AN OBLIQUE CONVERGENCE AND ROTATION MODEL FOR THE EMPLACEMENT OF THEBAFT OPHIOLITIC MÉLANGE IN IRAN

Abbed Babaei*, Mohsen Arvin** and **Hassan A. Babaie*****

***** *Department of Biological, Geological and Environmental Sciences, Cleveland State University, Cleveland, Ohio, 44115, USA (e-mail: ababaei@bges.csuohio.edu).*
****** *Department of Geology, College of Sciences, Kerman University, P.O. Box 123, 76135 Kerman, Iran.*
******* *Department of Geology, Georgia State University, Atlanta, GA 30303.*

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ABSTRACT

The Late Cretaceous -Early Tertiary Baft ophiolite sequence in central Iran is a part of the Mesozoic ophiolitic belt that surrounds the Central Iranian Microcontinent (CIM) for several hundred kilometers. The ophiolitic complex includes blocks of gabbro, hypabyssal rocks, and spilite (both as lava flows and pillow lavas) enveloped in a matrix of tectonized harzburgite. Geochemical studies reveal two mafic lava groups, a tholeiitic basalt, which is similar to mid-oceanic ridge basalt, and a transitional tholeiitic basalt similar to intra-plate basalt. Geological observations and chemical analyses suggest that the Baft ophiolite might have formed at or near a ridge-transform intersection in a small, slow spreading (<1 cm/year) oceanic basin (Nain-Baft basin). This ophiolite was emplaced on the Central Iranian Microcontinent due to oblique convergence of the Afro-Arabian Plate with Eurasia. Slow spreading of the basin is suggested by the absence of cumulate gabbro and lack of evidence for pure melt segregation of magma. Support for the oblique convergence and for a counter-clockwise rotation of the spreading system includes (1) the juxtaposition of the metamorphic complex of eastern Central Iranian Microcontinent with the metamorphic belt of southern Iran (Sanandaj-Sirjan Belt) to the west and (2) the intersection of the older, north-south trending doleritic dikes with younger, east-west trending doleritic dikes. The sheared contacts between different lithological units, the development of a pronounced schistose foliation at the contact between serpentinized harzburgite and gabbro, as well as sheared clasts and dismembered rocks within basalt and serpentinized peridotite, are further evidence for the oblique convergence model.

INTRODUCTION AND GEOLOGICAL BACKGROUND

The Baft ophiolitic mélange in Kerman region of southeast Iran, which lies between the volcanic belt of central Iran to the north and the metamorphic belt of southern Iran (Sanandaj-Sirjan Belt) to the south is part of the Central Iranian ophiolitic mélange belt which marks a Mesozoic tectonic boundary between the Afro-Arabian and the Eurasian Plates. The Central Iranian ophiolite complex wraps around the Lut Block (Davoudzadeh 1972; Stöcklin et al., 1972; Sabzehi, 1974; McCall and Kidd, 1981; Desmons and Beccaluva, 1983) and is exposed in areas near Baft, Anarak, Nain, Sabzevar, Sirjan-Esfandagheh region and northern parts of Baluchestan.

The ophiolite complex constitutes two sub-belts; the southern or outer belt, is located south of the Main Zagros thrust fault, the northern or inner belt is located north of the Main Zagros thrust fault (Fig. 1). The rocks of the southern belt were emplaced on the southeastern margin of the Iranian Microcontinent due to the collision of an oceanic plate (Tethys) with the Afro-Arabian Plate along the Main Zagros thrust fault (Berberian and King, 1981). The rocks on the northern belt, which includes the Baft ophiolitic mélange, have been emplaced by closure of a narrow and small ocean (Nain-Baft basin) of Red Sea type during a rifting process in early Mesozoic. (Stoneley, 1974; Stöcklin, 1968; 1977; Berberian and King, 1981; Weber-Diefenbach et al., 1986; Sengör, 1984; 1990; Alavi, 1991) (Fig. 1).

The two sub-belts are distinct in characteristics and in rock types. For example, the Triassic and Jurassic metasedimentary and volcanic rocks of the southern belt are slightly deformed compared to the intensely deformed Cenomanian to Eocene volcanogenic and terrigenous sedimentary rocks of the northern belt (Dimitrijevic, 1973; Stöcklin, 1977; Delaloye and Desmons, 1980).

