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Two contrasting modes of continental break-up associated with the formation of the Paleo- and Neo-Tethys in Iran: Implications for petrological and geodynamic evolution at a regional scale

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Introduction

In Iran, two incomplete ophiolitic sequences, which are classifiable as Continental Margin Ophiolite (CMO) (Dilek & Furnes, 2011), record the tectono-magmatic processes occurring during the continental break-up preceding oceanic basin formation. They are represented by: (1) the Early Carboniferous Misho Mafic Complex in NW Iran; (2) the Triassic sequences in the Kermanshah ophiolite in the Zagros Belt (Fig.1), which are associated with the formation of the Paleo-Tethys and Neo-Tethys, respectively. Both CMOs consist of gabbros, sheeted dykes and basaltic lavas. Moreover, the Kermanshah CMOs also includes exhumed sub-continental mantle lherzolites. These sequences include rocks showing variable incompatible element enrichments, ranging from N-MORB to E-MORB, P-MORB and alkaline basalt compositions and are interpreted to have formed from partial melting depleted MORB-type (DMM) mantle sources metasomatized by variable proportions of plume-type, enriched components. Nonetheless, geological evidence and petrogenetic modeling suggest that the continental break-up of the Paleo-Tethys (Saccani et al., 2013a) and Neo-Tethys (Saccani et al., 2013b) occurred in two different ways.

The aim of this work is to compare the geochemistry and petrogenesis of magmatic rocks associated with the initial rift-drift tectonics of the Paleo-Tethys and Neo-Tethys in Iran in order to assess the possible geodynamic mechanisms responsible for the formation of these two oceanic basins.

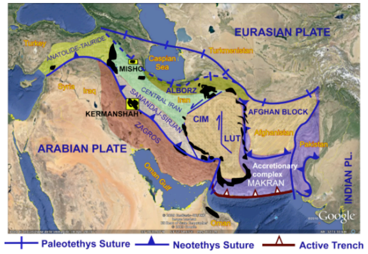

Fig.1. Tectonic scheme of Iran and surrounding areas and location of the study areas.

The Carboniferous Misho Mafic Complex

Geological setting

The Misho Mafic Complex (MMC) (Fig.2) consists of gabbros crosscut by abundant basaltic dykes, a basaltic sheeted dyke complex, and rare basaltic lavas. Gabbros are intrusive into the Precambrian continental basement representing the northern margin of Gondwana. The U-Pb zircon age reveals an igneous emplacement age of 356.7 ± 3.4 Ma (Early Carboniferous). The MCC is unconformably covered by Permian-Jurassic sedimentary rocks. With the exception of scarce Cambrian-Ordovician lagoonal sedimentary rocks, an important Cambrian-lower Paleozoic sedimentary gap is documented at a regional scale.

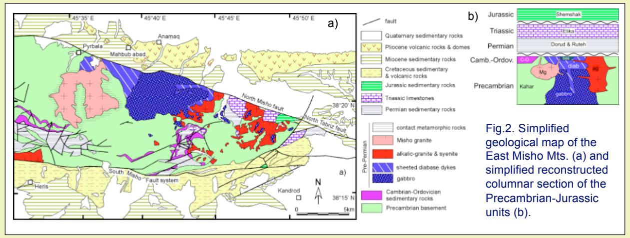

Fig.2. Simplified geological map of the East Misho Mts. (a) and simplified reconstructed columnar section of the Precambrian-Jurassic units (b).

Geochemistry

Two main chemical groups of rocks are recognized: (1) LREE/MREE depleted rocks (La_N/Sm_N <0.67) with N-MORB type chemistry that are represented by cumulate gabbros, isotropic gabbros and basaltic dykes (Fig.3a); (2) LREE/MREE and LREE/HREE enriched rocks with P-MORB type chemistry (Fig.3b) that represent the most abundant rock-type in the Misho Mafic Complex including all varieties of intrusive, and subvolcanic rocks. Group 2 shows a wide range of geochemical variations, from less enriched to more enriched rocks. Within this group, there is a continuity of compositions between the less enriched to more enriched rocks in incompatibile element and many geochemical indicators. Nonetheless, we can further identify two subgroups of samples, using the REE compositions (Fig3b): (2a) LREE/HREE highly enriched rocks (La_N/Yb_N > 10) and (2b) LREE/HREE enriched rocks (La_N/Yb_N = 3.5-7.5).

