

PETROGENESIS AND ORIGIN OF THE CHENAR GRANITOID STOCK, NW OF KERMAN, IRAN: EVIDENCE OF NEOTETHYS SUBDUCTION RELATED ARC MAGMATISM

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Abstract

The lower to middle Miocene Chenar granitoid stock, a part of Central Iranian volcanic belt, is intruded into Eocene volcano-sedimentary complex in northwestern Kerman in south Central Iran. The Chenar granitoid stock consists mainly of coarse to medium grain granodiorite and monzogranite with subordinate tonalite and syenogranite. Alkali granites as aplitic veins and quartz dioritic dykes frequently cut through the granitoid stock. Enclaves of various types and sizes (andesitic and microgranular mafic, few meters to several centimeters wide) also occur near the margin. The granitoid rocks represent convergent margin magmas enriched in large ionic lithophile elements (LILE) such as Rb, Ba, K, Ce and depleted in high field strength elements (HFSE) such as Y, Nb and Zr. The REE patterns have relatively smooth LREE enriched chondrite normalized REE profiles with $(La/Yb)_n$ between 4.28 to 14.66. A lack of Eu anomalies along with a continuous increase in the slope of LREE profile from tonalite to syenogranite exhibit a relatively low fractionated chondrite normalized pattern $[(La/Yb)_n]$ and also involvement of plagioclase in the melting processes. Small negative Eu anomaly in alkali granite is an indication of more differentiated rock type $[(La/Yb)_n=42.78]$ in Chenar granitoid stock. Geochemical data, various trace element discriminant diagrams, common igneous microgranitoid enclaves, and ocean ridge granite normalized multi-element diagrams indicate that the Chenar granitoid stock has characteristics of metaluminous to slightly peraluminous, calc-alkaline, I-type granite of a volcanic arc settings and is formed in an active continental margin environment. In this model, a NE-dipping subduction zone of Neotethys could have accounted for the arc volcanism of the Central Iran where felsic, Andean-type magmatic arc volcanics and plutonics were formed. As a result of subduction mafic arc magmas with significant fluids were produced following the dehydration of oceanic crust and partial melting of mantle wedge which in turn provoke partial melting of considerably metasomatized and enriched subcontinental lithosphere, leading to generation of siliceous magma. Its low-pressure crystal fractionation gave rise to generation of hydrous calc-alkaline magmas, represented in part by Chenar granitoid stock.

Keywords: Chenar stock; Volcanic arc granitoid; I-type; Neotethys; Central Iran

1. Introduction

The lower Miocene Chenar granitoid stock [9] is part of Dehaj- Sarduiyeh volcano-sedimentary belt, which

forms a distinctive part of Central Iranian volcanic belt or the "Urmiah-Dukhtar belt" of Schroeder [23] (Fig. 1). This belt forms a characteristic, linear, intrusive-extrusive complex (~150 km width) which extends for

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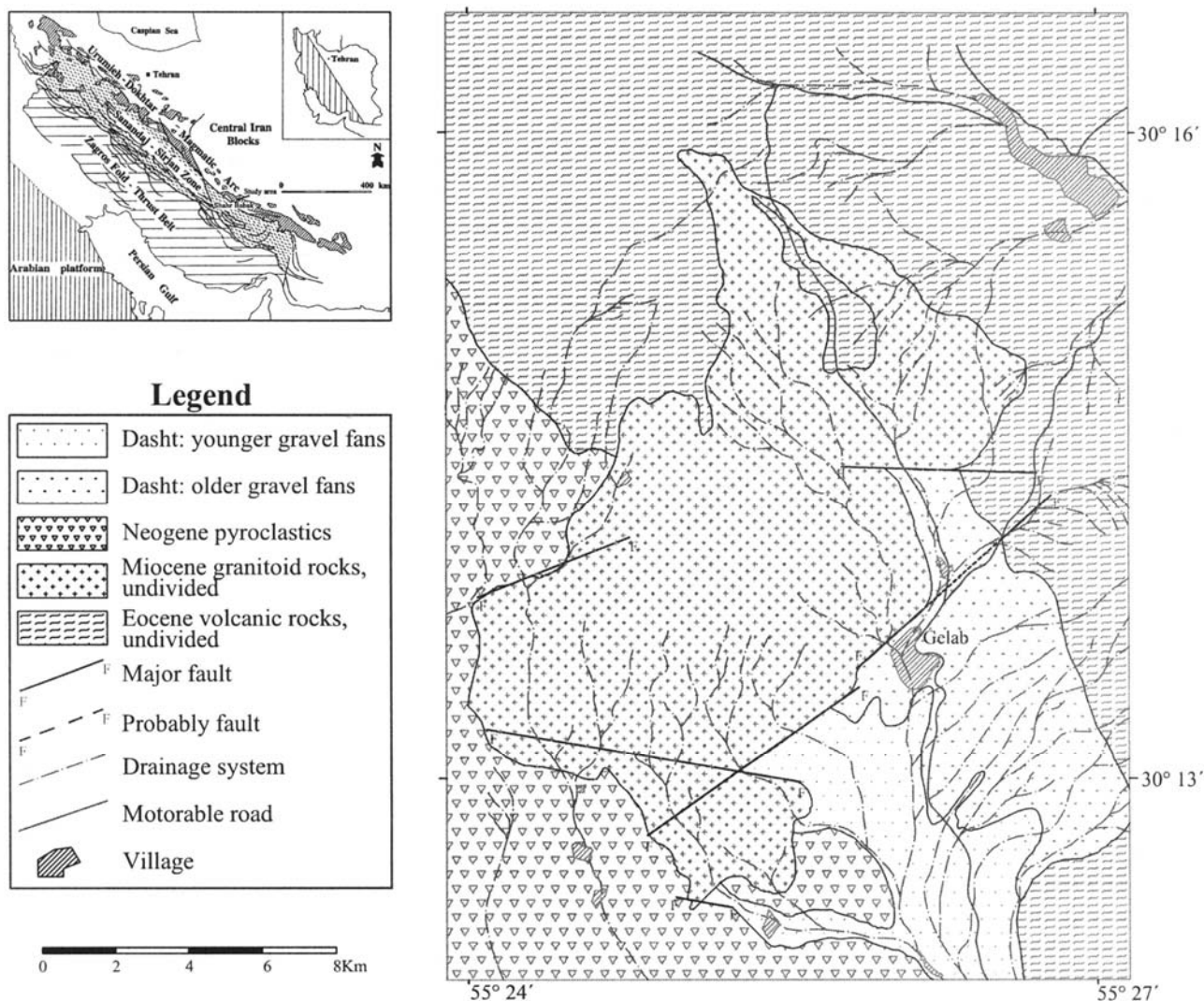


