mantle at low-grade conditions of talc and chlorite stability along east dipping foliation planes that abut on the Asimah metamorphic inlier. (b) Cross section through the Asimah metamorphic window, after British Geological Survey (2006) and unpublished data. The Asimah metamorphic inlier, 12 km in maximum extension, is totally asymmetrical, composed of a pile of greenschist rocks (metavolcanics including alkaline basalt, and metacherts) thrust eastward. The Asimah window is edged at its western margin, by a complex interlayering of high-grade amphibolites with highly sheared mantle peridotite. At its southern termination, the Asimah window is reduced to a metamorphic section that is 1 km thick, west dipping, and having the characteristics of a metamorphic sole. (c) Field view, looking west, on the thrust contact of Khor Fakkan hydrated harzburgite over Asimah metavolcanics (d) garnet-bearing granulitic metapelites interlayered with folded metacarbonates representative of Bani Hamid granulitic facies. (e) Field view of mica-bearing granite injections reacting with the enclosing harzburgite of eastern Khor Fakkan block. Locally granite intrusions are crosscut by basaltic dikes. (f) Cross section through the Khor Fakkan massif. The abundant granitic intrusions invade selectively the eastern oceanic lithosphere of the upper plate, reacting with the enclosing hot mantle. Hydrated mantle from the western lower plate is thrust, at greenschist facies condition, against the imbricated volcano-sedimentary prism component of the Asimah inlier.

western one with porphyroclastic to mylonitic fabrics (Figure 3a). The granulite facies foliations and lineations in the metamorphic rocks of Bani Hamid can be correlated with porphyroclastic textures developed at decreasing temperature in the associated peridotites (Gnos & Nicolas, 1996). The presence of abundant quartzite (1) with enstatite-corindon-sillimanite-spinel-sapphirine assemblage, associated with alkaline mafic granulite (2), and calcsilicate (3) assemblages (Figure 3d) are unique to the Bani Hamid inlier (Gnos & Kurz, 1994; Searle & Cox, 1999). The three lithologies are roughly distributed from west to east, and any steep inverted metamorphic gradient is absent (Gnos & Kurz, 1994). The peak metamorphism points to 800–850 °C at 9 to 6 kbar based on the stability of sapphirine (Gnos & Kurz, 1994; Searle et al., 2015), and retrograde temperatures are recorded down to ~300 °C.

2.5. Granitic Intrusions

A collateral characteristics of the Khor Fakkan massif is the extreme development of a K-poor calc-alkaline suite evolving from grano-diorite to mica-bearing granite invading the eastern domain of Khor Fakkan mantle (Figure 3a; British Geological Survey, 2006). Intrusions occur as irregular and anastomosing dikes 100 m thick, to meters scale lenses and patches (Gnos & Nicolas, 1996; Peters & Kamber, 1994). The granitoids clearly crosscut the mantle fabric, but some reactive margins (Figure 3e), and later injection of crosscutting diabase dikes locates their injection during cooling of the mantle section. The negative εNd values combined with the most mantle-like initial $^{87}Sr/^{86}Sr$ point to a mixed origin of a LILE-enriched mantle component and a “continental” sedimentary component (Briqueu et al., 1991; Cox et al., 1999).

Two series of dating zircon fractions on granite intrusions (Styles et al., 2006) provide ages 93 and 91–92 Ma (Figure 4a). Interestingly, a unique well-defined Rb-Sr isochron (whole rock on two samples) in a granite intrusion from Fujayrah area provides an inconsistent age 130 Ma (Briqueu et al., 1991).

Such granitic intrusions exist but are not common in the Oman part of the ophiolite (Béchennec et al., 1992; Nicolas et al., 2000b; Figure 2a). They are exposed into a major lineament located below paleo-Moho in Haylayn massif where they form kilometric-sized lenses. Their enrichment in mobile trace elements (Rollinson, 2009) characterizes a continental component, also signed by a negative εNd (Rioux et al., 2013). The granitic intrusion of Wadi Haymilyah is dated U/Pb on single-grain zircon, providing an age 95.2–95.3 Ma, slightly younger than average accretion age 96.0 (Rioux et al., 2013; Figure 4a). Two other exposures of peralkaline granite locate along major shear zones (Figure 2a), at limits of Wuqhah and Miskin massifs, and south of Sumail massif (Béchennec et al., 1992). The mixed oceanic-continental signatures of these granitic intrusions are indicative of continental contamination in the still hot mantle peridotite, well localized along the Semail belt.

A marginal type of silica contamination of mantle rocks is the development of listwaenite, a carbonated-silicified alteration of basal peridotite. Liswaenite alteration is largely developed at the basal section of Aswad massif, and in basal peridotite enclosing the Fanjah saddle (Figure 2a), but exposed sporadically along major discontinuities separating northern and central massifs (Nasir et al., 2007). The thermal conditions of listwaenite development are not documented.

2.6. Ages of Detachment

Recent U-Pb dating on single-grain zircon from metamorphics (Rioux et al., 2016) have complemented data obtained on ^{40}Ar-^{39}Ar from amphibole compiled in Hacker and Gnos (1997) and U-Pb on zircons fraction (Styles et al., 2006; Warren et al., 2005). New dates on Sumeini and Wadi Tayin soles located the peak metamorphism at 96.16 and 94.82 Ma, respectively, with a precision 0.02–0.03 Ma on single-grain zircon measurements (Figure 4b). These dating substantiate ancient $^{40}Ar/^{39}Ar$ ages on amphibole that suggested slightly older ages of detachment in the northern Semail ophiolite compared to the southern one. As an achievement of high-precision measurements, new data at Sumeini window indicate an overlapping age of the metamorphic sole (96.16 ± 0.02 Ma; Figure 4a) with that of magmatism (96.75 to 95.30 Ma; Rioux et al., 2016), suggesting that first stages of detachment are coeval of late accretion stages, in this northern Oman part of the ophiolite nappe.

In the Emirates, U-Pb dating on zircon fractions is available (Figure 4a), providing 95–96 Ma in Masafi window, and 91.5 to 93.5 Ma in various lithologies from Bani Hamid (Styles et al., 2006). Single-grain zircon dating in Bani Hamid brackets these data at 94.5 for amphibolite and 92.5 on felsic pod (Searle et al., 2015).

