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GEOCHEMICAL AND PETROLOGICAL CHARACTERISTICS OF DEH SIAHAN GRANITIC ROCKS, SOUTHWEST OF KERMAN, IRAN: DATA BEARING ON GENESIS

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Abstract

The Oligocene-Miocene granitic rocks of Deh Siahan, part of central Iranian volcanic belt, are intruded into Eocene volcano-sedimentary complex where their contact is marked by albite-epidote hornblende hornfels facies and granitic apophyses. The granitic rocks show enhanced LIL element abundances and low HFS/LIL ratios. Geochemical data, various trace element discriminant diagrams, enhanced Y/Nb and Ce/Nb ratio, and ocean ridge granite normalized multi-element diagrams indicate that the Deh Siahan granitic rocks have characteristics of high-K, calc-alkaline, I-Cordilleran type granites of volcanic arc settings. In this aspect, it may represent part of an Andean-type magmatic arc formed in response to subduction of Neotethys oceanic crust beneath Central Iran, unrelated to a rift settings. The partial melting of subducted oceanic crust led to the formation of basic magma. Its emplacement under the mantle wedge provoked melting in the considerably metasomatized and enriched sub-continental lithosphere. This caused generation of siliceous magma which its low pressure crystal fractionation eventually led to the formation of Deh Siahan granitic rocks.

Introduction

The Deh Siahan Oligo-Miocene granitic rocks [19] are part of the Dehaj-Sarduiyeh volcanic belt, situated on the southeastern margin of the Central Iranian tectonic block. The Dehaj-Sarduiyeh belt forms a distinctive part of Central Iranian volcanic belt, or the “Urmiah-Dukhtar belt” of Schroeder [37] (Fig. 1). This belt forms a characteristic, linear, intrusive-extrusive complex (~150 km width) which extends for 1700 km parallel to the entire length of the Zagros orogenic belt (Fig. 1). It consists of various lithologic units including: granites, diorites and gabbros as small to large plutonic bodies, widely distributed basaltic lava flows, trachybasalts (locally shoshonitic), andesites, dacites, trachytes, ignimbrites and pyroclastics (mostly tuffs and agglomerates). The oldest known pluton in this assemblage are calc-alkaline intrusive rocks of Precambrian age exposed in the southeastern margin of Central Iran [8]. The youngest rocks (mainly lava flow and pyroclastics) belong to Quaternary-Pliocene volcanic cones of alkaline and calc-alkaline composition. Except for a preliminary report on the

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geology and mineralization of the Kerman region [19,36], no information has been published on the Deh Siahan granitic rocks in the Kerman region.

This paper considers the petrochemistry of the Deh Siahan granitic rocks, and in particular determines their petrogenesis and initial instrusive environment within the contex of Central Iranian volcanic belt. The data represented here were obtained through a detailed study of the Dehaj-Sarduiyeh volcanic belt in the Kerman province.

Field Geology

The Deh Siahan granitic rocks, located 135 km southwest of Kerman in southern Iran (Fig. 1), form a stock-like intrusive mass of acidic to intermediate composition (Fig. 2). They are intruded into surrounding folded Eocene volcano-sedimentary rocks consisting mainly of andesite, trachyandesite, basaltic andesite, basalt, tuff and sandstone. The Deh Siahan granitic rocks are exposed at intersections of several faults with mainly east, northeast-southwest, and southeast trends. It is possible that their emplacement significantly controlled by these major crustal lineaments, which is now well established for the emplacement of many granites [15,29]. The Deh Siahan granitic rocks consist mainly of fresh to altered granite, quartz-monzonite, porphyritic quartz-monzonite, granodiorite and minor monzonite. Their magmatic contact with andesitic to basaltic andesites is marked by albite-epidote hornblende hornfels facies and granitic apophyses. Enclaves of various sizes (from several centimeters to a few meters) also occur near the margin. They can be divided into two groups, according to Clark [14]: a) autoliths or cognate enclaves- elliptical to spherical in shape and quartz-monzonitic in composition; b) xenoliths enclaves- angular in shape and andesitic in composition. Aplitic, rhyodacitic and doleritic dykes (1-2 m in width and 300-400 m in length) with northwest-southeast and east-west trends are also present. The aplitic dykes normally cut through the monzonite and quartz-monzonitic rocks, clearly post-dating them. The doleritic dykes show pronounced

