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Geochemistry of Sabzevar regional metamorphic rocks, northern Central Iranian Microcontinent Blocks (CIM)

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Abstract: HP/LT metabasite rocks can preserve some evidences of tectonic and geochemical processes of a subduction zone. Sabzevar Ophiolite and metabasites which are located at the north of Central Iranian Microcontinent Block (CIM) have preserved such evidences. The metabasites are fossil oceanic crust of Neotethys-related basin. Metabasites are composed of glaucophane schist, amphibolite and greenschist. Major and trace element contents of the rocks indicate that blueschist and amphibolite protoliths were MORB basalts. Rare earth elements show presence of two MORB types, N- and E-MORB. ΣREE is 132-246 (ppm) and 617-744 (ppm) for the N- MORB and E-MORB basalts, respectively. La/Yb ratio is ranging from 0.43-0.79 for N-MORB and 8.7 and 1.1 for E-MORB. The $Mg^{\#}$ ranges are between 0.24-0.27, 0.23-0.24, 0.42 and 0.38 for glaucophane schist, garnet amphibolite, amphibolite and chlorite schist, respectively, which indicates a weak fractional crystallization in the original magma. High pressure rocks were formed due to northward subduction of Neotethys-branch of Sabzevar basin between CIM and Eurasia since Upper Cretaceous to Eocene.

Keywords: *Geochemistry; Metamorphic Rocks; Central Iranian Microcontinent; Neotethys; Upper Cretaceous-Eocene; Sabzevar; Iran.*

Introduction

Mountain ranges in Iran are a part of Alpine-Himalayan orogeny with different geological settings along Alborz and other Iranian blocks. Alborz Mountain is a suture between Gondwana and Eurasia continents (Paleotethys Ocean) with its final collision at Triassic. Along Zagros Mountain some ophiolite units such as Neyriz, Kermanshah and Khoy have outcrops which are remnants of the main Neotethys oceanic crust. Between Alborz (Paleotethys, until Triassic) and Zagros (main Neotethys), there are some other ophiolitic blocks (around CIM) which are related to Neotethys. They are Sabzevar ophiolite at north, Tchehel Kureh ophiolite at the east, northern Makran ophiolites (Band-e-Ziyarat, Dar Anar and Remeshk/Mokhtar Abad ophiolites) at the south and Nain-Baft ophiolite at the southwest boundary of CIM. Sabzevar basin formed due to northward subduction of the main branch of Neotethys [1] at lower Jurassic [2]. Stöcklin (1974) [2] believes that the maximum opening of Sabzevar basin occurred at Cretaceous. Presence of *Globotruncana* foraminifers indicates Upper Cretaceous deep sediments. Radiolarian sediments indicate that deep basin formed at Lower Cretaceous at the eastern Iran (eastern basin) [3]. Sabzevar Oceanic Basin demised at Eocene. This is picked up by the fact that high pressure metamorphic rocks are covered by *Nummulitic* sediments (Limestones).

Previous study of Sabzevar basaltic rocks has indicated that there are two kinds of MORBs and some basaltic arcs. Some rocks show N-MORB and some other E-MORB affinities. The third group shows island arc affinity [4]. Geochemistry study of granulite confirms presence on such MORB types [5].

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The goals of this paper are including the study of major and trace elements in metabasites and their whole rock geochemistry and comparison of them with results of the previous studies and then using of these data to constrain on geological evolution of the Sabzevar basin.

Petrography of Metamorphic rocks

As mentioned above, Sabzevar basin had a northward subduction. Sabzevar Oceanic crust had experienced blueschist, amphibolite and greenschist facies metamorphism during subduction and subsequent exhumation (prograde and retrograde metamorphism) [6]. These rocks have outcrops at the Chili and Govain mountains (Fig. 1). Until now, eclogitic outcrop is not reported from Sabzevar area. Glaucophane schist, amphibolite, chlorite schist and small outcrop of gneiss are a product of subduction and subsequent exhumation. Glaucophane schist includes sodic amphibole (glaucophane), phengite, epidote, calcite ± omphacite, albite, chlorite, and ±quartz and accessory minerals such as ± titanite, ± ilmenite and ±hematite (Fig. 2). Epidote amphibolite and (±garnet) amphibolite crop out at this area. Sodic-calcic amphibole, albite, phengite, quartz, ±omphacite, ±epidote, ±garnet, ilmenite and titanite are minerals of amphibolite. Gneiss outcrop is located at the southern Khoshab village which is composed of garnet, Ca-Na amphibole, epidote, albite, phengite, biotite, quartz and hematite. Greenschist samples are consisted of chlorite, plagioclase and pyrite. We couldn't find any evidence of eclogitic facies relict in the studied samples but presence of eclogite is not farfetched at this area. If this is the case, metabasites could be relics of an earlier eclogite stage.