The Baft ophiolite is bounded by two reverse faults, the Shahr-e-Babak fault in the north and the Nain fault in the south (Fig. 1). Dextral displacements and rotational shearing along these two steeply-dipping faults give distinct characteristics to the Baft ophiolite complex. For example, rocks in this complex are much more tectonized (with widespread chaotic coloured mélange) than the ophiolites of Neyriz and Kermanshah, which crop uot along the Zagros thrust fault to the west (Ricou, 1971; Hallam, 1976; Lensch and Davoudzadeh, 1982; Babaie et al., 2001).

Recent studies on the Troodos ophiolites of Cyprus, the Semail ophiolites of Oman, and the Zagros ophiolites of southwestern Iran which are parts of the Peri-Arabe Crescent of Ricou (1971) have helped to shed some light on the understanding of the emplacement of the Baft ophiolite (Moores and Vine, 1971; Miyashiro, 1973; Pearce, 1980; Saunders et. al., 1980; Laurent et. al., 1980; Moores, 1982; Alabaster et. al., 1982; Hall, 1984; Arvin, 1991; Arvin and Robinson, 1994; Babaie et al., 2001). The Baft ophiolitic mélange is a nearly complete section of ophiolites (from tectonized harzburgite at the bottom, to basaltic lava flows interlayered with radiolarian cherts, on top) and records a complex history of sea-floor spreading and subduction-accretion processes.

The purpose of this study is to propose a tectonic model for the origin and emplacement of the Baft ophiolitic mélange in relation to the regional tectonic setting of southeastern Iran.

GEOCHEMICAL CHARACTERISTICS AND TECTONIC ENVIRONMENT

The Baft ophiolite consists of various blocks of gabbro, hypabyssal rocks and spilite in a matrix of serpentinized harzburgite (Fig. 2). From bottom to top, the unit consists

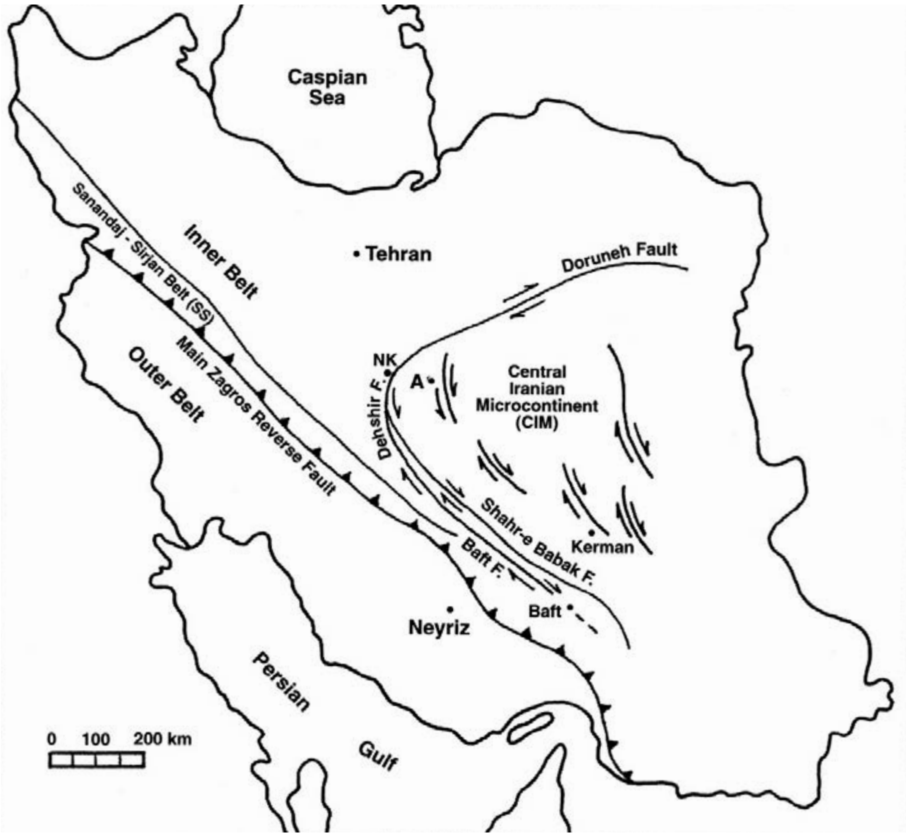

Fig. 1 - Map showing the Baft region and the distribution of major strike-slip faults around the Baft and the Central Iranian Microcontinent (CIM). The Inner and Outer belts of the ophiolite complex are also shown on the map. A- Anarak, NK- Nakhlak.