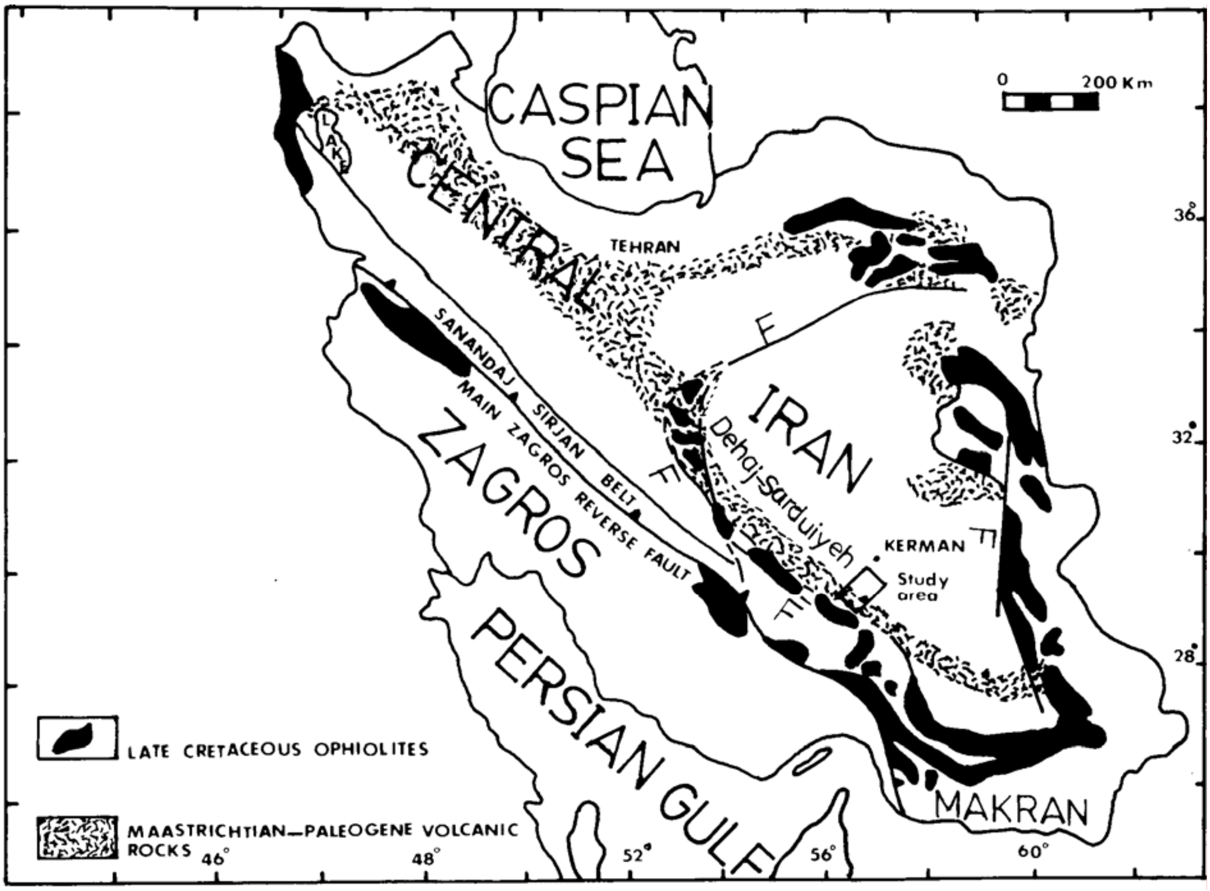

Figure 1. Map showing the position of Dehaj-Sarduiyeh volcanic belt in Central Iran and the study area.