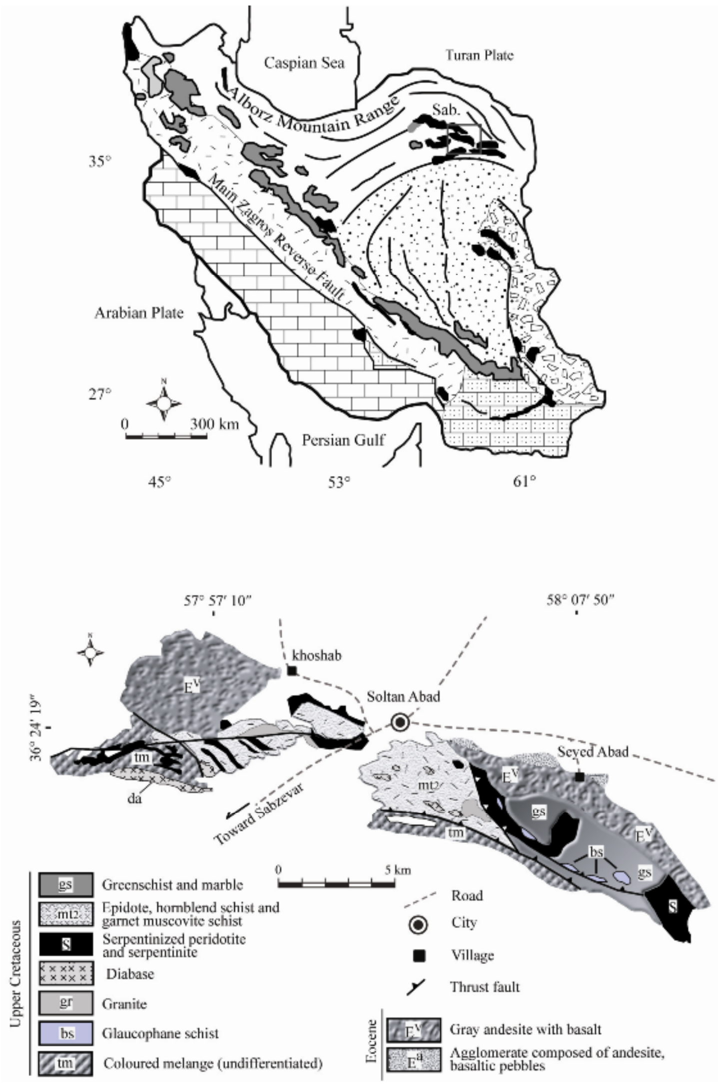

Figure 1 Simplified tectonic and geological maps of Iran and Sabzevar area. Black color on the Iran map shows ophiolite locations.

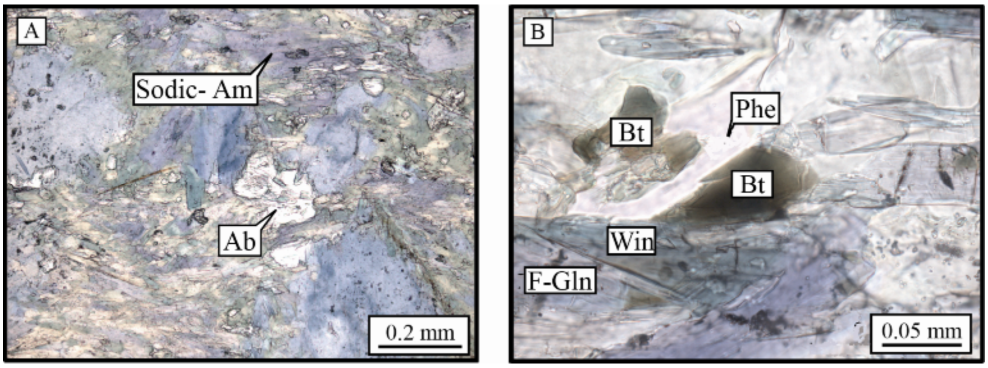

Figure 2. Photomicrographs of Sabzevar metabasite rocks (Abbreviation: Sodic-Am: Sodic Amphibole; Ab: Albite; Bt: Biotite; Phe: Phengite; Win: Winchite and F-Gln: Fe-Glaucophane).