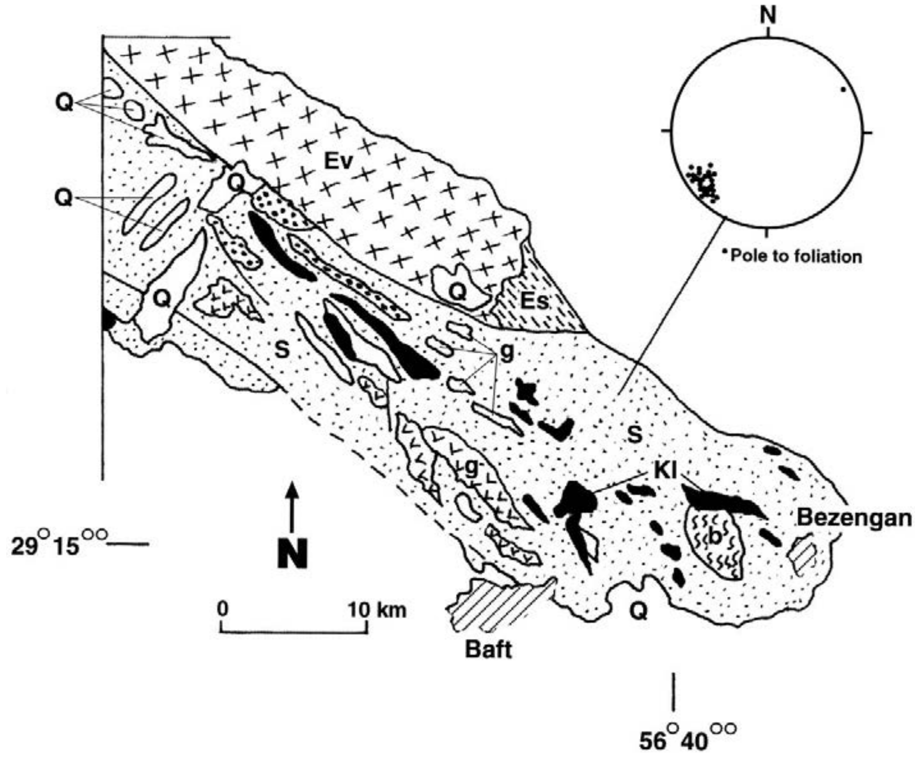

Fig. 2 - Geological map of the Baft area. The insert is the lower hemisphere stereographic projection of the poles of the schistose foliation at the gabbro-peridotite contact. S- Serpentinites, harzburgites and amphibolites; Kl- Cretaceous limestones; Ev- Eocene sandstones, conglomerates and volcanics; g- gabbros and dolerites; b- pillow basalts, radiolarian cherts and volcanics; Es- Eocene sandstones and conglomerates; El- Eocene limestones mixed with carbonate conglomerates; Q- Quaternary deposits. (Modified from Alavi, 1994).