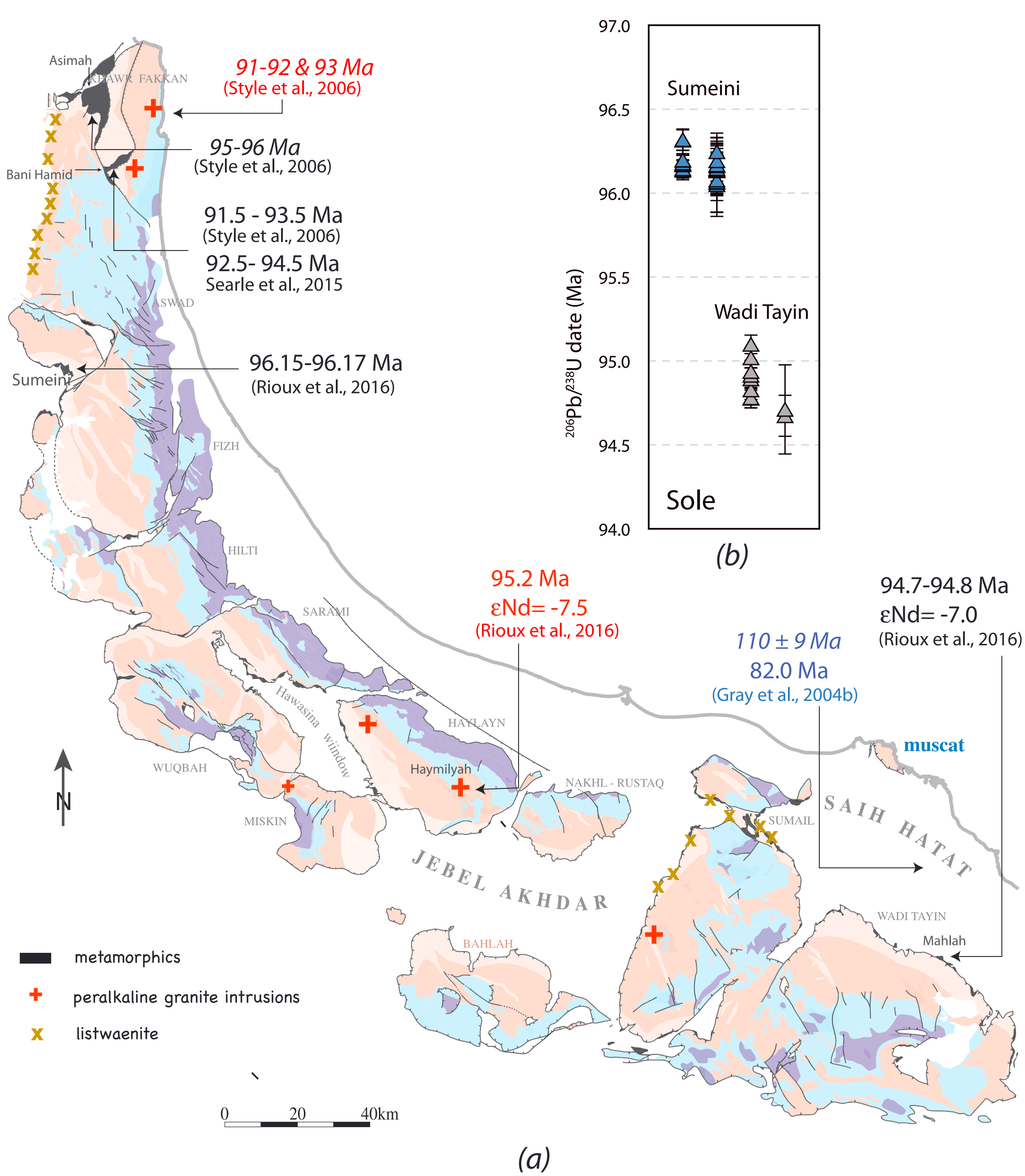

Figure 4. (a) Recent dating on metamorphic soles and windows (black label), on alkaline intrusions (red label), and on UHP metamorphics (blue label). Styles et al. (2006) are U/Pb dating on zircon population; Rioux et al. (2016) and Searle et al. (2015) are youngest precise single-grain date U/Pb on zircon, and εNd data. Gray, Hand, et al. (2004) are Sm/Nd isochrone and single-grain date U/Pb on zircon. (b) Integrated U/Pb ages on single-grain zircon from metamorphic soles at Sumeini and Wadi Tayin (northern and southern ophiolite, respectively; Rioux et al., 2016).

3. Arabia-Neotethys Margin

3.1. Shield Margin

The Arabian shield is exposed in the north Oman Mountains in two large tectonic windows open inside the ophiolite belt, Jebel Akhdar and Saih Hatat (Figure 2a). They form domes wrapped by the thick sedimentary cover of Permian to Cretaceous age, Hajar Super Group of Glennie et al. (1974), spectacularly excavated in the central part of the domes.

3.2. Jebel Akhdar Internal Structure

In Jebel Akhdar, the excavated dome exposes flyshoid formations into separate windows (Figure 5a), assigned Precambrian to Ordovician, mapped as Hatat Schists in Béchennec et al. (1992). A low-grade metamorphism is developed (anchi-zone to low greenschist facies from west to east), marked by a synmetamorphic schistosity. This deformation was inherited from Hercynian times according to Glennie et al. (1974), although it is assigned by Le Métour et al. (1990) to late Cretaceous Eo-Alpine event related to ophiolite emplacement, having affected the entire dome-shaped structure.

The structural map of the pre-Permian windows in Jebel Akhdar (Figure 5a) points to the ubiquity and consistency of lineations strongly marked by elongation of mud-balls and pull-apart of quartzite pebbles (Figures 5b and 5c), parallel to the intersection of S1 south dipping synmetamorphic foliation and a S2 cleavage. This ubiquitous NE trending stretching lineation, measured in the five pre-Permian Akhdar windows, is also recorded in the Mesozoic cover (Le Métour et al., 1990). The Mesozoic sequence unconformably overlies the pre-Permian formations. However, in many contacts, the S1 schistosity rotates into parallelism with Permian carbonate layers, and a refracted S2 cleavage crosscuts the lower Permian formation (Figure 5d), signing the post-Permian stage of the ductile deformation recorded in the Jebel Akhdar windows. Pointing to the consistent orientation of the flow-line compared to Saih Hatat (Figure 6a; Gray, Miller, et al., 2004; Gregory et al., 1998), we assume that the plastic-flow tectonics affecting the pre-Permian formations of Jebel Akhdar developed in contemporaneity of structuration in Saih Hatat. This interpretation gets some confirmation in the study of the Muscat Nappes (upper units of Saih Hatat complex; Michard et al., 1984), providing comparable ductile structures in similar facies and assigned by the authors to a Cretaceous event predating the ophiolite emplacement at ~80 Ma. To conclude, following Le Métour et al. (1990), we assign to an Eo-Alpine event the structuration of the pre-Permian shield margin exposed in the core of the Jebel Akhdar dome.

3.3. Saih Hatat HP/LT Metamorphism

The rocks exposed in the large window of Saih Hatat, at the eastern edge of the Oman Mountains (Figures 2a and 6a), underwent blueshist to eclogite facies metamorphism. Due to their exceptional situation inside the ophiolitic nappe and their integral preservation, the Saih Hatat formations have raised heated discussions. They are affected by intense deformation recorded at decreasing metamorphic conditions from the southeastern limit (eclogitic boudins from As Sifah) to carpholite-bearing greenschist facies rocks (Goffé et al., 1988) in the Muscat nappes. These HP/LT formations include continental and oceanic (metabasalt) components. Despite the complexity of overlapping layers and subsequent folding, the structural maps exhibit a consistent NE to NNE trending stretching lineation (Figure 6a), and a dominant NE overturning of numerous folds (Gray et al., 2005; Gregory et al., 1998). Based on the oceanward vergence of structural planes, the HP/LT metamorphic facies have been considered as related to intraoceanic offshore subduction (Searle et al., 1994), or to the ophiolitic nappe emplacement (Michard et al., 1984). Both group of authors retain the youngest age (78 Ma) among the many ^{40}Ar-^{39}Ar dating (Montigny et al., 1988), spreading between 130 and 80 Ma. The ^{40}Ar-^{39}Ar dating includes clear plateaus, mixed with uninterpretable isochrons (El-Shazly et al., 2001), that probably trace the retrograde evolution of amphibole- and phengite-bearing parageneses (El-Shazly & Sisson, 1999; Gray, Hand, et al., 2004). The youngest age (80 Ma) also confirmed by U/Pb on zircon from eclogite (Warren et al., 2005) was considered as dating the peak metamorphism. Alternately, a second group of authors (Gray, Miller, et al., 2004; Gray, Hand, et al., 2004; Gray et al., 2005; Gregory et al., 1998), based on most documented structural mapping and microstructural tracing of facies evolution, propose that the exhumation of high-pressure rocks is recorded in retrograde metamorphic facies, at a time scale bounded between 120 and 80 Ma (Figure 4; Gray, Hand, et al., 2004). Thus, the northeastward vergence expresses the exhumation phase, implying that the kinematics of prograde metamorphism is a SW-directed movement, occasionally sealed by helicitic inclusions in growing garnet from eclogitic boudins, and dated (Figures 6b and 6c; Gray, Miller, et al., 2004).