Figure 1. Location and geological map of the Chenar granitoid stock.

1700 km parallel to the entire length of the Zagros orogenic belt. It consists of various lithologic units such as small to large plutonic bodies of granite, diorite, gabbro, widely distributed basaltic lava flows, trachybasalts (locally shoshonitic), andesite, dacite, trachyte, ignimbrite and pyroclastics (mostly tuff and agglomerate). The oldest known pluton in this assemblage is calc-alkaline intrusive rocks of Precambrian age exposed in the southeastern margin of Central Iran [3]. The youngest rocks (mainly lava flows and pyroclastics) belong to Quaternary Pliocene volcanic cones of alkaline and calc-alkaline composition.

The purpose of this paper is to present petrographical, geochemical and petrogenetic characteristics of the Chenar granitoid stock and its role in the Oligocene-Miocene plutonism subduction related terranes in the

Kerman region.

2. Field Relationships

The Chenar granitoid rocks, located 230 km northwest of Kerman in southern Iran (Fig. 1), form a stock-like intrusive mass mostly of acidic composition. In the eastern part of the study area, the granitoid rocks intruded the Eocene volcano-sedimentary complex, which consists of andesite, trachyandesite, trachybasalt, andesitic basalt, trachyte, tuff and volcano-clastic, and to the west they are covered by Pliocene volcano-clastic rocks of Masahim volcano.

The Chenar granitoid rocks consist mainly of granodiorite and monzogranite, with subordinate tonalite and syenogranite (nomenclature follows

LeMaitre, [15]). Their magmatic contact with Eocene volcano-sedimentary complex is marked by albite-epidote to hornblende hornfels facies and granitic apophyses. The granitoid stock frequently cut by alkali granite as aplitic veins and quartz dioritic dykes. Enclaves of various types and sizes (centimeters to meters) occur near the margin. The enclaves can be divided into two groups: xenolithic enclaves (andesitic in composition) and microgranular mafic enclaves (dioritic, quartz dioritic, monzodioritic, quartz monzodioritic, quartz monzonitic and monzonitic in composition). The distribution of enclaves is not even in the area. In some section they form individual masses, while in other areas they form swarms. The swarms are mostly microgranular mafic enclaves and they exist as planar and nonplanar dyke shape, small raft, vortex and folded lens-shape swarms.

The Chenar granitoid rocks are cut by different types of dykes of different sizes and orientations. These dykes consist of aplitic to pegmatitic alkali granites (0.01-1.5 m wide), microgranular dykes (0.1-4 m wide) which are similar to mafic enclaves in composition and basic to intermediate aphanitic dykes (0.5-0.8 m wide).

The granitoid rocks also show evidence of hydrothermal and late magmatic activities, marked by argillation of K-feldspars, sericitization and saussuritization of plagioclase, uralitization of clinopyroxenes and tourmalinization. Sulfide minerals (mainly pyrite and to lesser extent chalcopyrite), azurite and malachite often occur along the joint systems.

3. Petrography

Rocks of the Chenar granitoid stock are coarse to medium grained and are hypidiomorphic inequigranular. They commonly contain quartz (<10-50%), plagioclase (<10-75%), alkali-feldspar (0-75%) and ferromagnesian minerals (5-25%). Fine (mm-size) accessory apatite and zircon are intergranular and form inclusions in amphibole and biotite. Other accessory minerals are titanite (as much as 4 mm long) and magnetite. The rocks are variably strained; typically with weak subgrain development in quartz grains marked with undulatory extinction and lesser, fish like biotite and bent or broken plagioclase. Quartz grains are generally clustered between the feldspars with micrographic and occasionally granophyric intergrowth. Often quartz phenocrysts with sutured boundaries have inclusions of the other granitoid minerals. Plagioclase varies from oligoclase to labradorite with some crystals exhibiting oscillatory zoning and sieve texture and are affected by saussuritization. Myrmekitic intergrowths and microperthitic textures are also common. Alkali feldspar

(orthoclase) occurs as phenocrysts with sutured boundaries, perthitic crystals and intergrowth with quartz in the matrix. The orthoclase is also affected by sericitization and kaolinitization processes. Ferromagnesian minerals includes biotite (altered to chlorite, titanite and iron oxides), hornblende (altered to chlorite, calcite and epidote), and clinopyroxene (diopside-augite, occasionally resorbed and overgrowth by hornblende) which is often uralitized. In the uralitized clinopyroxene, magnetite is formed along the cleavage traces, which may attest to reduction of lateral pressure during on the ascending magma, which resulted in the instability of diopside [19]. The absence of primary perthite, formation of plagioclase and alkali feldspar as a separate phases, and micrographic and myrmekitic textures along with deutric alteration suggest the crystallization of the Chenar granitoid rocks in a subsolvus condition at relatively high P_{H_2O} (>5 kb).