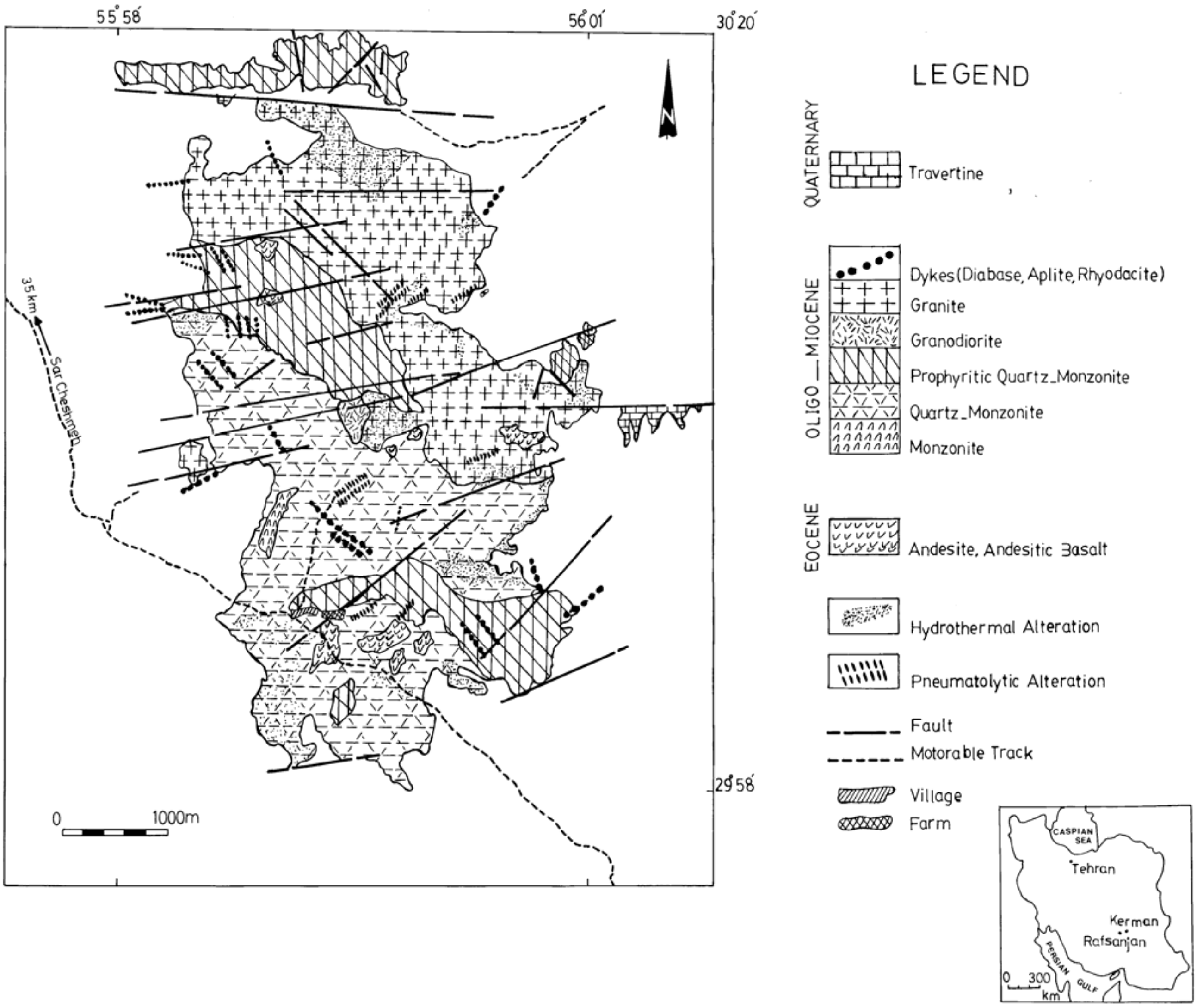

Figure 2. Geological map of Deh Siahan granitic rocks (after [36]).

flow differentiation, marked by linear alignment of 2 mm lath-shaped plagioclases. The Deh Siahan granitic rocks show evidence of hydrothermal and late magmatic processes, marked by argillation, sericitization, chloritization, carbonitization and tourmalinization, quite often along the mainly northeast-southwest trending faults. Porphyry-copper-molybdenum deposits also occur in the area. In this aspect prominent alteration halos around mineralized porphyry deposits have been used extensively as a guide to exploration.

Petrography

Petrography studies of 60 representative thin-sections of Deh Siahan intrusives show that the granitic rocks are composed essentially of quartz, K-feldspar, and plagioclase with variable amounts of hornblende, biotite, clinopyroxene, apatite, zircon, sphene, tourmaline, magnetite and hematite. The quartz making up to 20-40% of the rocks, generally clustered between the feldspars with occasional granophyric intergrowths. Occasionally quartz phenocrysts formed compound grains, sometimes with sutured internal boundaries, and are rounded and strongly corroded. Alkali feldspar (orthoclase) is the most abundant mineral in the Deh Siahan granites, making up to 30-40% of the rocks. It is generally turbid and occasionally perthitic textures can be observed. The large, mesoscopically euhedral, coarse tabular megacrysts of microperthetic K-feldspars, up to 2-4 cm in length with relatively uniform distribution, are also abundant in porphyritic quartz-monzonite. They are up to 20-30% modal plagioclase (oligoclase-andesine) and affected by sericitization. Ferromagnesian minerals vary from 10-15% which including biotite (altered to chlorite and iron oxides), hornblende (altered to chlorite, calcite and epidote), and clinopyroxene (augite) which is often uralitized. The granitic rocks have medium to micro allotriomorphic granular textures with interlocking grain boundaries, poorly controlled by crystal faces. The textures are predominantly of an equilibrium character and designated as primary granitic textures. Miarolitic cavities also occur, commonly filled with quartz and calcite crystals. The monzonite consists of essentially the same minerals as the granitic rocks, except for its <5% quartz. The occasional occurences of perthite and granophyric intergrowth, separate feldspar species, corrosion and regrowth of quartz, plagioclase (often with sericitic zones) and K-feldspars, and deuteric alternation in Deh Siahan granitic rocks suggest their formation under a limited range of P/T, high P_{H2O} and activity of f_{O2}, in a sub-solvus condition [14,38].