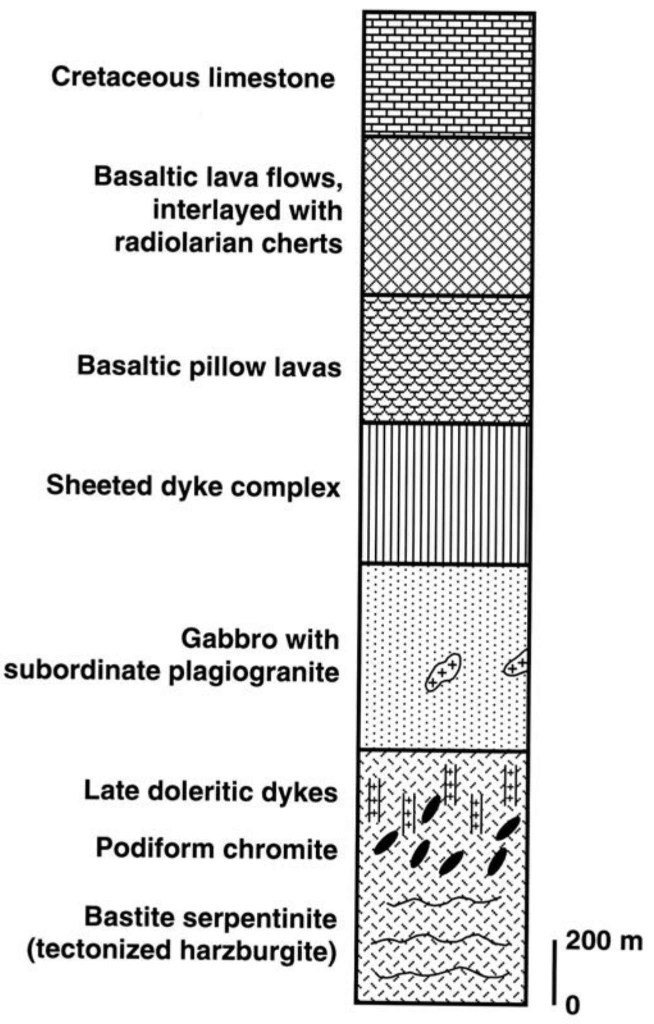

Fig. 3 - Stratigraphic column of the Baft ophiolite complex.

of: (i) Serpentinized harzburgite with minor chromite, which is intruded by noritic and normal gabbro and doleritic dikes (as both sheeted dikes and late individual dikes). The serpentinite is slickensided and has a "fish scale" texture formed by an anastomosing cleavage; (ii) Gabbro, keratophyre, amphibolite, porphyrite, tuff, volcaniclastic deposits with minor plagiogranite and sheeted dikes; (iii) Sheeted dike complex; (iv) An extrusive section of massive and pillowed flows; (v) An abyssal or bathyal sedimentary sequence, which includes radiolarian chert and, (vi) post-emplacement limestones and other shallow marine sediments (Fig. 3).

A recent geochemical study by Arvin and Robinson (1994) in the Baft area provided some useful information about the tectonic setting of the ophiolite complex. The authors studied the major, minor and rare earth elements to propose a model. This and similar studies suggest that the variations exhibited by most major oxides (such as SiO_2, MgO, CaO, Na_2O and K_2O) in the Baft ophiolitic complex unlikely reflect the primary composition of the volcanic rocks due to their mobility during low-grade submarine alteration and metamorphism (Cann, 1970; Matthews, 1971; Winchester and Floyd, 1976; Humphris and Thompson, 1978). Therefore, for altered volcanics in the Baft ophiolitic complex, recourse is generally made to elements such as TiO_2 and P_2O_5 which appear to be relatively immobile during low temperature alteration (Smewing and Potts, 1976; Pearce and Norry, 1979), and thus are useful in determining tectonic environments.

The high concentration of TiO_2 and P_2O_5 in nearly all lava flows and the TiO_2/P_2O_5 ratios which resemble the transitional tholeiites suggest that the Baft basalts originally formed in an oceanic ridge setting with similar to an ocean island (Arvin and Robinson, 1994). Supports for this interpretation are (i) the existence of noritic and normal gabbros which are locally accompanied by intermediate and felsic rocks such as plagiogranites, and (ii) rodingitization of micro-gabbroic dikes, and (iii) the presence of scattered clasts of volcaniclastic debris within the Baft complex. The presence of such volcaniclastics is reported by Sun and Nesbitt(1979) Larson and Schlenger (1981) as evidence for ocean-island volcanism (sea mount) with within-plate characteristics.

Trace element contents, and trace element discrimination diagrams such as Ti-Zr-Y, Hf-Th-Ta, Zr/Y-Zr and other geochemical patterns from the Baft ophiolite (Arvin and Robinson, 1994) also support this interpretation and confirm the existence of two different basic lava types in the Baft ophiolitic mélange: the tholeiitic basalts which are very similar to mid-oceanic ridge basalts (MORB), and transitional tholeiites typical of within-plate settings (Pearce, 1982; see Arvin and Robinson, 1994, for details).