3.4. Sedimentary Record

A considerable volume of work related to 1:100,000 geological mapping in Oman and Emirates Mountains (British Geological Survey, 2006; Bureau de Recherches Geologiques et Minières, 1986) provides a stratigraphical framework and paleogeographical reconstructions on the evolution of the Arabian continental

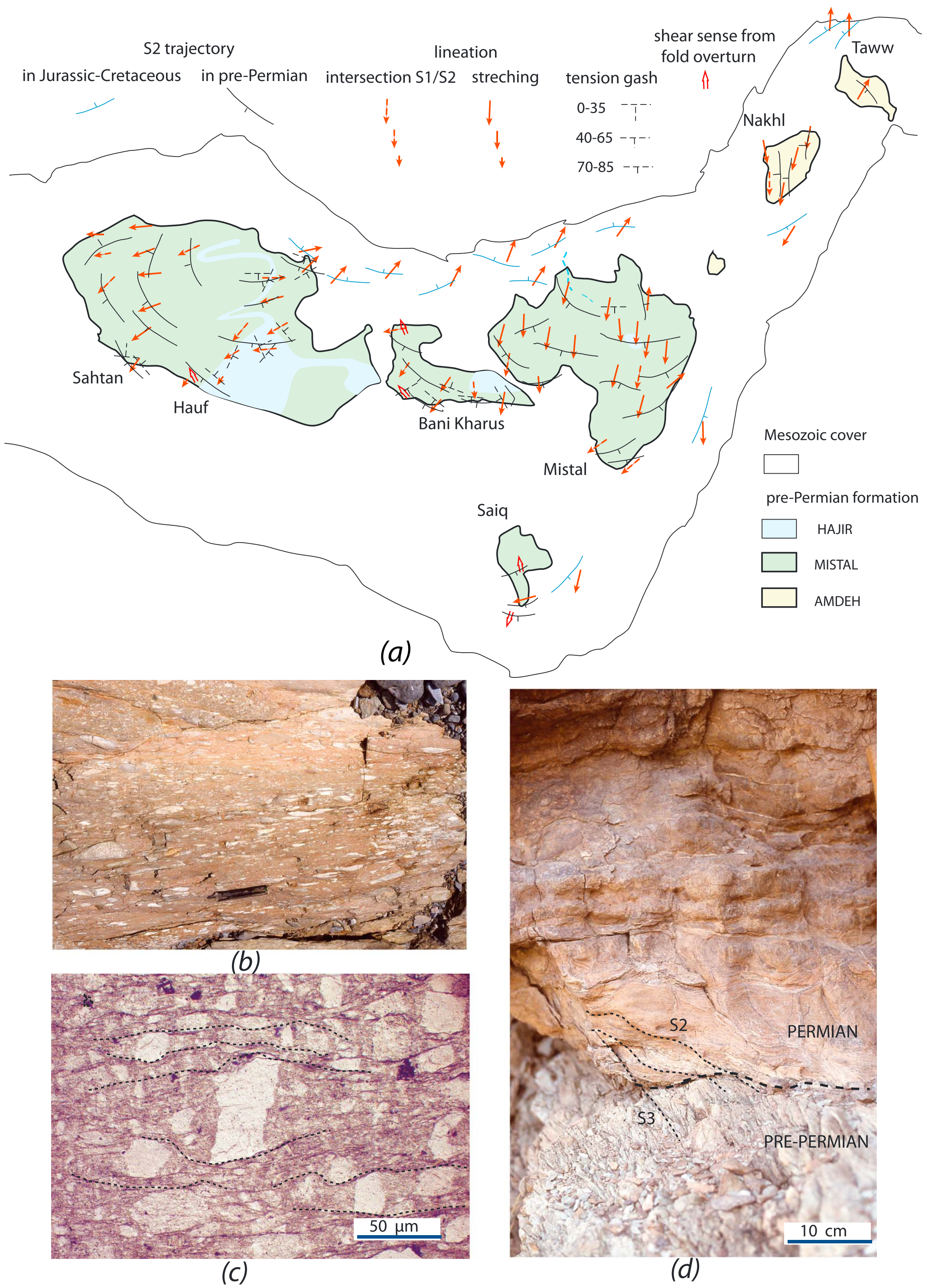

Figure 5. (a) L + S fabrics in pre-Permian windows from the Jebel Akhdar dome. Synmetamorphic shistosity and strong streching lineation in quartz-schist from the pre-Permian formation, affected by low-grade metamorphism (anchizonal to greenschist from west to east; Glennie et al., 1974). Planar structures and streching lineations in Jurassic-Cretaceous cover are from Le Métour et al. (1990). (b) Streching lineation in pre-Permian schists of Mistal formation, marked by elongated quartzite pebbles (sample 86OC48, scale marker = 10 cm). (c) Pull-apart of highly stretched quartz grains from quartz-rich schist in Hajir formation; slip plane along S1 are marked by low-grade phyllosilicates in anchimetamorphic pelite. Doted lines image streched quartz grains reconstructed after their pull-apart remnants (plane-polarized light, parallel Nicols; sample 86OC20). (d) Close view on pre-Permian/Permian discordance where S2 and S3 clivage affects the underlying Permian level (sample 86OC39).