Analytical Methods

The samples analyzed were finely powdered in a Tangestan carbide mill. The analysis of elements was performed in the College of Oceanic and Atmospheric Sciences at Oregon State University. Major and trace element analyses were proformed by the Varian ICP-AES. About 0.1 gr of sample powder were mixed with 0.9 gr lithium borate flux in a carbon crucible and heating in a furnace at 1100°C for 30 minutes. The fused glass was dissolved (using a magnetic stirring device) in 100 ml of 1% HNO_3 solution with germanium as internal standard. Dissolution of international granite standards such as G2, RGM1 was chosen for calibration.

The rare earth elements (REE), Hf, Ta, and Nb were determined by inductively coupled plasma mass spectrometry (ICP-MS) techniques. The sample powder (0.01 gr) was dissolved, using a mixture of HF, HCl and HNO_3 in special screw-top plastic vials. An internal standard solution containing indium element was then added and the spiked sample dissolution were diluted with 1% HNO_3. The internal standard was used for monitoring drift in mass response during mass spectrometric measurements. Dissolution of G2, RGM1, and GSP1 standards was chosen as calibration standard for calculation of element concentrations of the measured samples [24].

Geochemistry

Major and Trace Elements

Samples were carefully selected to avoid the effects of secondary alternation. The results of major and trace element analyses are presented in Table 1. The samples define a typical calc-alkaline trend on an AFM diagram (Fig. 3a), although a Peacock diagram classifies the rocks more correctly as calc-alkaline calcic (Fig. 3b). Classification by the aluminum saturation index (ASI) of Zen [43] indicates that the bulk of the samples are metaluminous to weakly peraluminous (ASI<1.1) (Fig. 3c). Major element Harker diagrams exhibit generally continuous trends: TiO_2, P_2O_5, FeO* and MgO (Fig. 4) abundances decrease with increasing SiO_2. Decrease in those oxides contents are reflected in the decreasing abundances of ferromagnesian silicates and magnetite in more differentiated rocks. The high K_2O contents of the Deh Siahan granitic rocks reveal their high-K, calc-alkaline shoshonitic nature (Table 1). As well as having enhanced K contents, they are enriched in other incompatible elements (REEs, see below). These geochemical features suggest the importance of crustal rocks in the magma source (s) [34].

Many authors have explored major and trace elements of various granitic rocks for the purpose of classification, determination of tectonic settings, and making inferences about the nature of source rocks [6,7,11,15,25,29,31,32,33,35,41]. Pearce *et al.*, [33] have indicated that they can, on the basis of Nb, Y, Ta, Yb, and Rb trace elements data, discriminate between syn-collision granites (syn-COLG), volcanic arc granites (VAG), ocean ridge granites (ORG), within-plate granites (WPG), and post-collision granites (PCG). They also emphasized that discrimination between VAG and syn-COLG can be completely achieved on the Ta-Yb diagram. Plots of our data on the Nb-Y, Ta-Yb (Fig. 5) show that the Deh Siahan granitic rocks can be classified as volcanic arc granites with some affinities toward within-plate type granites, which may be caused by crustal contamination [32]. Furthermore the Ta-Hf-Rb diagram is recommended for separation of acid-intermediate intrusive magmatism from volcanic arc, ocean floor, within-plate and collision tectonic settings [25,33]. This diagram of Deh Siahan granitic rocks (Fig. 6) points again to their VAG settings. To discuss the effects of fractional crystallization and source composition, the plot of Rb/Zr against Nb and Y was also used [11]. In Figure 7 the Deh Siahan granitic rocks plots in the field of normal continental arc (subduction enriched source) which is also in line with other discriminant diagrams. The lack of any increase in Nb and Y (Fig. 7) shows a relatively low degree of fractional crystallization.