DISCUSSION

Paleomagnetic analyses (Soffel and Forster, 1984) and geological data (Davoudzadeh and Schmidt, 1984) suggest that an orogenic belt, which extended from Turkey to the Makran area of southeastern Iran, formed during late Paleozoic times. The authors propose the fragmentation of the Iranian Plate had occurred between the Triassic and the Jurassic. During this time, the Central Iranian Microcontinent (CIM) drifted away from the Sanandaj-Sirjan(SS) block and opened a very slow-spreading (<1cm/year) rift zone (Nain-Baft basin) with an active north-south trending ridge-transform system (Fig. 4a) (Lensch and Davoudzadeh, 1982; Dercourt et al., 1986; Glennie et al., 1990).

The opening and rifting of the Nain-Baft basin is documented by basic sheeted dikes of Triassic age (trending N-S and dipping 45-60° to the west), with within-plate and transitional to MORB characters. Trace element studies and geochemical analysis of the dikes (Arvin and Robinson, 1994) confirm these characteristics and support their relationships with the rifting of the Nain-Baft basin.

Our field and analytical studies support the idea that the Baft ophiolitic mélange formed at or near a ridge-transform environment in a small and slow-spreading ocean basin. This hypothesis is based on: (1) occurrence of volcaniclastics in the volcanic units of the complex which represent an ocean-island (seamount) volcanism; (2) within-plate basalt and mid-oceanic ridge basalt geochemical affinities and, (3) occurrence of pelagic sediments on top of the ophiolite complex (Arvin and Robinson, 1994).

The slow-spreading ridge model is supported by: (1) absence of cumulate gabbros, (2) lack of evidence for pure melt segregation of magma, (3) lack of a mature island arc in the region, and (4) the presence of doleritic dikes which cut the serpentinized peridotites, as observed in many modern fracture zones around the world. The previous observations indicate that serpentinization occurred on or below the sea floor, before igneous intrusions (Arvin and Robinson, 1994). Cumulate gabbros and pure melt segregation develop mostly in fast spreading ridges (>50 cm/year), where magma supply rates are high enough to produce a thin melt lens above the crystal mush (McDonald, 1982; Fox and Gallo, 1984; Bloomer and Meyer, 1992; Sinton and Detrick, 1992).

Davoudzadeh and Schmidt (1984), in their discussion of the Mesozoic paleogeography of Iran, argue that between the Triassic and Jurassic, the Iranian block was fragmented by partial block rotation, and that drifting of the Central Iranian Microcontinent (CIM) away from the Sanandaj-Sirjan block to the southwest and opened a rift zone. A period of subsidence (which formed the Nain-Baft basin) followed