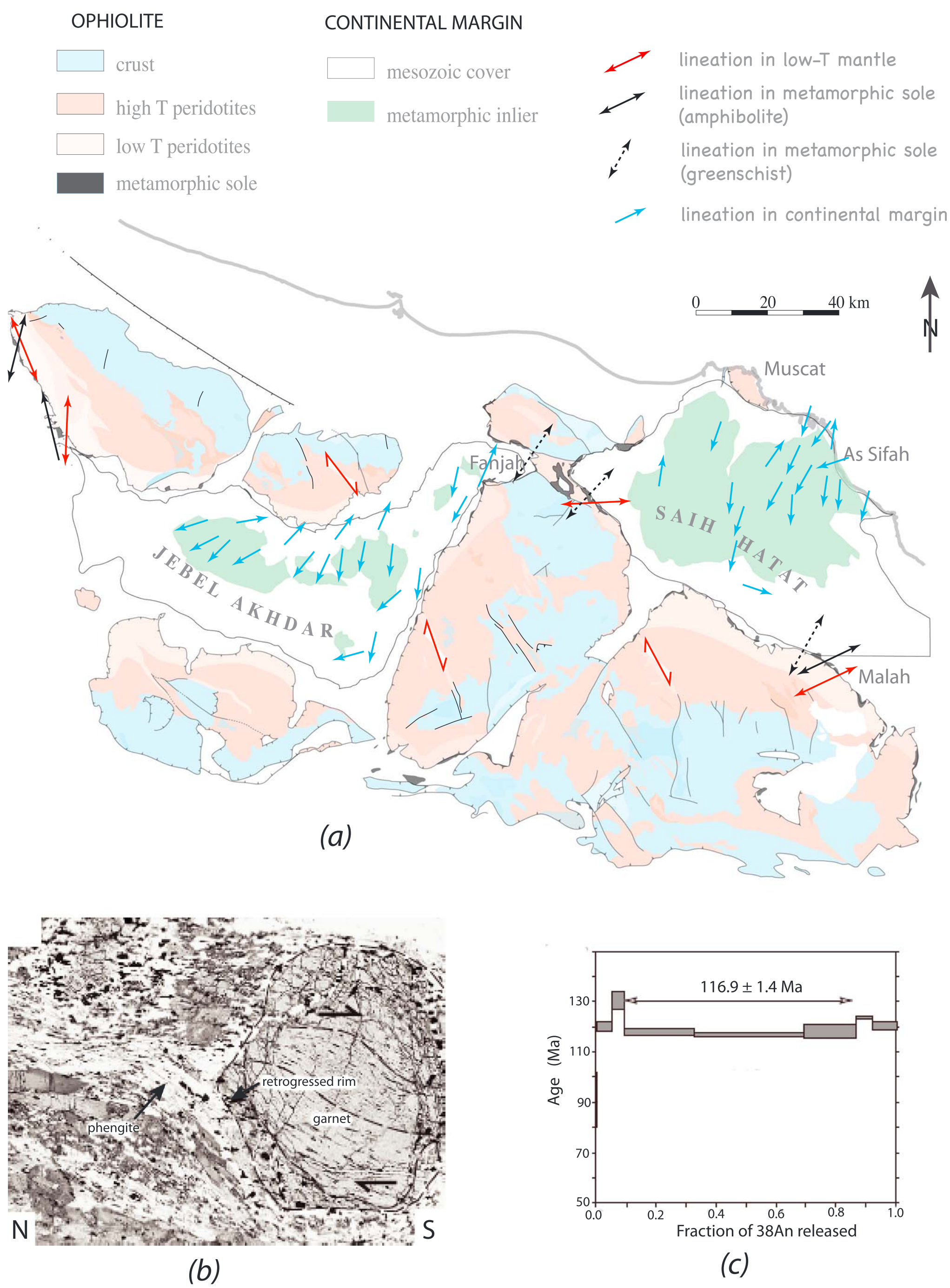

Figure 6. (a) Stretching lineations recorded in the continental margin, pre-Permian windows (this study) and Mesozoic cover (Le Métour et al., 1990) in Jebel Akhdar, and in lower and upper nappes from Saih Hatat (Gray, Miller, et al., 2004; Gregory et al., 1998). These ubiquitous streaching directions are compared with transport directions recorded in the greenschist rocks from metamorphic sole at the base of the southern ophiolitic massifs (Boudier et al., 1985). (b) Early formed garnet with helicitic inclusions (rutile and clinopyroxene) indicative of prograde rotation top-to-the-south in an eclogitic boudin from as Sifah, Saih Hatat (width of photograph ~5 mm). (c) Laser $^{40}Ar/^{39}Ar$ plateau spectrum in phengite from the same garnet eclogite sample (Gray, Miller, et al., 2004).

margin during opening and closing of Neotethys. We extract here the main scenario derived from joined studies of the autochtonous and allochtonous sedimentary sequences, and their evolution from south to north.

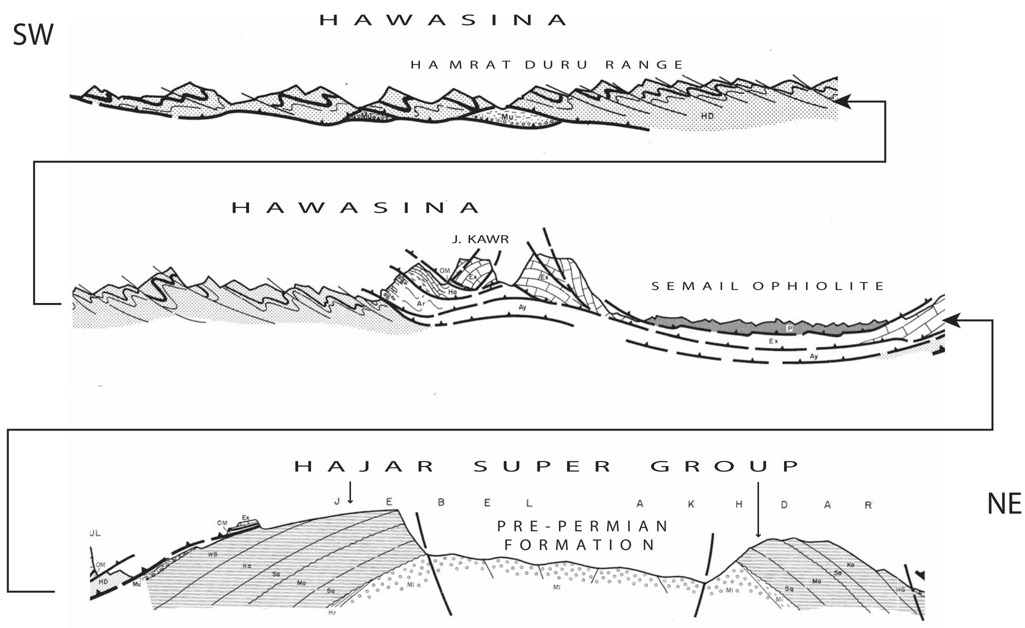

Figure 7. NE-SW cross section through the Hajar Mountains (see location in Figure 2). Hawasina allochtonous units, overlain by the Semail ophiolite, thrust on the autochtonous Hajar supergroup and pre-Permian formation of the Jebel Akhdar. Elevation not to scale (after Glennie et al., 1974).

In the southern Oman Mountains, a large part of the thrust-repeated allochtonous sedimentary formations are represented in Wadi Hawasina window, and by the Hamrat Duru Group (Figures 2a and 7). These sequences are deposited in a marginal basin open during Late Permian, rifting and subsiding during Triassic and Jurassic (Béchennec et al., 1988, 1990; Glennie et al., 1974). The outer limit of the continental basin is formed by Permo-Triassic reefal formation of the Kawr group. The most distal part of the Hawasina nappes belongs to Umar Basin, which Triassic to Mid-Jurassic sedimentation marks the transition to Neotethyan Ocean, spreading since Triassic. Following a period of extension during Triassic-Jurassic times, marked by within plate alkaline volcanism evolving to mid-ocean ridge basalt locally, a foundering of the continental margin recorded at the inner margin of Hamrat Duru Basin occurs during Titonian-Berriasian (~140 Ma). This event marked by an ~300-km southward retreat of the continental slope, followed by a starved sedimentation in the basin (Béchennec et al., 1988), is terminated in Santonian (~85 Ma), when the first stage of obduction is initiated (Béchennec et al., 1990).

In the northern Oman and Emirates Mountains, shelf slope marginal basin ramp sedimentation is dominantly represented by the Sumeini Group, toward a basin dominated through Triassic and Jurassic by radiolarian chert crosscut by intraplate alkaline volcanism, basin open on the Neotethyan Ocean (Glennie et al., 1974; Lippard et al., 1986; Searle et al., 1983; Styles et al., 2006). This ramp persists till late Cenomanian marked by foundering of the platform margin, preceded nevertheless by its increasing instability (uplift and erosion) during Late Jurassic-Early Cretaceous (Philips et al., 2013; Searle et al., 1983).

One key point concerning the dynamics of the Neotethys margin is represented by the position of exotic blocs of the Kawr Group (Figure 7), widespread along the frontal margin of the ophiolite. These recifal formations of Permian-Triassic age are deposited upon oceanic basalts and cherts indicative that the oceanic ridge was volcanically active through Permian, and spreading till Mid-Cretaceous. As postulated by Glennie et al. (1974), a considerable width of oceanic crust must have been generated between the Triassic exotics and Upper Cretaceous location of the Semail nappe at time of its detachment. The question is “What was the fate of this unknown extension of oceanic lithosphere?” The second question proceeds of the evolution of the rifted continental base of Hamrat Duru Basin, when its >200-km extended Hawasina sedimentary cover has been imbricated onto the continental margin. In other words, how would the “foundering” of the continental margin, dated Berriasian, at ~140 Ma (Béchennec et al., 1990) solve the space problem for continental basement that was beneath the Hamrat Duru basin prior to shortening?

3.5. Fate of Jurassic-Cretaceous Lithosphere

Vergence of the Mesozoic Tethyan suture as recorded in the Semail ophiolite is based on the early assumption (Pearce et al., 1981) that Semail oceanic lithosphere was formed offshore behind a subduction zone by back-arc spreading and volcanism (Alabaster et al., 1982). Then most structural and tectonic models proposed for the emplacement of the ophiolite have involved the NE directed subduction away from the passive continental margin of the Arabian plate (e.g., Goffé et al., 1988; Hanna, 1990; Le Métour et al., 1990; Lippard et al., 1986; Searle et al., 1994). Thrusting of the ophiolite and the underlying sedimentary sequences propagated from NE to SW with time, with more distal units thrust over more proximal units, and finally, the entire allochthon was emplaced onto the northern margin of the Arabian continent. The model largely accepted of oceanward subduction faces a problem of assimilation of thrust nappe emplacement initially described by Glennie et al. (1974; see Figure 7) with lithospheric plate limit represented by lithospheric subduction. Nappe emplacement, oceanic detachment, and oceanic subduction are documented events with different temporality and thermal conditions. Both systems, thrust of oceanic sedimentary cover versus lithospheric plate subduction, are not coeval and not necessarily consistent. In particular when referring to the Arabian continental margin, the northeast vergence of nappe emplacement does not imply northeast vergence of the subducted lithospheric plate. The complex geometry of detachment along-strike the ridge add consistence to this reasoning, and will be discussed further.