The geochemical patterns for Deh Siahan granitic rocks (Fig. 8) clearly reveal their enrichments in K, Rb, Ba, Th, Ce, and Sm relative to Nb, Hf, Zr, Y, and Yb. This is similar to typical patterns for volcanic arc granites [33]. They point to the enrichment of Ce and Sm in calc-alkaline and shoshonitic series and also to the low value of Y and Yb relative to the normalizing composition in the volcanic arc granites. The enhanced

Table 1. Representative analyses of Deh Siahan granitic rocks. Note: Major oxides are in weight percent, minor and trace elements are in parts per million. LOI: loss on ignition. Fe as total FeO. Ba=basalt, Ba-And=basaltic andesite, Diab=diabase, Gd=granodiorite, Gr=granite, Mon=monzonite, Qm=quartz-monzonite

Sample No.	**549 Gd**	**550 Qm**	**553 Qm**	**554 Qm**	**555 Qm**	**556 Gr**	**558 Gr**	**559 Qm**	**560 Gr**	**561 Qm**	**562 Qm**	**565 Qm**	**566 Mon**	**552 Ba-And**	**557 Diab**	**563 Ba**
SiO_2	64.89	62.56	65.94	63.94	66.86	71.67	72.12	64.57	73.01	68.77	67.36	68.99	58.30	54.07	44.57	50.87
TiO_2	0.46	0.73	0.53	0.60	0.63	0.36	0.29	0.60	0.39	0.45	0.61	0.40	0.72	0.90	1.11	0.90
Al_2O_3	15.66	16.29	14.94	14.39	14.03	13.65	14.17	14.89	14.82	14.66	14.49	15.04	16.99	14.79	16.89	17.85
FeO*	5.21	5.32	4.56	6.21	5.27	2.91	2.30	5.07	2.65	3.21	4.47	3.34	6.65	8.04	11.91	9.97
MnO	0.12	0.11	0.08	0.28	0.11	0.09	0.03	0.25	0.10	0.06	0.10	0.11	0.16	0.22	0.16	0.20
MgO	1.03	1.03	0.80	1.29	1.20	0.48	0.27	0.94	0.44	0.46	0.56	0.37	1.38	4.11	8.87	4.28
CaO	3.77	4.06	2.40	2.13	2.79	1.35	2.34	2.81	0.30	0.55	1.95	1.36	4.50	5.67	9.02	8.71
Na_2O	3.37	3.81	3.74	3.69	3.02	3.27	1.94	3.41	2.81	3.60	3.66	3.64	3.46	3.85	2.23	3.25
K_2O	3.56	5.73	5.22	5.91	5.53	5.65	5.26	5.54	5.90	5.63	5.20	5.19	5.50	3.10	2.44	3.40
P_2O_5	0.17	0.31	0.18	0.27	0.23	0.08	0.06	0.21	0.06	0.11	0.18	0.11	0.38	0.35	0.31	0.29
LOI	1.11	0.65	0.95	0.96	0.92	0.55	0.87	0.99	0.51	1.34	0.99	0.90	1.03	5.63	1.83	0.84
Sum	99.35	100.60	99.34	99.67	100.59	100.06	99.65	99.24	100.99	98.84	99.57	99.45	99.07	100.73	99.34	100.56
Sr	186	282	221	252	299	124	99	205	68	277	168	194	420			
Ba	374	522	353	489	369	249	326	312	506	346	7.26	340	773			
Zr	184	225	521	466	490	452	265	464	442	448	343	359	115			
Y	25	35	39	39	35	42	35	42	42	32	46	41	25			
Nb	10	17				16	14		27			25	6.93			
Cu	42	56					11		10			37	129			
Zn	53	68					153		675			72	92			
Co	6.77	6					1.72		1.72			408	200			
Rb	159	271					300		352			4.51	9			
La	26	47					30		49			47	28			
Ce	50	86					59		91			90	53			
Pr	5.98	9.70					6.78		10			9.98	6.37			
Nd	22	35					24.85		35			34	25			
Sm	5.21	7.50					5.35		7.40			7.44	5.67			
Eu	0.90	1.23					0.64		0.56			0.67	1.38			
Gd	4.07	5.58					4.41		5.82			5.88	4.48			
Tb	0.73	0.98					0.87		1.03			1.02	0.72			
Dy	5.25	6.65					5.98		7.34			7.25	4.69			
Ho	1.25	1.66					1.53		1.85			1.76	1.12			
Er	3.5	4.27					4.22		4.48			4.71	2.97			
Tm	0.67	0.83					0.85		1.06			1.01	0.56			
Yb	3.59	4.35					4.40		5.36			5.10	2.71			
Lu	0.54	0.69					0.71		0.81			0.84	0.39			
Hf	6.95	7.70					8.93		15			11.77	3.47			
Ta	0.93	1.31					1.27		2.41			1.96	0.48			
Th	28	50					44		72			66	10			
U	6	13					6.91		8			14	3.84			