4. Enclaves

Mafic microgranular enclaves in general consist of phenocrysts of plagioclase + alkali feldspar + quartz + hornblende in a groundmass of plagioclase, quartz, biotite, hornblende and opaque minerals. Plagioclase phenocrysts of andesine to bytownite, display oscillatory zoning and sieve textures. Alkali feldspar and quartz occur as oikocrysts near the contact with their host granitoid rocks. Some of these feldspars and quartz grains have formed in the host rock, and the others with poikilitic texture remain in enclaves surround the other crystals in the matrix. This places the root of oikocrysts in granitoid rocks (*i.e.*, porphyroblast origin). Thus the parent magma of mafic enclaves could have been diorite that has been contaminated later with a host acidic magma. This change of composition of enclaves into monzodiorite and monzonite and their enrichment in alkali feldspars depends on the rate of contamination.

Apatite is seldom present as equant grains. Other accessory minerals are subhedral to interstitial titanite and zircon as subhedral granular grains. The presence of igneous enclaves within granite indicates that more mafic magmas may have been involved for the formation of the origin of granitic magma [25].

Enclaves of host Eocene volcanic rocks (andesite and andestic basalt) also occur in granitoid rocks near the margin.

5. Geochemistry

Major and trace element abundances (Table 1) were determined for twenty-eight carefully selected fresh samples by X-ray fluorescence using a Phillips 1220-C

Table 1. Major, trace and rare earth element analyses of the Chenar granitoid stock

Sample Rock type	PD4 Tn	QRB6 Tn	AG3 Gd	QCL12 Gd	BG6 Gd	QDL13 Gd	CL9 Gd	DL30 Gd	RB3 Gd	AG19 Mg	AG8 Mg	BG11 Mg	BG7 Mg	CL21 Mg
wt%														
SiO ₂	61.34	61.33	65.10	67.38	66.26	64.35	67.22	68.28	68.42	63.29	68.02	71.49	66.12	67.06
TiO ₂	0.89	0.66	0.67	0.48	0.49	0.46	0.56	0.53	0.52	0.61	0.36	0.26	0.59	0.79
Al ₂ O ₃	18.16	15.93	17.22	14.83	16.81	15.92	16.41	16.50	16.43	17.39	16.30	15.85	17.08	16.04
FeO	4.82	6.27	4.42	3.66	3.54	4.14	3.63	3.86	4.95	4.30	2.94	2.56	4.15	4.95
MnO	0.17	0.14	0.10	0.10	0.09	0.10	0.12	0.10	0.08	0.11	0.07	0.06	0.09	0.10
MgO	3.39	2.92	2.05	1.98	1.67	2.45	2.09	1.67	1.11	2.59	1.30	1.28	2.31	2.12
CaO	5.67	7.88	4.73	5.28	4.04	5.32	5.14	4.36	4.28	5.16	3.41	2.59	4.20	4.07
Na ₂ O	3.64	2.29	3.26	2.13	4.41	2.66	3.08	2.96	2.75	4.44	3.77	3.20	3.47	2.95
K ₂ O	1.73	1.74	2.29	3.34	2.50	3.74	1.92	1.93	1.54	2.04	3.94	2.53	2.10	1.97
P ₂ O ₅	0.01	0.21	0.08	0.18	0.07	0.18	0.06	0.05	0.01	0.06	0.07	0.07	0.08	0.11
LOI	0.32	0.55	0.13	0.44	0.11	0.47	0.14	0.15	0.24	0.05	0.03	0.10	0.07	0.90
Total	100.14	99.93	100.05	99.79	99.99	99.79	100.37	100.39	100.33	100.04	100.21	99.99	100.26	101.06
ppm														
V	220	97		68		65		97		27		48		25
Cr	44	18		32		31		72		13		44		14
Ni	23	8		11		14		*		15		*		17
Cu	134	19		61		2		58		23		23		*
Rb	32	50		108		111		139		186		171		257
Sr	417	435		522		552		558		602		354		542
Y	20	16		20		20		18		21		12		21
Zr	97	105		127		134		169		119		117		115
Nb	4	2		6		7		7		4		9		5
Ba	446	400		825		793		1110		855		721		876
Pb	30	8		32		31		20		20		28		17
Th	4.7	2		6		6		16.9		13		24.3		16
U	1.2	1		7		4		5.2		5		3.1		4
Hf	2.6							4.4				3.4		
Ta	0.2							0.6				0.7		
Tl	0.2							0.7				1.1		
La	11.8							27.5				27.2		
Ce	24.4							48.8				42.7		
Pr	3.01							5.32				4.11		
Nd	12.8							20				13.9		
Sm	3.2							3.8				2.5		
Eu	0.99							1.1				0.68		
Gd	3.1							3.1				1.8		
Tb	0.6							0.5				0.3		
Dy	3.3							3				1.9		
Ho	0.7							0.6				0.4		
Er	2							1.8				1.2		
Tm	0.32							0.28				0.21		
Yb	1.9							1.8				1.4		
Lu	0.31							0.29				0.23		