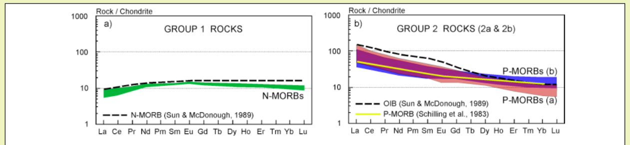

Fig.3. Chondrite-normalized REE patterns for isotropic gabbros and basalts from the Misho Mafic Complex. Normalizing values are from Sun and McDonough (1989).

The Triassic-Jurassic Kermanshah ophiolites

Geological setting

The Kermanshah ophiolites (Fig.4) crops out in the Main Zagros Thrust Zone (MZTZ) and consists of several rock associations, which record different stages of the geodynamic evolution of the southern Neo-Tethys ocean. Mantle metalherzolites, metagabbros and metadykes, as well as basaltic pillow lavas and dykes record the early stage of oceanic formation at the ocean-continent transition zone (OCTZ). In contrast, depleted mantle lherzolites and harzburgites are associated with the late phase of oceanic consumption. The MZTZ marks the suture between the Zagros belt (Arabian domain) and the Sanandaj-Sirjan zone (Iranian continental domain) (Fig.1). Along the MZTZ, ophiolites are tectonically imbricated with slices of Mesozoic shelf limestones and radiolarites and Eocene volcanic rocks and flysch.

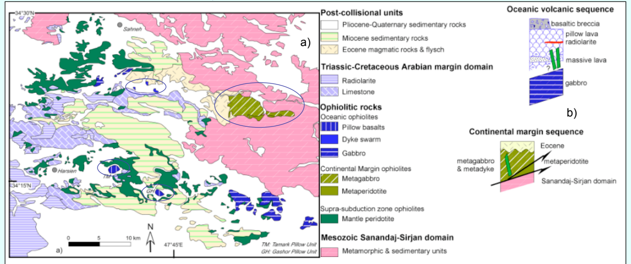

Fig.4. Simplified geological map of the Kermanshah area (a) and simplified reconstructed columnar section (b) of the ocean-continent transition zone ophiolites (also indicated in the map with circles).

Geochemistry

- ▶Metalherzolites have whole-rock geochemistry resembling that of the External Ligurides of Northern Apennine. They are relatively enriched in Al_2O_3 and REE and can easily be distinguished from other depleted lherzolites and harzburgite cropping out in the MZTZ (Fig.5a). These rocks are interpreted as representing portions of exhumed sub-continental mantle.
- ▶Metagabbros and metadykes associated with metalherzolites show overall composition resembling that of N-MORB. However, REE composition (Fig.5b) reveals two distinct groups of rocks. Rocks with low Sm/Yb ratios, which are similar to those of typical N-MORB and rocks with high Sm/Yb ratios. Basalts showing similarly high Sm/Yb ratios typically characterize the Alpine-type (i.e., amagmatic-type) OCTZ. The geochemistry of rocks showing low Sm/Yb ratios point to a genesis from partial melting of a pure depleted MORB-type mantle (DMM) source. In contrast, rocks showing high Sm/Yb ratios are compatible with partial melting of a DMM source bearing garnet-pyroxenite relics left in the depleted mantle melting source after the delamination and sinking of portions of the deep garnet-pyroxenite-bearing sub-continental mantle.
- ▶Volcanic rocks and dykes show three distinct chemical affinities (Fig.5c): (1) alkaline basalts and trachybasalts with ocean-island basalt (OIB) affinity; (2) rocks showing plume-type MORB (P-MORB) affinity; and (3) rocks showing enriched-type MORB (E-MORB) affinity. Many geochemical indicators support this distinction. In particular, REE compositions shown in Fig.5c show clearly different patterns. Alkaline basalts are very enriched in LREE very depleted in HREE and have relatively low $^{143}Nd/^{144}Nd$ and high $^{87}Sr/^{86}Sr$ ratios that are compatible with a genesis from an enriched, OIB-type (plume-type?) mantle source. P-MORBs and E-MORBs have variable, but generally high La/Yb, Sm/Yb, Th/Yb, Ta/Yb and Zr/Y ratios, and low Zr/Nb ratios. These features and the isotopic composition can be interpreted as the product of variable interaction between depleted MORB-type asthenosphere and OIB-type material.

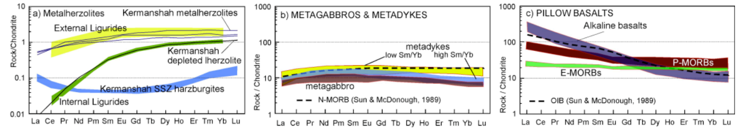

Fig.5. Chondrite-normalized REE patterns for the Kermanshah CMOs. SSZ mantle peridotites from the Kermanshah ophiolites and mantle peridotites from the Northern Apennine are shown for comparison in panel a). Normalizing values:Sun and McDonough (1989).