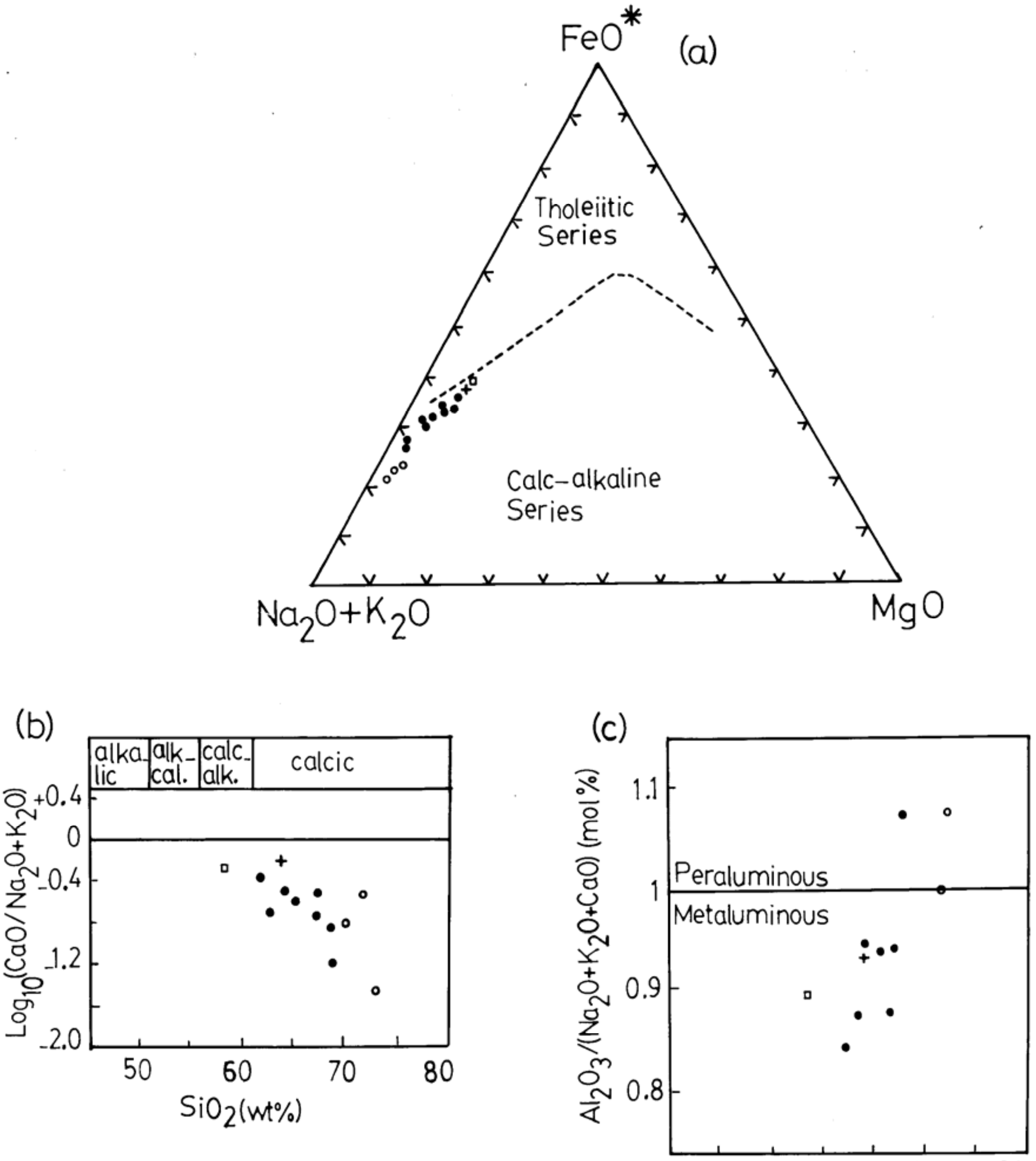

Figure 3. (a) AFM diagram showing chemical trend for Deh Siahan granitic rocks. Dot line: boundary line of Kuno [28], (b) Peacock index diagram (after [10]), and (c) plot of mol $Al_2O_3/(CaO+K_2O+Na_2O)$ versus SiO_2, showing the metaluminous to weakly peraluminous composition (ASI<1.1), for Deh Siahan granitic rocks. ●, granite; ○, quartz-monzonite; +, granodiorite; ×, monzonite.

level of LIL element relative to HFS element in the Deh Siahan granitic rocks point to the subduction-zone enrichment and/or crustal contamination of the source region.