* Not analyzed. Tn, tonalite; Gd, granodiorite; Mg, monzogranite; Sg, syenogranite; Ag, alkali granite; Di (dy), diorite (dyke); Di (en), diorite (enclave); Qd (en), quartz diorite (enclave); Qd (dy), quartz diorite (dyke)

Table 1. Continue

Sample	DL28	QAG13	NB9	QBG1	DL1	QDL1	BG61	QBG61	QBG81	CL111	CL112	QCL112	DL81	QDL101
Rock type	Mg	Mg	Mg	Mg	Sg	Sg	Ag	Ag	Ag	Qd(dy)	Di(dy)	Di(dy)	Di(en)	Qd(en)
wt%														
SiO ₂	67.55	65.64	68.30	66.71	72.21	69.37	73.43	77.35	74.79	52.83	47.81	50.81	52.38	57.12
TiO ₂	0.64	0.44	0.58	0.44	0.19	0.25	0.10	0.10	0.15	0.88	0.78	0.57	0.86	0.76
Al ₂ O ₃	16.59	15.78	16.67	15.42	16.01	15.33	14.26	12.36	13.69	16.13	15.14	15.24	18.90	16.35
FeO	3.86	3.92	4.02	3.51	1.90	1.54	1.88	0.74	1.22	10.00	13.08	11.80	8.70	7.19
MnO	0.12	0.09	0.08	0.08	0.04	0.04	0.06	0.01	0.02	0.19	0.24	0.19	0.20	0.18
MgO	1.91	1.94	1.46	1.92	0.92	0.61	0.64	0.02	0.26	7.29	9.21	7.14	4.27	3.27
CaO	4.50	5.11	4.22	4.74	1.99	2.25	1.11	1.21	1.37	6.78	9.96	8.89	8.15	7.47
Na ₂ O	2.94	2.45	3.24	2.28	3.00	2.35	4.37	2.34	2.72	3.79	2.44	1.74	4.17	3.07
K ₂ O	2.06	3.66	1.57	4.01	3.98	7.74	4.11	5.20	5.14	1.38	0.66	1.07	1.59	2.49
P ₂ O ₅	0.06	0.18	0.06	0.19	0.01	0.08	0.01	0.01	0.03	0.19	0.12	0.11	0.17	0.42
LOI	0.08	0.52	0.11	0.41	0.11	0.34	0.04	0.49	0.40	0.87	0.57	2.34	0.45	1.23
Total	100.31	99.73	100.31	99.71	00.36	99.90	100.01	99.83	99.79	100.33	100.01	99.90	99.84	99.56
ppm														
V		62		66	42	37	12	22	27	113	*	147	106	126
Cr		30		42	75	42	65	35	86	65	*	162	26	46
Ni		17		9	*	11	*	6	4	135	11	87	26	21
Cu		23		609	78	61	29	8	28	77	58	5	248	91
Rb		107		111	226	193	210	185	155	76	*	80	66	98
Sr		514		525	537	494	74	76	306	638	866	691	630	423
Y		20		19	8	23	14	24	21	40	24	15	29	20
Zr		136		132	149	130	94	87	96	161	101	63	163	120
Nb		6		4	5	4	15	7	3	8	5	2	10	6
Ba		729		827	2960	2183	131	49	705	628	338	192	772	520
Pb		21		30	27	36	37	49	32	18	16	18	24	30
Th		10		4	34.8	15	51.6	41	24	12	7	2	12	5
U		1		1	9.9	9	12	8	6	3	*	1	4	1
Hf					4.6		4.1							
Ta					0.5		1.5							
Tl					1.1		0.7							
La					56.1		38.5							
Ce					89		62.9							
Pr					8		5.87							
Nd					24.5		18.6							
Sm					2.9		2.8							
Eu					0.88		0.35							
Gd					1.4		1.8							
Tb					0.2		0.4							
Dy					1.3		2							
Ho					0.2		0.4							
Er					0.8		1.4							
Tm					0.11		0.26							
Yb					0.9		1.8							
Lu					0.16		0.31							

computerized spectrometer at Geological Survey of Iran. In addition, samples of major rock units in the Chenar granitoid stock were analyzed for rare-earth element (Table 1) by ICP-MS in Acta Laboratory in Canada. Major element oxides Al_2O_3 , FeO, TiO_2 , CaO, MgO and MnO all have a negative correlation with silica (Fig. 2).

Trace element distributions are erratic, with only two elements showing any significant trend. Vanadium has a negative correlation and Nb has a positive correlation with SiO_2 , and both are consistent with the general trend of a differentiation granitic magma.

The Chenar granitoid samples define a typical calc-alkaline trend on an AFM diagram (Fig. 3a), although on K_2O vs. SiO_2 diagram, some tendency toward high-k calc-alkaline trend is obvious (Fig. 3b) which may point to the depth of subduction. Classification by the aluminum saturation index (ASI) of Zen [28] indicates that most of the samples are metaluminous and some are slightly peraluminous (*i.e.* Al index < 1.1) (Fig. 3c). The peraluminous nature of samples may be the result of differentiation of hornblende [28] or heterogeneity of the water content in the protholith [26]. However, the overall mineralogy of the granitoid rocks which include clinopyroxene, hornblende, biotite, magnetite, apatite, zircon, titanite, allanite, and epidote strongly suggest a metaluminous source.

The major and trace elements have been used for classification of similar rocks, determination of their source rocks, and interpretation of their tectonic settings [5,11,13,16,17,20,21].