When referring to Tethys closure, alternate models of genesis and emplacement of the Semail ophiolite, namely, (1) the intraoceanic subduction channel (Searle & Cox, 1999) or (2) the detachment at a mid-ocean ridge (Boudier et al., 1988; Coleman, 1981), hardly account for the removing of a large extension of oceanic lithosphere accreted between the Semail paleoridge and the Arabian margin, at time of the ophiolite detachment ~95 Ma. The first model invokes a nascent subduction in order to comply with the 1-Ma time laps between accretion of the Semail ophiolite and its detachment, and the second model involving oceanic lithosphere duplication requires accretion and oceanic detachment at close distance to the continental margin.

The closure of Neotethys and plate reorganization in the Indian Ocean during Cretaceous time is subject of debate as subductions have removed vast areas of oceanic crust, obliterating a large part of the paleogeographic record. For most reconstructions, a large Neotethyan ocean is open eastward during Cretaceous, with a central spreading ridge, the northern Neotethyan plate being subducted northward (Transit Plate; Dercourt et al., 1986, 1993; Scotese, 1997; Stampfli & Borel, 2002). The southern Neotethyan plate has variable fate in paleogeographic reconstructions, northward oriented intraoceanic subduction for Stampfli and Borel (2002), southward oriented subduction for Scotese (1997), or a no-model between 140 and 94 Ma for Dercourt et al. (1993). A divergent reconstruction (Scotese et al., 1988) emphasizes the location, at the northern Arabian margin, of a triple junction during Mid-Cretaceous, accounting for Owen transform positioning. These pendent questions assign all the more value to complementary record from the obducted oceanic plates.

4. Toward an Alternative Model

The part of Neotethyan closure recorded through detachment and obduction of Semail ophiolite on the northern Arabian margin, definitely active before the end of Cretaceous, is certainly much more complex than figured in simple bidimensional models. In the course of this paper we have pointed a certain number of petrostructural facts concerning the evolution of the Neotethyan Arabian margin never integrated in the geodynamic models. Following Gray and Gregory involvement (Gray, Miller, et al., 2004; Gray et al., 2005; Gregory et al., 1998) in their study of Saih Hatat, we have proposed a model of ridge-trench convergence accounting for the Emirates part of Semail ophiolite (Nicolas & Boudier, 2017), and implying the existence of an Arabian platform-directed subduction during Mesozoic. Before tentatively extending this conceptual model to the entire Semail ophiolite, we recall here some characteristics of ridge-trench collision stem as a geodynamic situation possibly leading to detachment and obduction of ophiolite.

4.1. Pacific-America Analogue

The best interaction documented between an active fast spreading-ridge and a continental trench is the convergent margin of America and Pacific Plates. A pointed specificity of such convergence is to produce hybrid volcanism as documented at the Chile Trench (Bourgois et al., 1996; Klein & Karsten, 1995; Sturm et al., 2000),

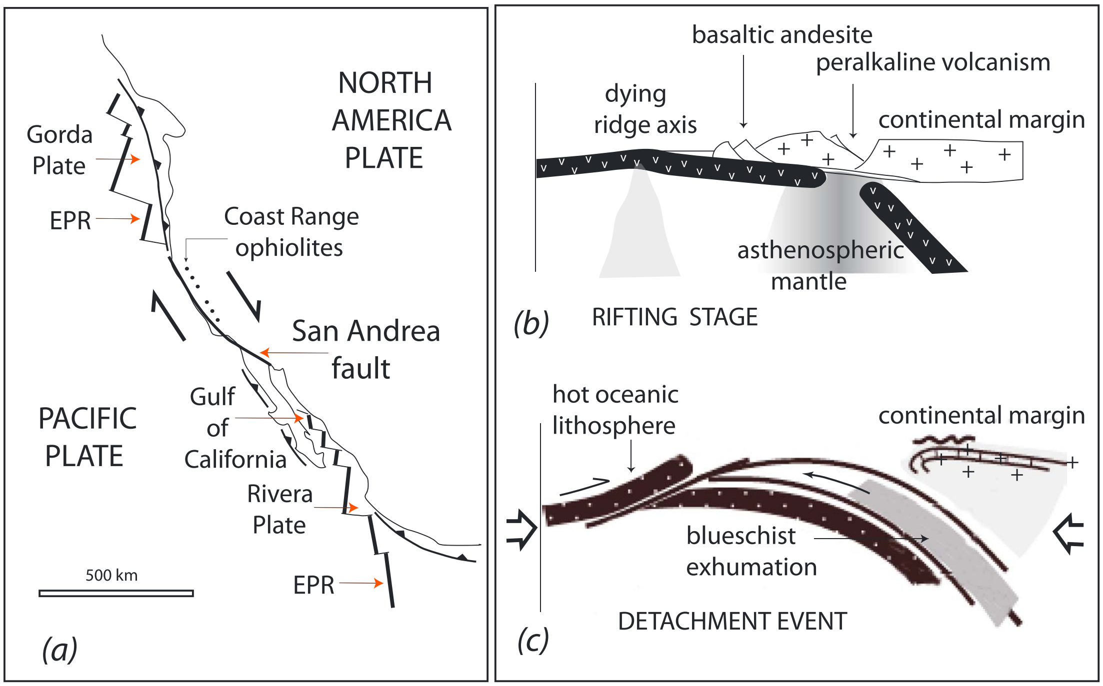

Figure 8. (a) Scheme of North America-Pacific convergent margin (Atwater, 1989; Thorkelson & Taylor, 1989) with the main assignments related to ridge subduction: migration of East Pacific rise (EPR) to rifted gulf of California, relayed by San Andreas transform fault zone, and future ridge-trench-transform (RTT) junction bounding the Gorda plate. (b) Slab window and related asthenospheric mantle upwelling evolving to rifting as represented by the Gulf of California. The area is characterized by multistage volcanism (after Calmus et al., 2011). (c) Possible evolution of a convergent margin at stage of ocean closure as inferred from southern Semail model (Coleman, 1981; Gray, Miller, et al., 2004; Gregory et al., 1998) detachment followed by obduction of a segment of hot oceanic lithosphere over an exhumed blueschist sequence.

and in the Baja California Peninsula (Aguillon-Robles et al., 2001; Benoit et al., 2002; Calmus et al., 2011; Pallares et al., 2007). The model we propose for Semail ophiolite is inspired from the segment of East Pacific Rise-North America junction, between the Baja California Peninsula and Gorda Plate (30° to 50°N; Figure 8a). The central part of this region is a slab-free zone or slab gap (Atwater & Severinghaus, 1989), where the continent-oriented subduction is converted into strike-slip movement (e.g., Fletcher et al., 2007) that controls the San Andrea fault stem. Where the spreading ridge intersects the subduction zone, spreading may cease, but the rigid plates must continue to diverge even when their boundary has moved beneath the subduction zone, thereby creating slab windows (Thorkelson & Taylor, 1989). The opening slab window (Figure 8b) may also generate an upwelling of warm asthenospheric subcontinental mantle (for review, see Bourgois & Michaud, 2002), seen through shear waves splitting at Chile Ridge convergent margin (Russo et al., 2010). There are other implications of this model that would have consequences for the Oman margin, like predictable migration of the triple junction and progressive transform slip.