Discussion and Conclusions

The Dehaj-Sarduiyeh volcanic belt, which includes the Oligocene-Miocene granitic rocks of Deh Siahan [19], is part of Central Iranian volcanic belt. This belt is

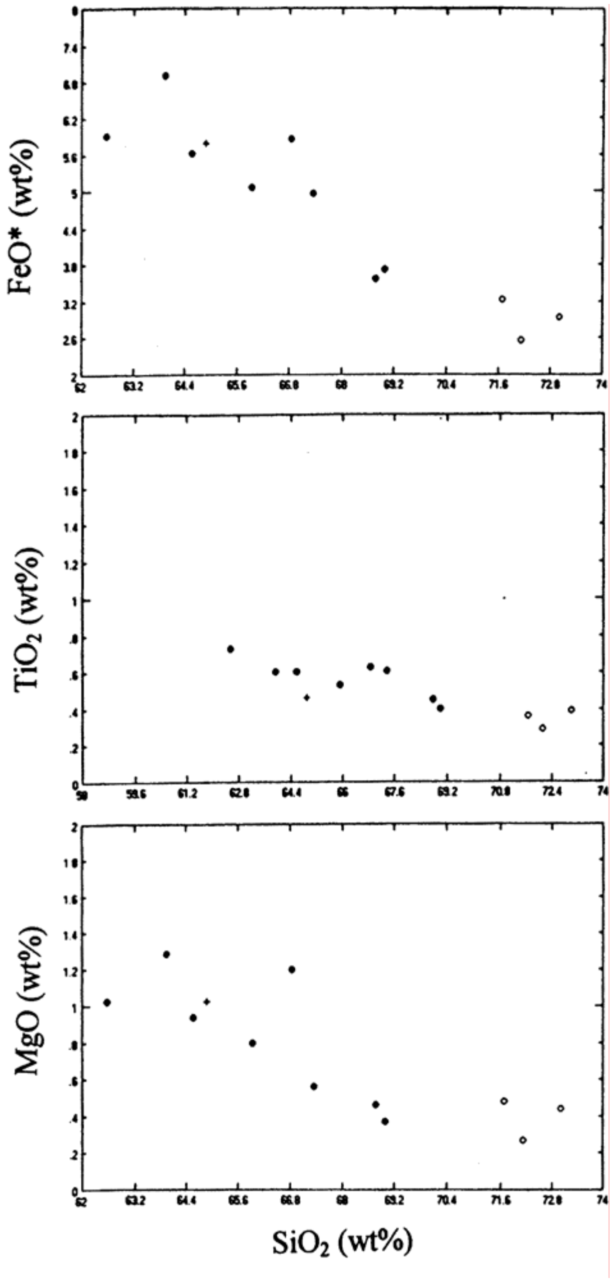

Figure 4. Selected major element oxide variation plotted versus SiO_2 content, see Figure 3 for key to symbols.

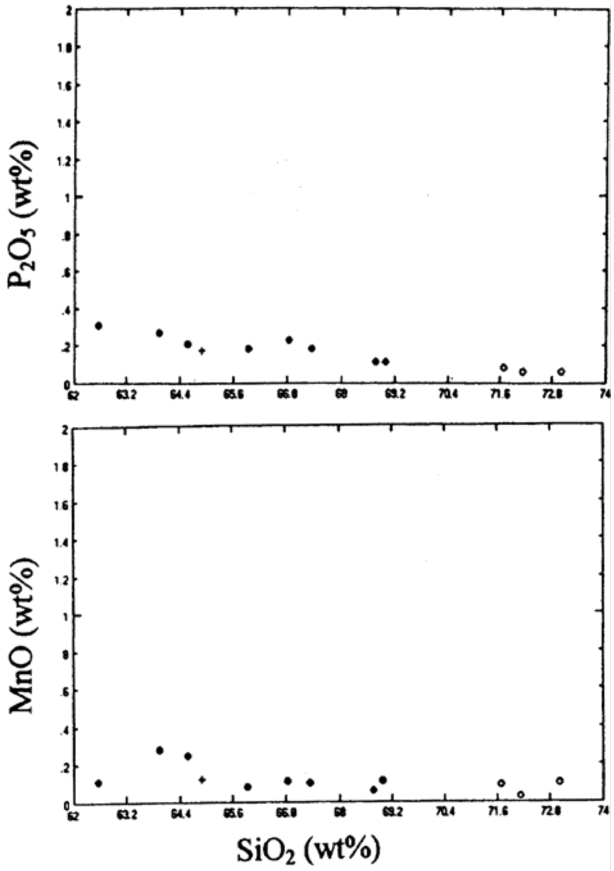

Figure 4. Continued.

the subject of considerable controversy concerning the nature and dating of the final closure of the Neotethys ocean and of the Arabian-Central Iranian continental collision. The Central Iranian volcanic belt was explained by many authors as being the result of northeast dipping subduction along the Main Zagros Reverse Fault, at an Andean-type magmatic arc along active continental margin of Central Iran [1,2,3,9,16,17,23,27,39,40]. The latest Andean-type magmatic activity took place during the Oligocene-Miocene and that the magmatic arc migrate in land [9]. Alternatively Eocene volcanic activities in Central Iran have been also explained by the opening up of the basins and creation of horst-graben system, leading to alkali volcanism along deep-seated fracture [4,5,13,18,21,30]. They regard a mutual contamination between a basaltic magma and bulky paligenetic acid magma responsible for the few volcanic rocks with calc-alkaline shoshonitic trends in the Central Iranian volcanic belt.