Petrogenesis and Tectono-Magmatic implications

The REE petrogenetic modeling indicate that the different rock-types were generated from different mantle sources and different partial melting degrees, as well as at different melting depth. Results are summarized in Table 1.

Table.1. Summary of the melting conditions for the different rock-types. Abbreviations, DMM: depleted MORB mantle; EM: enriched (plume type) mantle; OIB: ocean island basalt chemical component; gt=garnet; sp=spinel. The number of arrows indicates the relative amount of OIB-type chemical contribution, 1=minor, 2=moderate, 3=significant.

Rock-type	Mantle source composition	Mantle facies	Melting depth (approximative)	Melting degree (average)
Misho Mafic Complex				
N-MORB	DMM	gt+sp	Deep to shallow (polybaric melting)	3% gt + 10% sp
P-MORB (a)	DMM + OIB (↑↑↑)	gt+sp	Deep to shallow (polybaric melting)	0.5% gt + 4% sp
P-MORB (b)	DMM + OIB (↑↑)	gt+sp	Deep to shallow (polybaric melting)	0.5% gt + 5% sp
Kermanshah				
N-MORB low Sm/Yb	DMM	spinel	shallow	15%
N-MORB high Sm/Yb	DMM + gt-pyroxenite	spinel	shallow	15% (total)
Alkaline basalt	EM	spinel	shallow	5%
P-MORB	DMM + OIB (↑↑)	spinel	shallow	10%
E-MORB	DMM + OIB (↑)	spinel	shallow	15%

The different mantle melting styles and the different rock associations, as well as different regional geologic evidence observed in the Misho and Kermanshah areas indicate different geodynamic mechanisms for the continental rifting and opening of the Paleo- and Neo-Tethys, respectively.

Paleo-Tethys

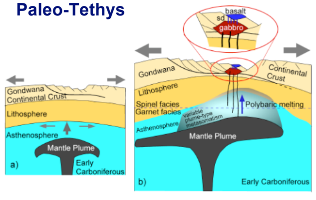

Fig.6. Schematic 2D model (not to scale) illustrating the initial rift-drift tectonics of the Paleo-Tethys in Iran.

The initial rift-drift tectonics of the Paleo-Tethys was triggered by mantle plume activity and was affected by plume-related magmatism and associated lithospheric weakening at a regional scale (Fig.6a) The mantle plume is responsible for variable metasomatic enrichment of the overlying asthenospheric mantle. The polybaric melting of the mantle from deep to shallow levels was facilitated by the uprising of hot plume material (Fig.6b). This conclusion is consistent with the models proposed for the Paleo-Tethys margins in central-eastern Asia. The regional doming and the widespread occurrence of oceanic plateaus in the Paleo-Tethys further support this hypothesis.

Neo-Tethys

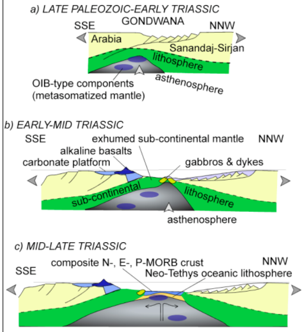

Fig.7. Schematic 2D model (not to scale) illustrating the initial rift-drift tectonics of the Neo-Tethys in Iran.

The initial rift-drift tectonics of the Neo-Tethys was characterized by a Ligurian Tethys-type passive extension (Fig.7a), which led to the exhumation of sub-continental mantle and formation of high Sm/Yb N-MORBs (Fig.7b). However, in contrast with the Ligurian Tethys model, the Neo-Tethys drift stage was also associated with volcanism featuring a marked influence of plume-type components (Fig.7c). Nonetheless, no geological evidence (e.g. regional doming, anomalous thermal regime, basaltic plateaux, magmatic evolution from more depleted to more enriched rocks, etc.) supporting the existence of a Triassic mantle plume activity in this area has been documented. Therefore, the plume-type geochemical signature observed in the Kermanshah CMO sequences can likely be explained with the re-activation of portions of enriched mantle (mantle heterogeneities) that were inherited from the Paleozoic mantle plume associated with the opening of Paleo-Tethys. This implies that the Neo-Tethys in Iran was characterized by intermediate-type continental margins (see Robertson, 2007 for the definition of continental margin types).

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