Initiation of an intraoceanic thrusting event and ophiolite obduction from a ridge-trench-transform intersection has not been documented in the modern framework of America-Pacific Plate junction, except the little Taitao exposure at Chile Trench (Bourgois et al., 1996). However ophiolites have been emplaced on the America margin during the past, including the Jurassic Coast Range ophiolites (e.g., Hopson et al., 2008).

4.2. Relationship Accretion-Detachment

The complexity of Semail ophiolite detachment dynamics as recorded by mid-T (700°–900 °C) textures and fabrics in the sheared peridotite (Figure 2a) gains consistency in the frame of the North America-East Pacific Rise analogue (Figure 8a). In particular, the ridge-trench-transform triple junction has for consequence (1) unstable spreading accretion, marked by isochron pattern offsets; (2) along-strike variability of the convergent system driven by migration of spreading to transform slip; and (3) the eventuality of overthrusting a hot fragment detached from the oceanic lithosphere. These peculiarities meet with the along-strike variability of detachment kinematics recorded in structures of the Semail ophiolite as summarized in Figure 9 and insert. For this reason, 2-D models fail in representing the complete dynamics of ophiolite emplacement.

In the kinematics of lithospheric mantle flow (detachment) of Semail ophiolite summarized on the map of Figure 9, the inhomogeneity of the system is pointed: (1) opposite shear sense of detachment in Emirati Khor Fakkan and Aswad massifs, (2) prevalent strike slip in northern and central Oman massifs marking a southward transport in a sinistral strike-slip system, and (3) contrasted southwestward transport in Oman southern massifs.

Such variability of detachment kinematics must be inherited from a complex accretion framework, the more so as the most recent high-precision Zr dating (Rioux et al., 2016) emphasizes the synchronism of accretion and detachment (see Figures 1b and 4). The inferred ridge-trench interaction drives to a complex reorganization of the spreading system, as documented at America-Pacific Plate junction (Atwater, 1989; Klitgord & Mammerickx, 1982; Lonsdale, 1989), that would control the detachment dynamics.

In Semail, detachment structures develop at decreasing temperature (T~1,100–800 °C), and in structural continuity with accretion structures ($T > 1{,}100$ °C; Figures 1 and 2). This continuous path is confirmed by the extremely reduced time gap separating both processes. Accretion proceeds from a unique spreading axis that we compare with the EPR at America-Pacific plate junction. One effect of active ridge-trench interaction is to reorganize the spreading ridge, at the time scale of a few millions years, into individual segments, then dragged along the RTT convergent system. The inference is that the north-south segmentation observed in lithospheric structures (Figure 9 and insert) is inherited from accretion instability.

4.3. Synchronous Tectonics of Continental Margin

The tectono-metamorphic evolution of the Arabian margin during Cretaceous, as well as the sedimentary record chart a progressive breakup of the Arabian continental margin and closure of Neotethys during Middle to Late Cretaceous (Philips et al., 2013; Searle et al., 1983). As pointed in the sedimentary record (see section 3.4), the episode of starved sedimentation in Hamrat Duru Basin following an ~300-km inland retreat of the continental slope is assigned to foundering of the Hamrat Duru continental basement, initiated at the end of Jurassic (Béchennec et al., 1988, 1990). This Late Titonian event meets with oldest Ar/Ar ages (140 Ma) obtained on phengites from the Saih Hatat high-pressure shield area (Gray, Miller, et al., 2004 and Gray, Hand, et al., 2004; see section 3.3).

The joined mapping of the continental shield exposed in Sayh Hatat and Jebel Akhdar domes (Gregory et al., 1998; Le Métour et al., 1990; Figure 6a) emphasizes an ubiquitous distribution of the synmetamorphic foliation and a SW-NE directed stretching lineation. This concerns the anchizonal to greenschist-carpholite facies (external zone of Saih Hatat) as well as the high-pressure domain. Shear sense indicators like S/C planes in the external zone (Le Métour et al., 1990), and sense of overturned folds, or garnet pressure shadows in the HP formations (Gregory et al., 1998), yield transport direction south over north. Few opposite southward indicators belong to intracrystalline kinematic record, quartz fabric in quartzite (Michard et al., 1984) or helicitic inclusions in garnet from eclogite (Gray, Miller, et al., 2004; Figure 6b), both indicative of a prograde evolution. Being the only documented kinematics, these records militate for a southward oriented prograde tectonic phase (subduction) followed by a northward oriented exhumation (Gregory et al., 1998). Disputed ages in Saih Hatat HP metamorphics scattered between 120 and 80 Ma (see section 3.3) would record progressive cooling during exhumation (Gray, Miller, et al., 2004; Gray, Hand, et al., 2004).

The integrated data stress the tectonic activity recorded in the Arabian shield margin (Figure 6), preserved in retrograde metamorphism from Saih Hatat dome, blue-schist to green-schist facies, and represented in the Jebel Akhdar with similar NE directed transport direction (see section 3.2). These ubiquitous stretching directions are also expressed during Late Cretaceous in southern Semail, as recorded in the greenschist phase of sole metamorphism from Fanjah and Malah areas (Figure 6). This tectonic activity meets with instable sedimentary record extending over the same period, and questions the synchronous history of continental margin tectonics and nappe emplacement in a convergent system.

The next integrated feature relies on contamination of continental origin in the ophiolite, marked at first order by alkaline magmatism of Late Cretaceous age (see section 2.5 and Figure 3). Pregnant in the Emirate part of the ophiolite, present in the Oman part of Semail, these calk-alkaline intrusions never accounted for in previous models get consistency in a convergent plate model (see section 4.1 and