The discrimination between ocean ridge granites (ORG), volcanic arc granites (VAG), within plate granites (WPG) and collision granites (COLG) have been purposed by Pearce *et al.* [21] using Nb, Y, Ta, Yb and Rb trace element data. Pearce [20] explained the importance of Rb vs. (Nb+Y) for determining the source for the granites and their geological background. On the Nb vs. Y and Rb vs. (Nb+Y) diagrams (Figs. 4a, b), the Chenar granitoid rocks plot within the volcanic arc granite (VAG) field with slight affinity toward syn-COLG. This could be due to crustal contamination [21]. The VAG setting and pre-plate collision nature of the Chenar granitoid rocks are further evident from Ta-Hf-Rb diagram [11], and Y vs. Zr diagram [17] (Figs. 5a,b).

The Nb and Y concentrations in volcanic arc granites usually represent the type of source. Pearce [20] suggested that the source for the volcanic arc granites could be a depleted asthenosphere that juxtaposes against a crustal counterpart during a subduction process. The lack of any increase in Nb+Y (Table 1) is a sign of relatively low degree of fractional crystallization in volcanic arc granites.

The studies of similar plutons (Pearce *et al.*, [21], for example) suggest that the granitoid stocks (such as Chenar) enriched in large ionic lithophile elements (LILE) relative to high field strength elements (HFSE) (Fig. 6) are typical of continental margin. Enrichment of K_2O , Rb, Th, Ce and negative Nb anomaly in Chenar granitoid stock are compatible with the concentration of these elements in continental arc suites.

The REE patterns of the granitoid stocks must reflect the residual mineral assemblages of their source region [26]. The whole rock REE analyses for five representative rock types from the Chenar granitoid rocks are included in Table 1. Most samples have a relatively smooth, LREE enriched, chondrite-normalized REE profiles (Fig. 7) with $(La/Yb)_n$ between 4.28 to 14.66. A lack of Eu anomalies in four of the samples (tonalite, monzogranite, granodiorite, syenogranite) along with a continuous increase in the slope of LREE profile from tonalite to syenogranite, clearly exhibit a relatively low fractionated chondrite normalized REE patterns [$(La/Yb)_n$]. Cullers and Graf [7] showed that granitic rocks containing no Eu anomalies, low to moderate REE contents and variable LREE/HREE ratios require little or no residual plagioclase in the source. This clearly shows that plagioclase was involved in the melting processes. This is in line with experimental data that suggest most I-type granites formed by hydration melting at temperatures greater than about 850°C [24]. However, small negative Eu anomaly in alkali granite is an indication of a more differentiated rock type [$(La/Yb)_n=42.78$] in the Chenar granitoid stock.

6. Discussion and Conclusion

The Dehaj-Sarduiyeh volcanic belt, which includes the lower Miocene granitic rocks of the Chenar, is part of Central Iranian volcanic belt. This belt is the subject of considerable controversy concerning the nature and dating of the final closure of the Neotethys ocean and the Arabian- Central Iranian continental collision process. The existence of the Central Iranian volcanic belt has been explained by many as the result of a northeast dipping subduction along the Main Zagros reverse fault, at an Andean-type magmatic arc along the active continental margin of Central Iran. Berberian *et al.* [4] believed that the latest Andean type magmatic activity took place during the Oligocene-Miocene that was followed by the magmatic arc migrate inland. Other studies suggest that the Eocene volcanic activities in Central Iran began by the opening up of the basins and creation of a horst-graben system [1,2,6,8,10]. This aspect suggests that the contamination of a basaltic