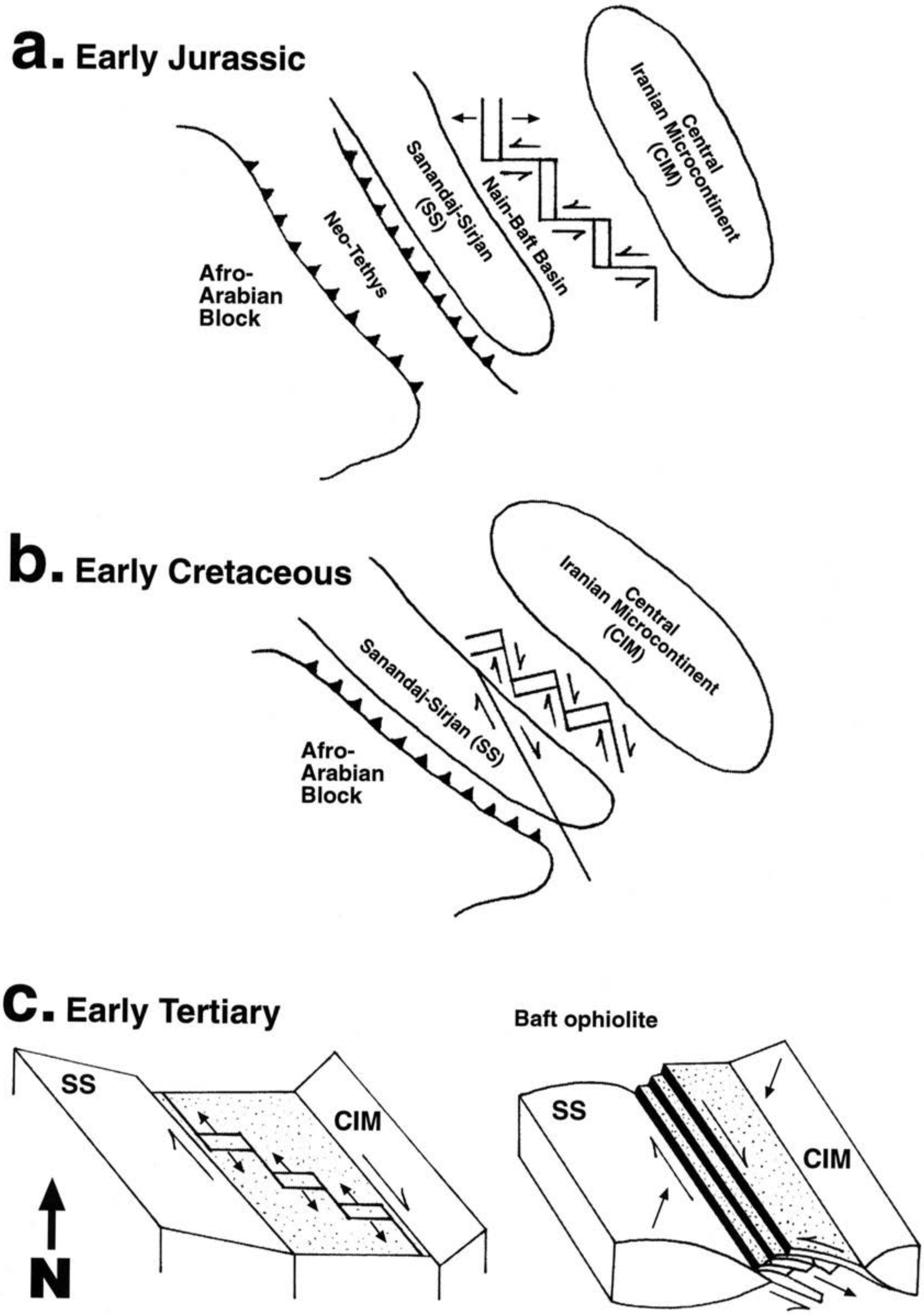

Fig. 4 - (a) A model for the original north-south ridge-transform system (Baft-Nain basin) between Central Iranian Microcontinent (CIM) and the Sanandaj-Sirjan during Jurassic (modified from Dercourt et al., 1986). (b) Counter- clockwise rotation and oblique convergence of (SS) with (CIM) during Cretaceous-Early Tertiary times. (c) Emplacement of the Baft ophiolite during Tertiary.

the continental break up and rifting (Fig. 4a). Subsidence of the basin is recorded by basinal sedimentation which is mostly composed by biomicritic limestones with microfauna of Campanian to Maastrichtian age (Dimitrijevic, 1973). The conformable deposition of sandy marls, algal biomicritic siltstones, shaly limestones of unknown age, Jurassic radiolarian cherts, and reddish to pink shaly limestones, further support the gradual subsidence of the Nain-Baft basin following the rifting period.

During the Early Jurassic the Afro-Arabian Plate began drifting northeastwards, (Fig. 4a) and the oblique convergence with the Eurasian Plate (Fig. 4b) started about 80 million years ago. This motion, which initially was predominantly compressional, later changed to transform mode (Kidd and McCall, 1981). The latter reorientation of motion generated a counter-clockwise rotation of the Central Iranian Microcontinent (CIM), which resulted in the southwards drifting of the microcontinent , and closure of the Nain-Baft basin (Kidd and McCall, 1981; Desmons, 1982). Both convergence of the continents and consequent closure of the Nain-Baft basin may have been the result of a change in the spreading rate of the rift axis, which affected the direction of the plate motions.

The process of convergence, subduction and shrinking of the Nain-Baft basin continued until the early Tertiary, when the Central Iranian Microcontinent (CIM) and the Sanandaj-Sirjan (SS) block joined together, and the Baft ophiolite was consequently emplaced (McDonald, 1982; Fox and Gallo, 1984) (Fig. 4c).