Whole rock geochemistry

Analyses for whole rock geochemistry (major and minor elements) were obtained using Phillips PW-2400 X-ray fluorescence (XRF) spectrometer at the Potsdam and GeoForschungsZentrum Potsdam (GFZ) universities. The H_2O and CO_2 contents were analyzed by quantitative high-temperature decomposition with an Elemental CHN analyzer.

Rare earth elements (REE) were measured by inductively coupled plasma-optical emission spectrometer (ICP-OES, Vista MPX) at the Geochemical Laboratory of the University of Potsdam.

Geochemical data, especially less mobile and immobile trace elements and rare earth elements (REE) can be used to provide information on character and the geodynamic setting of protolith of metamorphic rocks, within which primary textural and structural information has been obliterated [7]. Major and trace element composition of the analyzed rocks are summarized in Table 1. Sabzevar metamorphic samples have variable LOI (CO_2 + H_2O) of 1.5 to 3.28 wt%, with an average of 2.02 except for sample 15a with a LOI of 4.55 wt% (Table 1). Major and trace element contents of metamorphic rock protoliths may change during high pressure processes due to water-slab interaction or subduction and metamorphism. Some samples of the Sabzevar area are enriched in Rb, Sr and K and some other incompatible elements but other samples are depleted in these elements. There is no correlation between La-Rb and Sr-K contents in the samples except for sample 42c that have very low LOI (1.93 wt.%). Sample 15a have a high Ba (1051 ppm), LOI (4.55 wt.%) and K_2O (1.7 wt.%) contents. This may show that this sample has experienced secondary processes modifying its chemistry. However, chemical compositions for most of the Sabzevar metabasites indicate that they have not experienced important secondary alteration process and elements values can reflect the protolith nature. Despite this fact we have avoided using mobile elements in petrogenetic interpretations discussed below. All samples have low K_2O content (<1) except for samples 15a (2.90 wt%) and 42c (1.70 wt%, Table 1). The $Mg^{\#}$ (Mg/(Mg + Fe)) shows no significant variation. This ratio is 0.24-0.27, 0.23-0.24, 0.42 and 0.38 for glaucophane schist, garnet amphibolite, amphibolite and chlorite schist, respectively, which indicates weak fractional crystallization in the original magma. Most of the samples have SiO2 content lower than 53 wt% except 42c (blueschist, 67.80 wt%) and 50e (garnet gneiss, 72.98 wt%). Cr and Ni contents are lower than 64 ppm (average = 36 ppm) and 85 ppm (average = 52 ppm), respectively but sample 38b has higher Cr content (274 ppm). The protolith of sample 50e is granite to granodiorite. P2O5 and TiO2 are almost immobile and can be used for preliminary discrimination of the metabasites (e.g. [8]). P2O5 content is lower than 0.5 wt% (average= 0.21 wt%). Samples have TiO2 content between 0.28-4.09 wt% (average = 1.77 wt%). On the Zr/TiO2 versus Nb/Y diagram [9], samples are plotted in the basalt and basaltic andesite/andesite fields (Fig. 3). Since Zr is more incompatible than TiO2, the Zr/TiO2 ratio is influenced by the degree of partial melting and processes that cause mantle heterogeneity [10]. Sabzevar metamorphic rocks plot in two different fields on diagram of Zr/Y versus Zr [11], namely within plate basalt field and interface between MORB and island arc basalt fields (Fig. 4). In order to discriminate between the MORB and island arc basalt origins for the protolith of the metamorphic rocks, Ti-Zr-Y [12] and Nb-Zr-Y [13] ternary diagrams are employed (Fig. 5). In the Ti-Zr-Y ternary diagram, most of the samples are plotted in the MORB field.