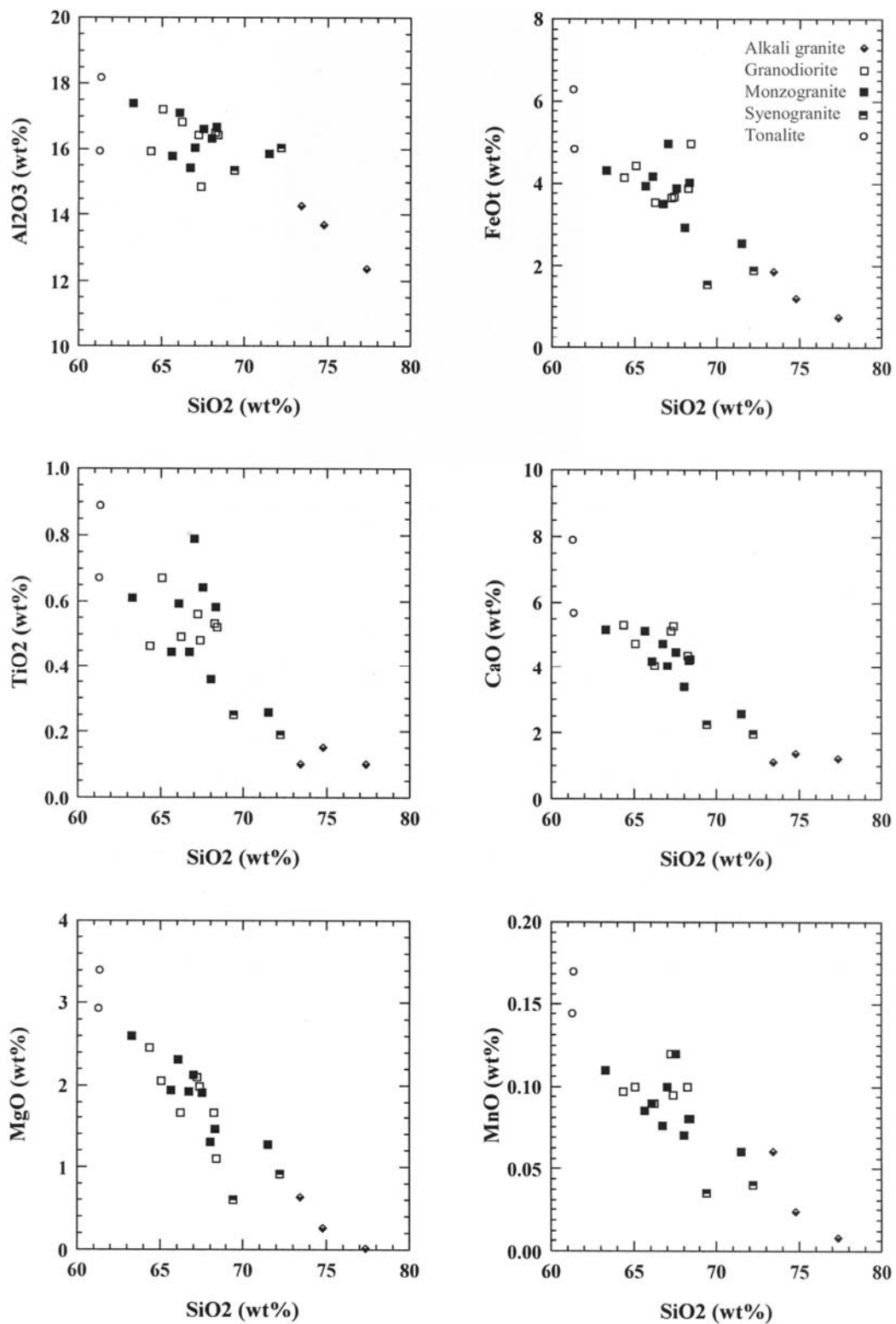


Figure 2. Selected major element oxide variation plotted vs. SiO₂ content.

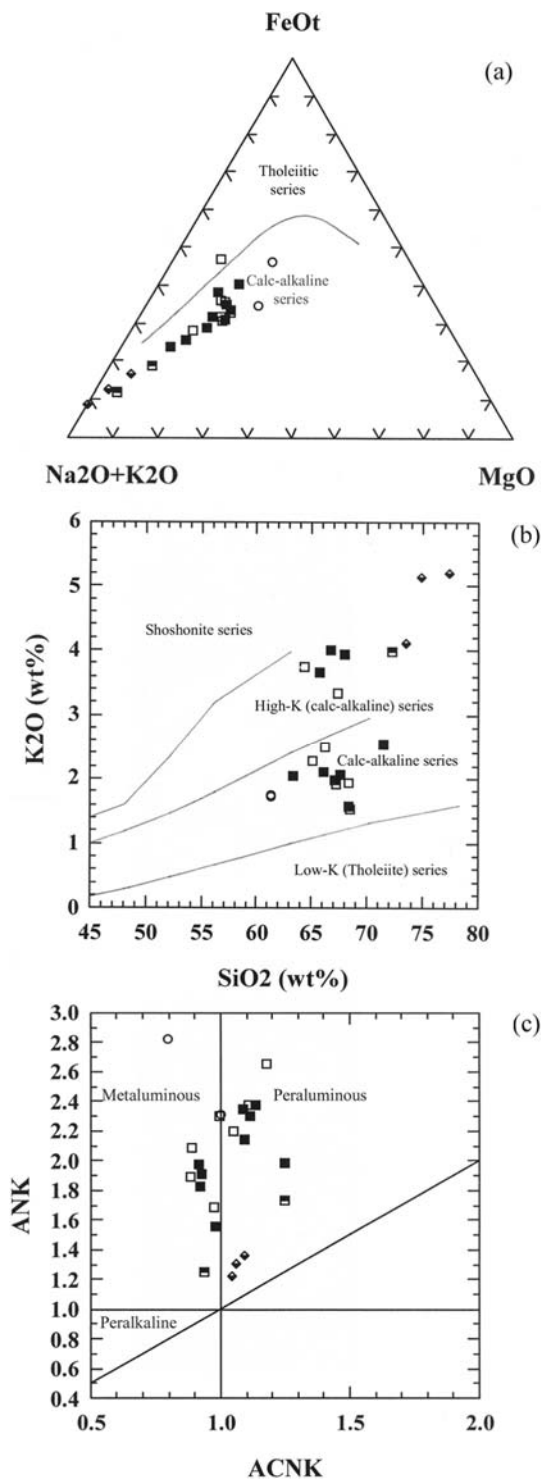


Figure 3. AFM diagram showing chemical trend for the Chenar granitoid rocks. Dot line: boundary line of Kuno [14], (b), SiO₂ vs. K₂O classification diagram (after [15]) for the Chenar granitoid stock and (c) plot of A/NK vs. A/CNK [A/NK=molar ratio of Al₂O₃/(Na₂O+K₂O); A/CNK = molar ratio of Al₂O₃/(CaO+Na₂O+K₂O)] for the Chenar granitoid stock. Symbols as in Figure 2.