According to Davoudzadeh and Schmidt (1984), evidence for counter-clockwise rotation and for transpressional motion is recorded by both lithofacies and isopach maps of the Lower and Middle Triassic sediments that occur in the region. For example, the pre-rotation Nakhlak complex, with its post-rotation Triassic marine rocks, cropping out in the western part of the Central Iranian Microcontinent, is juxtaposed to the Herat complex of Afghanistan._Furthermore, the juxtaposition of the Late Triassic-Jurassic Anarak and Deh Salm metamorphic complexes of eastern Central Iranian Microcontinent: central Lut), with the metamorphic rocks of Sanandaj-Sirjan metamorphic belt (Fig.1) to the west is considered to be the result of this rotation.

Davoudzadeh et al. (1981) argued that Central Iranian Microcontinent rotated about 100° counter-clockwise between Late Triassic to Middle Jurassic. Then, a 35° counter-clockwise rotation, that occurred during Middle-Late Jurassic to Cretaceous closed the Nain-Baft rift zone. This convergence event culminated with the emplacement of the Baft ophiolitic mélange on the southwestern margin of the Central Iranian Microcontinent, during in Early Tertiary (Davoudzadeh and Schmidt, 1984).

Field evidence for the rotations is scattered in both the volcanic and sedimentary rocks of the area. Regional strike-slip faults (Baft fault, Nayband fault, Kuh-e Banan fault, for example), and the occurrence of folds with oblique orientation with respect to the overall tectonic trend, and a noticeable change in the trend of doleritic dikes from north-south (the older dikes) to northwest and east-west (the younger dikes) give support to the counter-clockwise rotation of the rifting axis. Similar rotations of doleritic dikes in Troodos of Cyprus (Simonian and Gass 1978; Varga and Moores, 1985; Murton,1986) were also attributed to rotations in a major shear zone.

Evidence for shearing is also recorded along the contacts between different lithological units. For instance, the subvertical contact between the doleritic dikes and the peridotite is marked by faults in many places. This faulted contact also occurs between gabbro and serpentinized harzburgite. The result of faulting and shearing is a foliation that strikes northwest, steeply dips to northeast, and has a steeply-plunging mineral lineation (see insert in Fig. 2). The contact between pelagic sediments, volcanic rocks and peridotite is also a fault_contact, and in places the biomicritic limestones are surrounded by strongly sheared serpentinite. The flaky serpentinite anastomoses around the enclosed rock lenses. Clasts of sheared and dismembered lithological units within basalts and serpentinized peridotites are further evidence for shearing in these rocks.

CONCLUSION

One of the most difficult problems concerning Iranian geology in terms of plate tectonic models is the interpretation of the ring of mélange-like rocks which circumscribes the Lut Block (Central and East Iran Microcontinents). It has been suggested that there has been an additional zone of sea floor spreading, north of the southern Tethys Ocean, which separated a long continuous strip of continental crust, capped by shelf sediments in the south, from the Lut Block.

The tectonic history of the Baft ophiolitic complex in south-central Iran is modeled in the context of a ridge-transform-subduction setting. It is also believed that the Central Iranian Microcontinent (CIM) rifted apart between Triassic and Jurassic time, leading to the opening of the Nain-Baft basin and to the counter-clock wise rotation of Central Iranian Microcontinent. During Late Cretaceous, the oblique convergence of the Arabian Plate with Eurasia led to the (a) closing of the Nain-Baft basin and, (b) emplacement of Baft ophiolitic complex during Tertiary southwest of the Central Iranian Microcontinent.

Further, detailed petrographic, geochemical, and isotope studies of the Baft area are needed in order to demonstrate the hydrothermal activity and the metamorphic gradation within these ophiolites caused by ascending geothermal fluids. Paleomagnetic studies offer an important contribution to the reconstruction of the structural framework of the ophiolitic mélange in the region. Structural data are similarly important in order to asses whether large scale rotations are a fundamental process in the formation of oceanic crust, and for a better understanding of time of emplacement, deformational style of this dismembered ophiolitic mélange. Finally, a comprehensive geochronological study of the least-altered rocks within this complex is needed to obtain isochron ages in order to put different geological events in their right order.

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