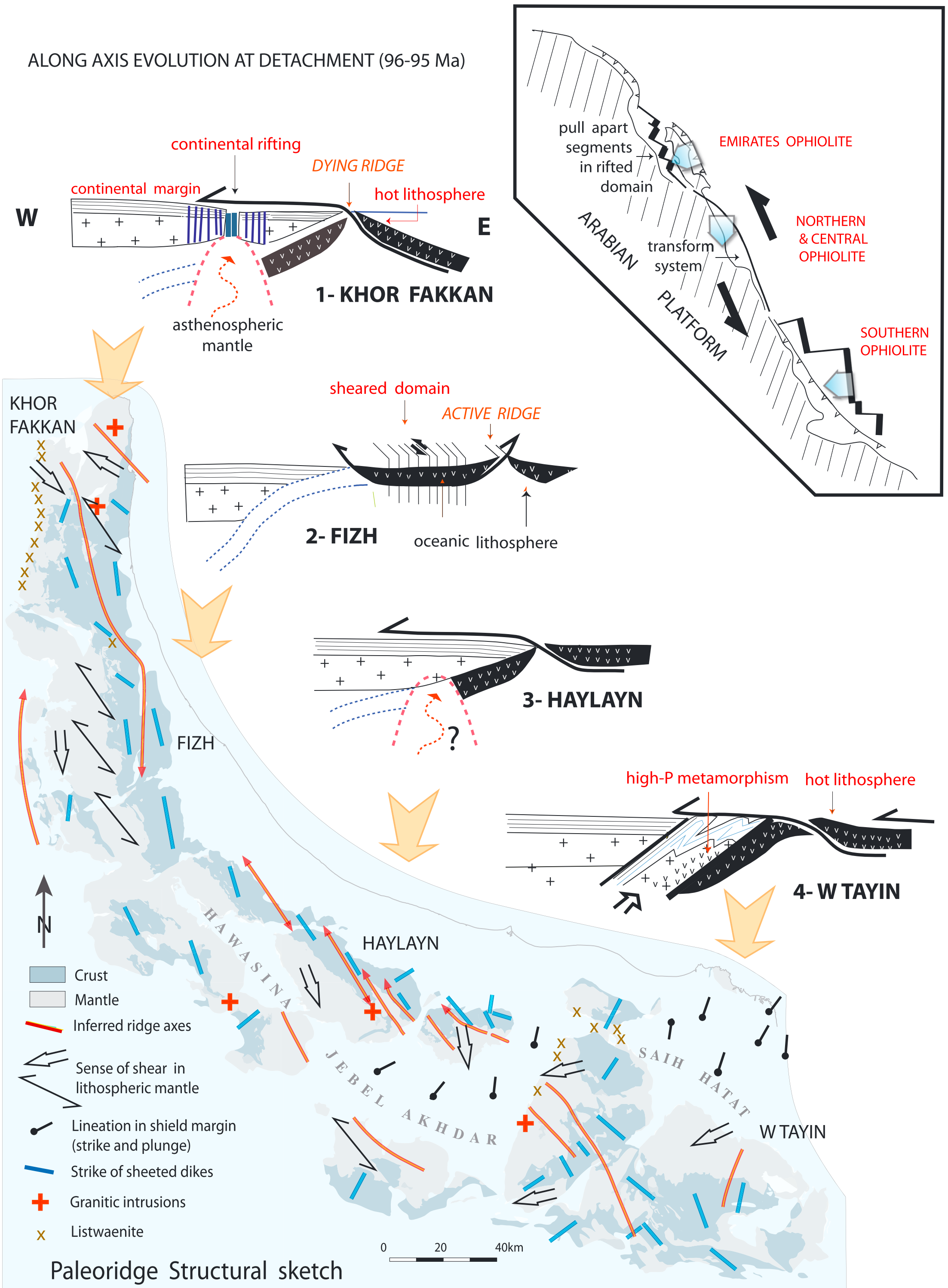

Figure 9. Cross sections representative of local geodynamic situation along-strike the Arabian continental margin at time of Semail ophiolite detachment, as inferred from the analyzed kinematics (structural map) and ridge-trench-transform model (insert). (1) Khor Fakkan section from Emirati massif, marked by multiple akaline intrusions is assumed to relate with an incipient rifting generated above a slab window (see text). (2) Fizh section is characterized by transcurrent high-T shear zones, inferred to represent a segment where the continent oriented subduction is converted to strike-slip movement (see insert). (3) Haylayn section is representative of the central massifs split in two lineaments along Jebel Akhdar-Hawasina upwelling, and containing local marks of continental melt intrusion. (4) Wadi Tayin and Sumail southern segments are representative of a microplate detached at the spreading ridge, then obducted over the exhumed high-pressure rocks of Saih Hatat (see text).

Figure 8b). The geochemical and isotopic characteristics of granitic intrusions in Khor Fakkan massif are assigned to melting of a metasedimentary source (Briqueu et al., 1991; Cox et al., 1999), an assumption that requires a heat source close to the trench locus of the sedimentary deposition, itself close to the inferred continental source. Such proximity is also suggested from contaminated dikes by a continental source dated only 0.25 to 0.50 Ma after oceanic accretion (Rioux et al., 2013).

4.4. Along-Strike Evolution of Semail Ophiolite Exhumation

The along-strike evolution accounts for the petro-structural variations observed along the Semail belt, including the kinematics of lithospheric mantle flow, as well as the tectonics of the continental margin, all compiled in the first part of this contribution. In the model proposed of convergent margins, the blocking situation created by active ridge-trench interaction initiates segmentation at the accretion stage, leading then to specific evolution of segments before they are obducted on the continental margin at the compression stage.

The along-strike evolution of Semail ophiolie is represented in four sections having specific characters (Figure 9), imaging the geodynamic situation at time of detachment, Upper Cretaceous at 95–96 Ma. The four sections are restored in a N-S evolution scheme inspired from the California-East Pacific Rise RTT system (Figure 9, insert).

The abundance of alkaline rocks either intrusive in mantle section, or as component of the metamorphic windows in Emirati massifs, Khor Fakkan, and Aswad (Figure 9 and section 1), is a distinctive mark of an early continental contamination of the ophiolite. The substantial development of alkaline magmatism in this area requires a heat source at the continental margin. This heating has been assigned to the effect of an asthenospheric mantle upwelling at a slab window, and led to propose a model of rifted margin for this part of the Semail ophiolite, in the frame of convergent margins situation (Nicolas & Boudier, 2017). Following the invoked rifted stem related to active ridge-trench interaction during Cenomanian, ~96 Ma, a scenario of evolution of the convergent margins during next compression phase is proposed (Figure 10c), based on detailed mapping of Khor Fakkan massif (Figures 3a and 3f). The oceanic lithosphere of the eastern block (upper plate) is injected by the alkaline magma during its obduction over the rifted domain, at ~93 Ma (Figure 4) coeval with extrusion of granulitic rocks from the Bani Hamid inlier. We speculate that the western block from Khor Fakkan massif, hydrated mantle and imbricated volcano-sedimentary prism, could represent the mantle and crustal basement of the rift, respectively, thrust westward at greenschist facies condition.

The consistent information sorted from compilations in northern Oman ophiolite (Fizh and Hilti massifs; Figure 9 and section 2) is a homogeneous south directed detachment, parallel to the paleoridge, recorded in the basal mantle section. This kinematics is associated with transcurrent shear zones slightly oblique to the paleo-ridge, largely developed with a clear sinistral strike slip in Fizh massif. We infer that Fizh and Hilti massifs are composed of oceanic lithosphere transported southward through a penetrative strike-slip system affecting the shallow mantle section. The lithospheric shear zones would represent the deep traces of conversion of rifting into strike-slip dynamics, by reference to present framework of East Pacific (see Figure 9, insert).

Massifs forming the central part of Oman ophiolite (Figure 9 and section 3) split around the Hawasina window and western Jebel Akhdar. The interpretation of this section is highly dependent on the structuration of the pre-Permian shield (Figure 5). Internal shear zones in these massifs are numerous and shear sense obtained are inconsistent (Figure 2a), but interestingly, the southernmost shear zones are intruded by granites that mark a continental contamination at temperature of continental crust melting. The detachment model for these massifs is most speculative, inferring that splitting of the ophiolite into northern and southern lineaments is a consequence of Jebel Akhdar doming, an event following immediately the ocean-lithospheric plate obduction, and possibly due to residual heat of an asthenospheric mantle upwelling. The assumption is supported by the interpretation of Jebel Akhdar pre-Permian Hatat schist structures, assigned to late Cretaceous Eo-Alpine events (Le Métour et al., 1990; Figure 5).

The sense of detachment related to the southern Oman ophiolite (Sumail and Wadi Tayin massifs; Figure 9 and section 4) is divergent compared to the major part of Semail ophiolite (Figures 2a and 9), but happens to be consistent with kinematics associated with the retrograde evolution of high-pressure rocks from Saih Hatat, and the strong linear structuration of the pre-Permian schists of Jebel Akhdar (Figures 5a and 6a). More precisely, basal peridotite and metamorphic sole at Wadi Tayin indicate a progressive rotation of