Blueschist sample (20e) is plotted in the calc-alkali basalt and island arc basalt fields. This observation is not supported by Nb-Zr-Y ternary diagram. Most of the samples are plotted in the MORB field, except sample 38b. Sample 38b sample (amphibolite) is plotted in the within plate basalts/volcanic arc basalts field that differs from its position in the previous diagram (Ti-Zr-Y). Five samples were selected for REE analysis. The results are shown in Table 1. All REE data are normalized to Evenson et al., 1978 [14]. Chondrite- normalized REE patterns are shown in figure 5. Three samples show flat patterns with slightly lower LREE than HREE contents. Lack of distinct negative Ce anomaly shows that LREE were not experienced significant changes during alteration and metamorphism and consequently preserved La(N)/Ce(N) ratio are reliable (e.g. [15]). The chondrite- normalized REE patterns show two distinct groups of metabasites in the Sabzevar area. La/Yb ratio ranges from 0.43-0.79 for samples 20e, 50e and 20d. This ratio is 8.7 and 1.1 for samples 42c and 47h, respectively. ΣREE is 132-246 (ppm) and 617-744 (ppm) for the first and the second groups, respectively. These two groups are comparable with N-MORB and E- MORB (Fig. 6). Shojaat et al. [4] introduced some extrusive rocks of basaltic composition with N- and E-MORB affinity in this area (Fig. 6). $Eu^{\#}$ (Eu number) is higher than 1 except for samples 42c and 50e. The negative $Eu^{\#}$ can be due to plagioclase fractionation or oxygen fugacity parameters in the primary magma.

Geochemical study of gneiss sample indicates that its protoliths has been differentiated series of oceanic crust [16].

Table 1. Whole rock major and trace elements of the Sabzevar metamorphic rocks.

Sample	SAB.20e	SAB.47w	SAB.20d	SAB.43	SAB.47h	SAB.47a	SAB.42c	SAB.15a	SAB.50e
SiO_2	49.36	46.70	53.57	49.47	46.93	47.60	67.80	44.78	72.98
TiO_2	1.11	3.41	1.14	0.44	4.09	3.43	0.56	1.27	0.29
Al_2O_3	15.61	10.80	14.80	16.51	10.62	10.95	12.34	13.56	11.71
FeO^t	14.45	18.84	12.07	6.81	18.79	17.96	6.59	11.39	5.58
MnO	0.15	0.29	0.19	0.11	0.32	0.31	0.14	0.23	0.06
MgO	4.64	5.62	4.03	4.91	5.71	5.71	2.44	7.10	1.89
CaO	6.89	5.95	5.16	14.91	7.24	6.02	1.67	14.75	0.63
Na_2O	4.13	5.66	5.52	4.69	3.71	5.73	3.30	0.31	3.53
K_2O	0.15	0.32	0.99	0.11	0.28	0.33	2.90	1.70	0.86
P_2O_5	0.06	0.50	0.10	0.20	0.44	0.19	0.17	0.12	0.09
CO_2	0.25	0.06	0.12	0.07	0.12	0.05	0.20	0.09	0.15
H_2O	3.03	1.52	2.12	1.43	1.57	1.58	1.73	4.46	2.17
Total	99.83	99.67	99.80	99.66	99.80	99.85	99.84	99.76	99.93
Mg*	0.24	0.27	0.25	0.23	0.31	0.23	0.24	0.42	0.25
Ba	31	22	98	<20	<20	<20	355	1051	117
Cr	55	29	22	64	25	26	61	24	18
Ga	20	20	21	18	14	18	16	10	13
Nb	2	<2	2	5	9	3	<2	2	<2
Ni	70	37	27	85	44	39	80	26	39
Rb	<3	<3	10	<3	<3	<3	71	8	6
Sr	187	66	316	766	74	37	62	74	27
V	834	520	342	162	471	521	72	365	27
Y	22	87	32	29	73	68	25	27	15
Zn	31	154	103	51	153	142	80	73	20
Zr	48	243	75	84	321	262	139	77	33
La	7.10		9.64		50.22		147.68		10.36
Ce	7.09		9.86		51.67		89.56		5.95
Pr	6.41		10.19		56.43		88.59		4.97
Nd	8.05		11.83		56.17		68.76		5.35
Sm	11.18		16.56		59.96		44.09		7.06
Eu	13.91		20.16		61.02		23.52		5.26
Gd	14.00		19.60		58.46		29.00		9.53
Tb	13.19		17.32		49.95		23.35		9.78
Dy	15.02		20.65		51.79		18.95		10.81
Ho	14.86		20.46		45.14		16.32		10.77
Er	16.31		22.05		48.78		16.71		12.30
Tm	17.15		22.27		62.04		17.46		12.81
Yb	16.33		22.20		45.35		16.90		13.07
Lu	17.24		22.88		47.36		16.56		13.96
Eu*	1.11		1.12		1.03		0.66		0.64
La/Yb	0.43		0.43		1.11		8.74		0.79

