Lithos 117 (2010) 209–228

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Petrological and geochemical constraints on the origin of the Nehbandan ophiolitic complex (eastern Iran): Implication for the evolution of the Sistan Ocean

Emilio Saccani [a,*], Morteza Delavari [b], Luigi Beccaluva [a], Sadraddin Amini [b]

[a] Dipartimento di Scienze della Terra, Università di Ferrara, Via Saragat 1, 44100 Ferrara, Italy
[b] Department of Geology, Faculty of Science, Tarbiat Moallem University, Tehran, Iran

ARTICLE INFO

Article history:
Received 11 June 2009
Accepted 27 February 2010
Available online 6 March 2010

Keywords:
Ophiolite
MORB
Supra-subduction zone
Sistan suture zone
Iran

ABSTRACT

The Nehbandan ophiolite complex (NOC) crops out in the Sistan suture zone, which marks the boundary between the Lut and Afghan continental blocks. The NOC is composed of various ophiolitic lithotypes included in a tectono-sedimentary mélange, which are commonly interpreted as remnants of the oceanic lithosphere of the Sistan Ocean. Three different sequences (or associations) of ophiolitic rocks can be recognized in the NOC: (1) mantle peridotites consisting of clinopyroxene- (cpx-) rich harzburgites and depleted harzburgites; (2) olivine websterite–pyroxenite–gabbronorite sequence; (3) wehrlite–troctolite–cumulate gabbro–isotropic gabbro–basalt sequence. Petrographic observations, mineral chemistry, whole-rock chemistry, and rare earth element (REE) modelling carried out on the different rock associations led to the following conclusions: (1) the wehrlite–troctolite–cumulate gabbro–isotropic gabbro–basalt association represents a portion of oceanic crust generated in a mid-ocean ridge setting; (2) the cpx-rich harzburgites represent the residual mantle after 5–20% removal of mid-ocean ridge basalt-type (MORB) melt. This residual mantle was subsequently enriched in light REE (LREE) by subduction-derived fluids in a supra-subduction zone (SSZ) setting and it compositionally represents the typical mantle source for boninitic melts; (3) the olivine websterite–pyroxenite–gabbronorite association represents a portion of oceanic crust generated in an intra-oceanic arc setting; (4) the depleted harzburgites represent the residual mantle after 10–30% removal of boninitic melts in an intra-oceanic arc setting. The data presented in this paper provide new constraints for the tectonic evolution of the Iranian sector of the Neo-Tethys. In fact, in contrast with previous geodynamic models, the occurrence of SSZ ophiolites in the NOC implies that the phase of convergence between the Lut and Afghan blocks, which led to the closure of the Sistan Ocean, was accompanied by the development of an intra-oceanic arc setting.

1. Introduction

Iranian ophiolites are part of the Tethyan ophiolite belt of the Middle East (Fig. 1a), which links the eastern Mediterranean (Hellenides–Dinarides) ophiolites, to the west, with the Asian ophiolites, to the east. They record a series of complex plate interactions that occurred in this region from late Paleozoic to Cenozoic. The consumption of the Paleo-Tethys as a consequence of pre-Liassic collision and suturing of the central Iranian microcontinent (Fig. 1a) with Laurasia is documented in northern Iran, along the Alborz Range (Stöcklin, 1977; Sengor, 1979; Wensink and Varekamp, 1980). The Maastrichtian (Berberian and King, 1981) or Miocene (Bird et al., 1975; Sengor and Kid, 1979) consumption of the Neo-Tethys and the associated collision of the Arabian shield with the central Iranian microcontinent along the main Zagros thrust (Stöcklin, 1977) are recorded by the southern Iranian ophiolites (Fig. 1a). In southeastern Iran, east of the Zagros suture, a northward subduction of ocean floor in the Gulf of Oman has continued beneath the Makran since Late Cretaceous time (Farhoudi and Karig, 1977). In eastern Iran, thick piles of deep-water marine sediments with ophiolitic mélanges (Delaloye and Desmons, 1980) crop out along the Sistan suture zone, which marks the boundary between the Lut (eastern sector of the central Iranian microcontinent) and Afghan continental blocks (Fig. 1a). These ophiolites are interpreted as remnants of oceanic lithosphere (Sistan Ocean) mainly consumed in a subduction zone and, in part, obducted onto the Lut margin during the Eocene continental collision between the central Iranian microcontinent and the Afghan block. (e.g., Tirrul et al., 1983).