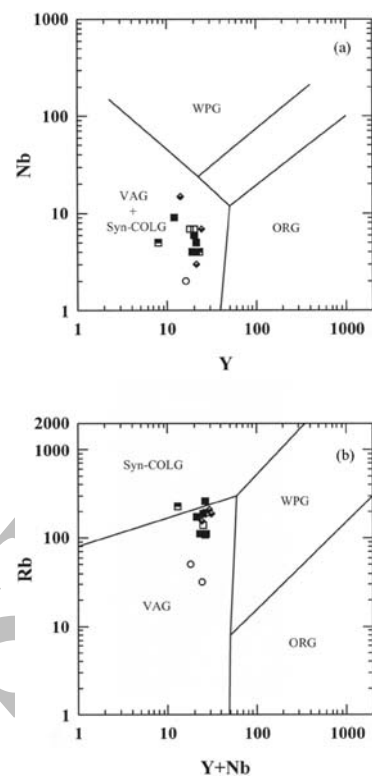


Figure 4. Trace element discrimination diagrams for the Chenar granitoid rocks [20, 21]. VAG=volcanic arc granites, ORG=ocean ridge granites, WPG=within-plate granites, syn-COLG=syn-collision granites, and post-COLG=post-collision granites. Symbols as in Figure 2.

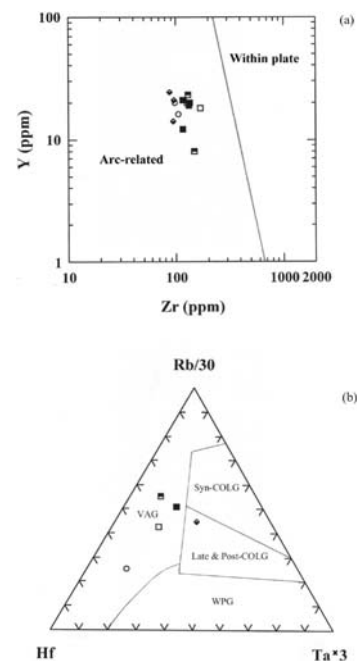


Figure 5. Zr vs. Y [17] and Hf-Rb-Ta [11] discrimination diagrams for the Chenar granitoid rocks. Symbols as in Figure 2.

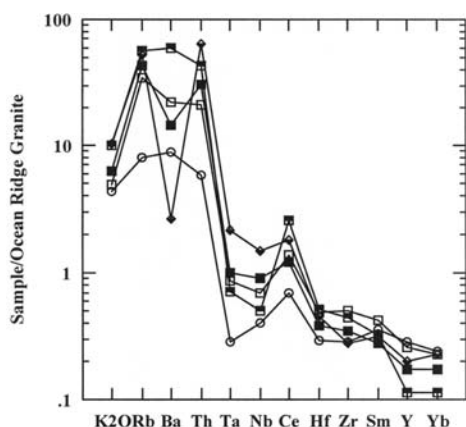


Figure 6. Ocean ridge granite (ORG) normalized geochemical patterns for the Chenar granitoid stock (normalization factors from Pearce *et al.*, [21]). Symbols as in Figure 2.

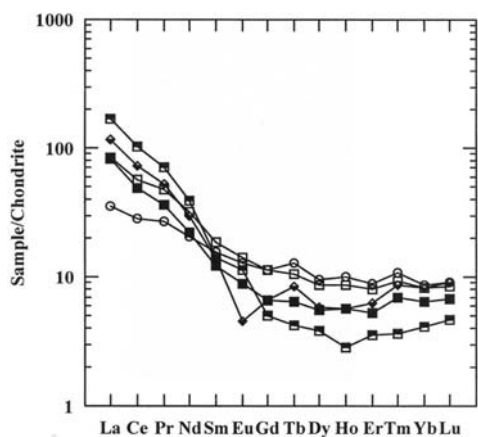


Figure 7. Chondrite-normalized REE plots of the Chenar granitoid rocks. Normalizing values used are from Nakamura [18]. Symbols as in Figure 2.

magma by a bulky, paligenetic acid magma is the explanation for the few volcanic rocks with calc-alkaline trends in the Central Iranian volcanic belt.

The Chenar granitoid stock consists mainly of granodiorite and monzogranite with subordinate tonalite and syenogranite (an evidence of an *in situ* differentiation), and all of them contain hornblende and to certain extent mafic enclaves. Alkali granite (as aplitic vein) and quartz dioritic rocks also frequently cut through the granitoid stock. Metaluminous composition, strong mineralogical (magnetite and titanite bearing) and geochemical ($A/CNK < 1.1$) characteristics, amphibole-bearing minerals, and common igneous microgranitoid enclaves indicate plutonic rocks of the

Chenar have affinity with I-type granite. On the various trace element tectono-magmatic discrimination diagrams [17,20,21], the Chenar granitoids are classified as continental arc type. In this context, a NE dipping subduction zone could have accounted for arc volcanism established over the Central Iranian microcontinental mass along which felsic, Andean-type arc volcanics and plutonics were formed [4,12]. As a result of this subduction mafic arc magmas with significant fluids were produced following the dehydration of oceanic crust and partial melting of mantle wedge which in turn provoke partial melting in the subcontinental lithosphere which is considerably metasomatized and enriched [22,27]. This led to generation of siliceous magma. Low-pressure crystal fractionation of such magma gave rise to generation of hydrous calc-alkaline magmas, represented in part by the Chenar granitoid stock. Deep-seated crustal melting, and some mantle-derived mafic magma hybridized with crustal melts formed intermediate mafic melt that consequently formed the mafic enclaves and dykes. All these suggest that mixing of mafic and granitic magmas was the main mechanism for the formation of mafic enclaves and dykes in the Chenar granitoid stock.