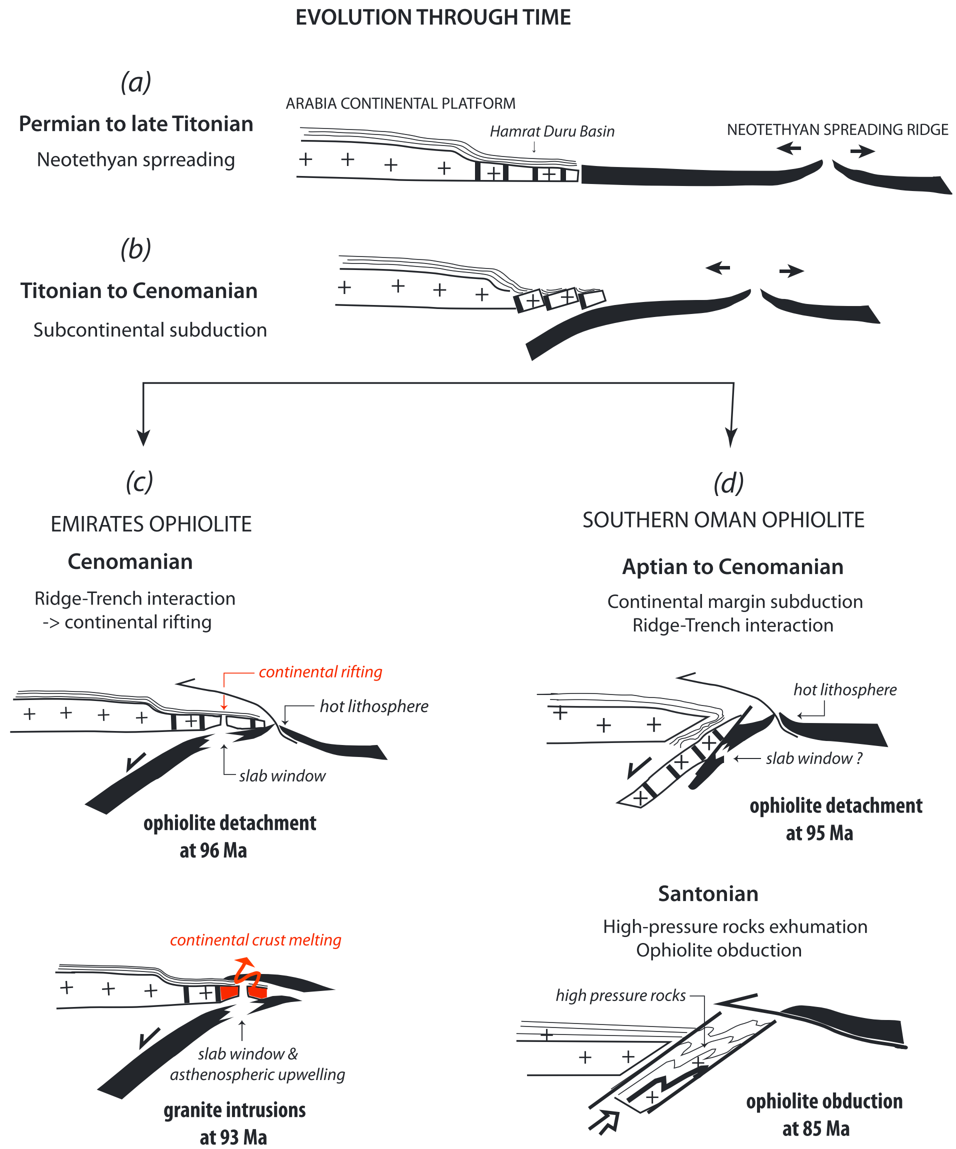

Figure 10. Evolution through time of Semail-Arabia convergent margins. (a) Oceanic lithosphere created at contact with the Arabian passive margin. (b) Initiation of subcontinental subduction, inferred to relate with Titonian foundering of the thinned Hamrat Duru basement. (c and d) Upper Cretaceous evolution in the best documented northern and southern segments (see text).

transport direction from ENE-WSW to N-S at decreasing temperature (Figure 2c), meeting with similar directional evolution in retrograde metamorphic facies from Saih Hatat, as already pointed by Gregory et al. (1998). The tectonics in southern Oman ophiolite and underlying Arabian margin illustrates the possible blocking of an Arabian platform-oriented subduction at junction with an active ridge, resulting in overriding of the hot oceanic lithosphere onto the continental margin (Figure 10d). The youngest age measured in Saih Hatat schists (~80 Ma) indicates that the exhumation proceeded continuously after the ophiolite obduction. Interestingly, listwaenite (silica alteration of mantle rocks) is developed locally at junction of Sumail massif with the underlying shield margin, along the Semail gap and Fanja saddle (Figures 2a and 9), like at the base of Emirati Aswad massif, possibly indicative of silica-rich fluid circulation.

4.5. Evolution Through Time

The evolution through time (Figure 10) tentatively integrates chronology of the tectonic evolution of the continental margin as recorded in the sedimentary deposits from the Hamrat Duru basin, and in the tectono-metamorphic framework of Jebel Akhdar and Saih Hatat domed shield. Following the passive margin extension during Early Mesozoic (Figure 10a), and anticipating the Upper Cretaceous ophiolite detachment, we tentatively assign the premise of an Arabian platform-oriented subduction, to the Titonian-Berriasian foundering of the Hamrat Duru basement (Figure 10b). This Early Cretaceous dating would meet with oldest ages obtained for the ultrahigh-pressure peak metamorphism from Saih Hatat (see Figure 4).

The ~20-Ma spanning activity of Arabian platform-directed subduction would drive the active Neotethyan spreading ridge at contact with the Arabia margin, developing at Upper Cretaceous time the complex geodynamics that characterize a ridge-trench-transform stem. The limited subduction span favored in the model may account for the fact that there is no obvious record of a volcanic arc developing over the ophiolite. Furthermore, it is noticed that in the modern framework of East Pacific referred to, there is no arc volcanism along California, where the spreading ridge has been subducted, during the ~20 Ma lasting Neogene activity (Atwater, 1989).

During Cenomanian, the ophiolite detachment phase is marked by the along-strike variations as described above (Figure 9 and section 4.4).

To comply with a restriction formulated that there is no documented emplacement of ophiolite at the present convergent margin referenced, America-Pacific, we infer that driving a hot piece of oceanic lithosphere over the continental margin requires transition to ocean closure. Obduction on the Arabia continental margin at the premise of Neotethys closure has preserved the Semail lithosphere from destructive collisional effect having affected the coeval Zagros belt.

5. Conclusion

The model we present is deviating from the more commonly accepted concept of detachment and emplacement of Semail ophiolite, and denies some specific common knowledge. The tectono-metamorphic evolution of the Arabian margin during Cretaceous as well as the sedimentary record indicate clearly that the northern Arabian platform gets unstable after Mid-Jurassic, which discredit the common concept of a passive Arabian margin during Mesozoic. We like to point that the oceanward vergence along the Semail line concerns the sedimentary nappes, and extending this vergence to the lithospheric plate is model-dependent.

In the course of this review, we have integrated both detachment kinematics recorded in lithospheric flow structures of the ophiolite, and Cretaceous tectonics at the Neotethyan Arabian margin, and we have pointed the synchronism of these dynamics.

Trying to account for some aspects of the complex evolution preserved in the Semail ophiolite and surroundings leads to think differently, and to renew with a model of Arabian platform-oriented subduction defended by Gregory et al. (1998), resulting in a ridge-trench interaction at time of continental margin connection. This is the model proposed here, referring to present America-Pacific ridge-trench junction.

One main corollary of the system is the incidence of a slab window as a consequence of ridge-trench interaction, and the thermal effect of related asthenospheric mantle upwelling. This thermal effect is critical and could be recorded in the ophiolite/basement system by contamination and melting product of continental origin. We have tentatively interpreted the specific relationships ophiolite/basement in the Emirates as relevant to an asthenospheric window-induced rift. Pursuing the analogy with the California Cenozoic continental margin, we speculate that an asthenospheric upwelling residual heat could be related with splitting of the central Oman ophiolitic massifs (Figure 9). The deep continental root of Jebel Akhdar mountain (~7 km thick) inferred from Bouguer gravity modeling and teleseismic wave data (Al-Lazki et al., 2002) matches with a substantial lithospheric thickening.

Our tentative at pointing some specificities of the synchronous evolution of oceanic lithospheric segments with joined continental basement, and highlighting the complexity of the ocean-continent system at the premise of obduction, is a proposal for further investigations.

Acknowledgments
We thank the Directory General of Minerals, Ministry of Commerce and Industry of the Sultanate of Oman, for providing us their kind assistance during the many years of mapping in the Oman Mountains, and the Ministry of Petroleum and Mineral Resources of United Arab Emirates for providing the freedom of accessing any area in the ophiolite. We thank all the participants to the Oman and UAE structural map, in particular Jean-Luc Bouchez and Christophe Sotin, for their contribution to structural mapping in the shield margin. Both anonymous reviewers are warmly acknowledged for their constructive review, as well as Chantal Andrea for her contribution to language improvement. All data used are listed in the references.

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