Geodynamic models are available in literature for the evolution of the Sistan oceanic basin (Tirrul et al., 1983; Dercourt et al., 1986; Sengor et al., 1988; Bagheri and Stampfli, 2008). These models are based on general geological and tectonic evidences, but lack petrological data on the ophiolitic rocks, whose tectonic setting of formation has not yet been constrained. For this reason, new petrological and geochemical data on

* Corresponding author. Tel.: +39 0532 974719; fax: +39 0532 974767.
E-mail address: sac@unife.it (E. Saccani).

0024-4937/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.lithos.2010.02.016

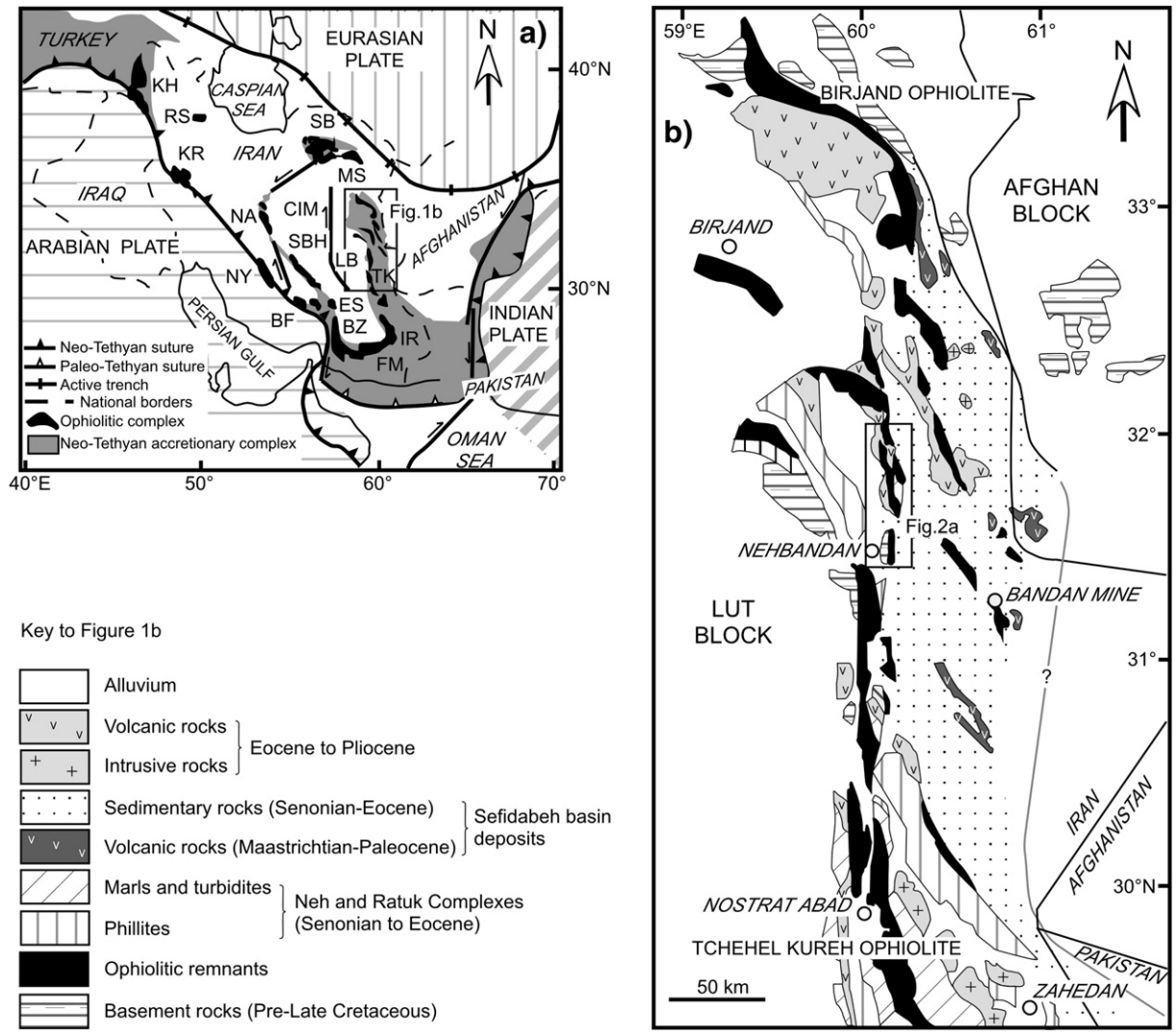

Fig. 1. (a) Generalized tectonic map of the Middle East. Key, 1: Neo-Tethyan suture; 2: active trench; 3: Paleo-Tethyan suture; 4: national borders; 5: Neo-Tethyan accretionary complex; 6: Ophiolitic complexes. CIM: central Iran microcontinent, which includes the Lut, block (LU) as its eastern part. The locations of the major Iranian ophiolites are also reported. Abbreviations, BF: Baft; BZ: Band-e-Zeyarat; ES: Esphandagheh; FM: Fanuj-Maskutan; IR: Iranshahr; KH: Khoy; KR: Kermanshah; MS: Mashhad; NA: Nain; NY: Neyriz; RS: Rasht; SB: Sabzevar; SHB: Shahr-Babak; TK: Tchehel Kureh. The box indicates the location of the Sistan suture zone (expanded in Fig. 1b). (b) Geological sketch map of the northern part of the Sistan suture zone (modified after Tirrul et al., 1983). The box indicates the location of the Nehbandan ophiolites, as well as the area expanded in Fig. 2a.

the Nehbandan ophiolitic complex (Fig. 1b), which represents a key area of the Sistan suture zone, are presented in this paper with the aims of: (1) shedding light on the geochemical and petrogenetic processes behind the formation of the Sistan suture zone ophiolites and (2) using these data to test and develop the models proposed in literature for the tectonic evolution of the Sistan Ocean within the context of the Neo-Tethyan tectonic reconstruction models of Iran and the Middle Eastern region.

2. General geological setting