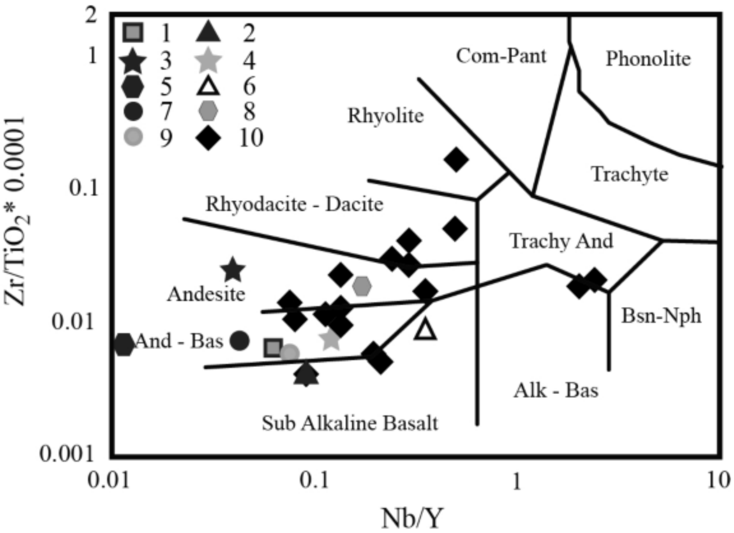

Figure 3. Zr/TiO_2 vs. Nb/Y geochemical discrimination diagram (after [8]), showing basalt and andesitic basalt/andesite protolith for the studied metamorphic rocks.

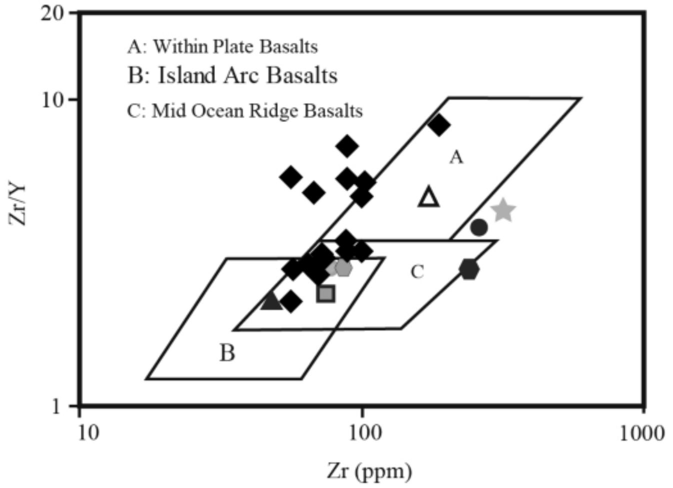

Figure 4. Zr vs. Zr/Y diagram (after [9]), showing the tectonic setting for protoliths of the studied metamorphic rocks.

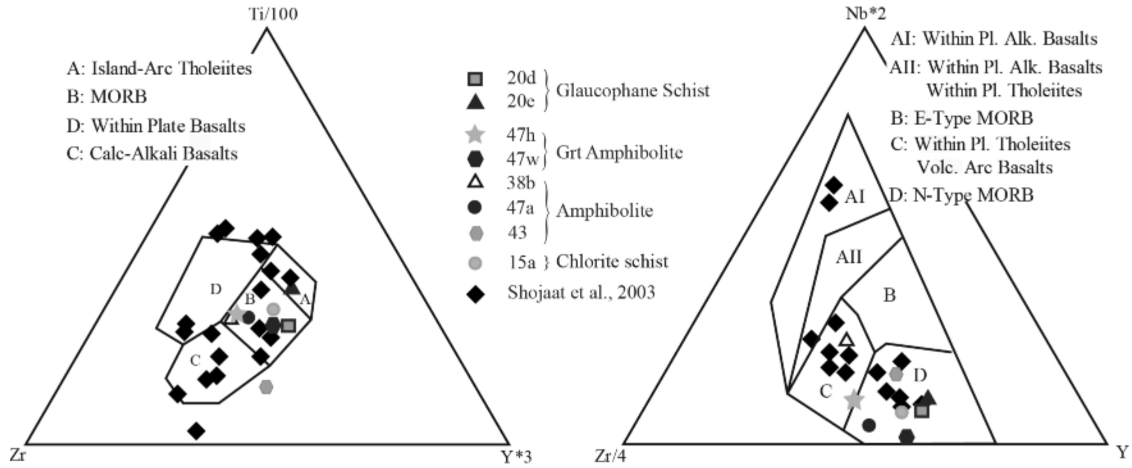

Figure 5. A: Ti-Zr-Y geochemical discrimination diagram (after [11]) shows that most of the Sabzevar metamorphic rocks are plotted in the MORB field. B: Nb-Zr-Y geochemical discrimination diagram (after [12]), shows N-MORB affinity for most of the samples.