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References

1. Amidi S.M. Contribution a l' etude stratigraphique, petrologique et petrochimique des roches magmatiques de la region de Natanz-Nain-Surk (Iran Central). [Dissertation], Grenoble, 316 pp. (1975).
2. Amidi S.M., Emami M.H., and Michel R. Alkaline character of Eocene volcanism in the middle part of Central Iran and its geodynamic situation. *Geol. Rundschau*, **73**: 917-932 (1984).
3. Berberian F. and Berberian M. Tectono-plutonic episodes in Iran. Geodynamic Series 3, working group 6, American Geophysical Union, 5-32 (1981).
4. Berberian F., Muir I.D., Pankhurst R.J., and Berberian M. Late Cretaceous and Early Miocene Andean-type plutonic activity in northern Makran and Central Iran. *J. Geol. Soc. London*, **139**: 605-614 (1982).
5. Bowden P., Batchelor R.A., Chappell B.W., Didier J., and Lameyre J. Petrological, geochemical and source criteria for the classification of granitic rocks: a discussion. *Physics of the Earth and Planetary Interiors*, **35**: 1-11 (1984).
6. Caillat C., Dehlavi P., and Martel-Jantin B.C. Geologie de la region de Saveh (Iran) contribution a l'etude du volcanisme et du plutonisme tertiaires de la zone de l' Iran

- Central. [Dissertation], Grenoble, 325 p. (1978).
7. Cullers R.L. and Graf J.L. Rare earth elements in igneous rocks of the continental crust: intermediate and siliceous rocks- or petrogenesis. In: Henderson, P. (Ed.), *Rare Earth Element Geochemistry*. Elsevier, 510 pp. (1989).
 8. Didon J. and Gemain Y.M. La Sabalan volcan plio-Quaternaire de l'Azerbaïdjan oriental (Iran). [Dissertation], Grenoble, 304 pp. (1976).
 9. Dimitrijevic M.D. Geology of Kerman Region. G.S.A., Rep. No. Yu/52., 334 pp. (1973).
 10. Emami M.H. Geologie de la region de Qom-Aran (Iran). Contribution a l'etude dynamique et geochemique du volcanisme Tertiaire de l'Iran Central. [Dissertation], Grenoble, 489 pp. (1981).
 11. Harris N.B.W., Pearce J.A., and Tindle A.G. Geochemical characteristics of collision zone magmatism. In: Coward M.P. and Rise A.C. (Eds.), *Collision tectonics. Geol. Soc. Spec. Publ.*, **19**: 67-81 (1986).
 12. Hassanzadeh J. Metallogenic and tectonomagmatic event in the SE sector of Cenozoic active continental margin of Central Iran (Shahr-e-Babak), Kerman Province. Ph.D. thesis, California, Los Angeles, 204 pp. (1993).
 13. Ishihara S. The magnetite-series and ilmenite-series granitic rocks. *Min. Geol.*, **27**: 293-305 (1977).
 14. Kuno H. Differentiation of basalt magmas. In: Hess H.H. and Poldervaart A. (Eds.), *Basalts*, 2, John Wiley and Sons, 623-688 (1968).
 15. Le Maitre R.W. *A Classification of Igneous Rocks and Glossary of Terms*. (with Bateman P., Dudek A., Keller J., Lameyre J., LeBas M.J., Sabin P.A., 16-Schmid R., Sorensen H., Streckeisen A., Wooley A.R., and Zanettin B.), Blackwell, Oxford, 193 pp. (1989).
 16. Maniar P.D. and Piccoli P.M. Tectonic discrimination of granitoids. *Geol. Soc. Am. Bull.*, **101**: 635-643 (1989).
 17. Muller D., and Groves D.I. *Potassic Igneous and Associated Gold-Copper Mineralization*. Springer, 241 pp. (1997).
 18. Nakamura N. Determination of REE, Ba, Mg, Na and K in carbonaceous and ordinary chondrites. *Geochim. Cosmochim. Acta*, **38**: 757-775 (1974).
 19. Nelson S.T. and Montana A. Sieve-textured plagioclase in volcanic rocks produced by rapid decompression. *Am. Mineral.*, **77**: 1242-1249 (1992).
 20. Pearce J. Sources and settings of granitic rocks. *Episodes*, **19**: 120-125 (1996).
 21. Pearce J.A., Harris N.B.W., and Tindle A.G. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *J. Petrol.*, **25**: 956- 983 (1984).
 22. Pe-Piper G., Piper D.J.W., and Matarangas D. Regional implications of geochemistry and style of emplacement of Miocene I-type diorite and granite, Delos, Cyclades, Greece. *Lithos*, **60**: 47-66 (2002).
 23. Schroeder J.W. Essai sur la structure de l'Iran. *Ecologae Geol. Helv.*, **37**: 37-81 (1944).
 24. Sheppard S.; Occhipinti S.A., and Tyler I.M. The relationship between tectonism and composition of granitoid magmas, Yarlalweelor gneiss complex, western Australia. *Lithos*, **66**: 133-154 (2003).
 25. Soesoo A. Fractional crystallization of mantle derived melts as a mechanism for some I-type granite petrogenesis; an example from Lachan folded belt, Australia. *J. Geol. Soc. London*, **157**: 135-149 (2000).
 26. Waight T.E., Weaver S.D., and Muir R.J. The Hohonu Batholith of North Westland, New Zealand: granitoid compositions controlled by source H₂O contents and generated during tectonic transition. *Contrib. Mineral. Petrol.*, **130**: 225-239 (1998).
 27. Wilson M. *Igneous Petrogenesis: A Global Tectonic Approach*. (2nd Ed.), Harper Collins Academic, London, 466 p. (1991)
 28. Zen E.-an. Aluminum enrichment in silicate melts by fractional crystallization: some mineralogic and petrographic constraints. *J. Petrol.*, **27**: 1095-1118 (1986).