Along the Sistan suture zone, various ophiolitic complexes form a discontinuous N–S trending belt from Zahedan to Birjand (Fig. 1b); the main ones are: Tchehel Kureh, Nehbandan and Birjand ophiolites. The Nehbandan ophiolite complex (NOC) is located to the east and northeast of the town of Nehbandan (Fig. 1b).

According to Tirrul et al. (1983), the Sistan suture zone can be divided into two geological terranes, the Neh–Ratuk complex and the Sefidabeh basin, which represent an accretionary prism and a forearc basin, respectively (Fig. 1b). The Neh–Ratuk complex can be further subdivided into two zones, the younger Neh complex to the southwest and the older Ratuk complex to the east; both consist of a mélange incorporating ophiolitic rocks (about 30% in volume) associated with Cretaceous to Eocene phyllites and Paleogene terrigenous, marine sedimentary rocks. The Cenomanian to Eocene marine sedimentary rocks of the Sefidabeh basin onlap the accretionary prism of the Neh–Ratuk complex. The major deformation began in the Late Eocene.

The Sistan suture zone is also characterized by the widespread occurrence of calc-alkaline and alkaline volcanic rocks ranging in age from upper Cretaceous to Neogene. Upper Cretaceous–Paleocene calc-alkaline volcanics crop out in the eastern margin of the Sefidabeh basin (Camp and Griffis, 1982). Moreover, there are some syntectonic to post-tectonic intrusions formed after the closure of the Sistan suture zone in the Late Eocene–Early Miocene time span (Camp and Griffis, 1982; Sadeghian et al., 2005).

Lithological relationships show that the ophiolite emplacement occurred in the Late Cretaceous but the deep-water sedimentation continued until the early Eocene. After this time, the collision between the Lut and Afghan blocks resulted in the closure of the basin and regional uplift of the terranes of the Sistan suture zone. Moreover, the structural characteristics of the Sistan suture zone may have also been influenced by a counter clockwise rotation of the Lut block from Jurassic to Tertiary (e.g., Davoudzadeh et al., 1981).

Early studies suggested that the opening of the Sistan oceanic basin occurred in the Late Cretaceous, as deduced from the occurrence