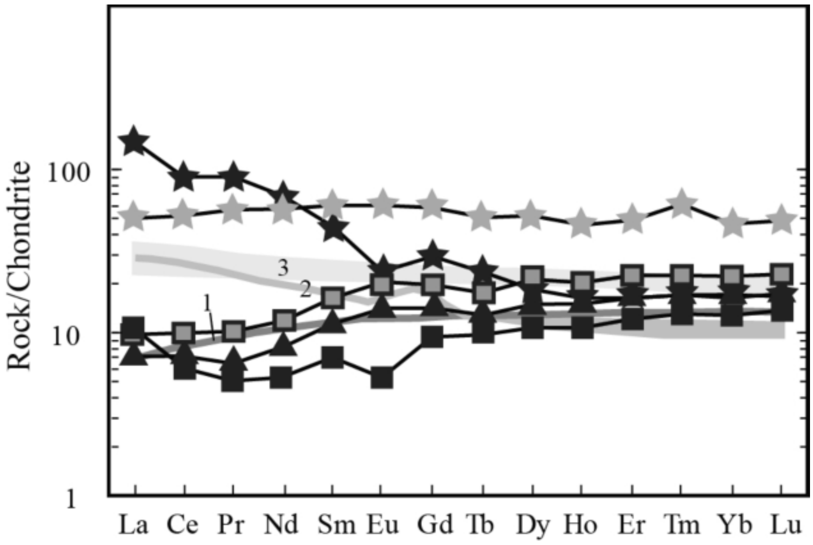

Figure 6. C1 -Chondrite [13] - normalized REE patterns for all Sabzevar metamorphic rocks. The patterns show N- and E- MORB characteristics. Number 1, 2 and 3 shows first, second and third basaltic group rocks of [4], respectively.

Geochemical study of Gazik metabasites (Birjand area, eastern Iran) yield E-MORB signature for basaltic protolith of subducted oceanic crust [17]. Study of isotopic and rare earth element data reveal that Band-e-Zeyarat/Dar Anar ophiolite (northern Makran, southeastern Iran) were derived from a mantle source with an E-MORB-like geochemical signature with fractionation of Cpx, Am and Pl [18]. Inner Ophiolite belt of Zagros [19]; Baft, Shahr-e-babak, Dehshir and Nain ophiolites) shows geochemical evidences of Supra-Subduction affinity [20, 21].

Discussion and conclusion

Metabasite samples of Sabzevar were experienced blueschist facies metamorphism during northward subduction of Sabzevar oceanic crust. The geochemistry of metabasites show N- and E-MORB affinity which is also reported from some volcanic rocks of the Sabzevar area by [4]. The extrusive rocks of Sabzevar Ophiolite show two main groups, the first with REE abundant of 10× chondrite (N-MORB) and the second with slightly HREE abundant (E-MORB; [4]). They also reported one more extrusive group which is not related to ophiolitic sequences. Geochemistry of Sabzevar metabasite shows MORB affinity with two different patterns, the first one (N-MORB) with flat pattern and lower La/Yb ratio (0.43-0.79) and the second group with higher value of 1.1 and 8.7 (E-MORB). Existence of both N- and E-MORB types in the Sabzevar metamorphic rocks is explainable in two ways. The original source for the parental magmas of the Sabzevar metamorphic rocks was not homogenous. Alternatively, presence of two types of MORB shows an ocean with low spreading rate. This is not common in oceans with fast spreading rate because of high and nearly steady degree of melting [22]. Both E- and N-MORBs are metamorphosed due to northward subduction of Sabzevar basin oceanic crust.

Intercalation of pelagic Cretaceous limestone and radiolarian chert with basalts at Shahr-e-Babak ophiolite, suggest Late Cretaceous age for youngest basalts during final phase of oceanic crust formation [4]. The Sistan zone at the eastern Iran (located between Lut and Helmand blocks) contain ophiolite, metabasite and sedimentary units. Albian to Cenomanian radiolarites were introduced in this region [23]. Sabzevar metabasites are covered by sedimentary unit with Nummulitic fossils. It shows that Sabzevar basin closed a little after closure of other CIM basins.

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