The Deh Siahan granitic rocks show very relationships in their chemical and mineralogical compositions. No evidence of in situ differentiation or inward zoning was observed. The occurrence of large volume of andesitic rocks, development of copper-molybdenum deposits, petrography, and various trace element discriminant diagrams, geochemical patterns, and enhanced Y/Nb and Ce/Nb ratios, all points to I-Cordilleran type nature and VAG settings for Deh Siahan granitic rocks, unrelated to rift settings. The high K_2O, enrichments in Ce and Sm reveal also their shoshonitic affinities (high-potassium, I-type granitoid). There is general consensus that potassic magmas cannot

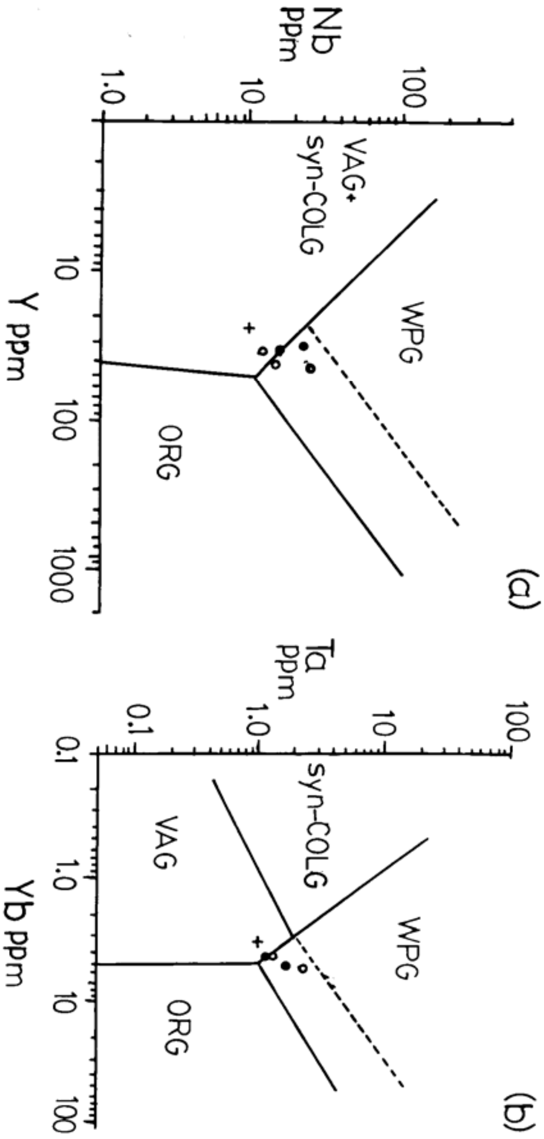

Figure 5. Trace element discrimination diagrams for Deh Siahan granitic rocks [32,33]. VAG=volcanic arc granites, ORG=ocean ridge granites, WPG=within-plate granites, syn-COLG=syncollision granites, and post-COLG=post collision granites.

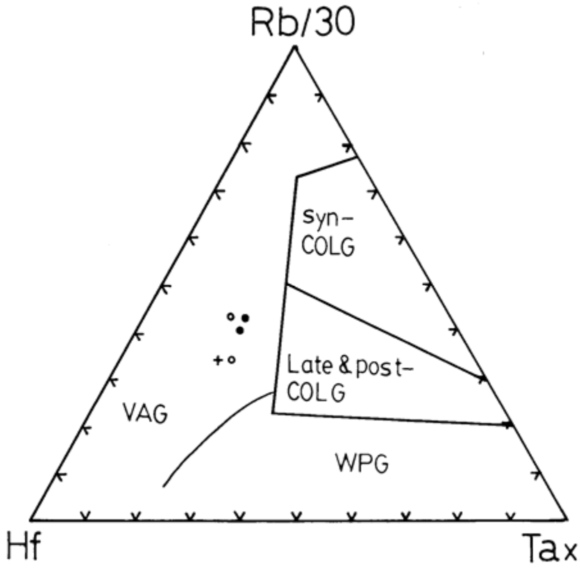

Figure 6. The Hf-Rb-Ta discrimination diagram for Deh Siahan granitic rocks [25].

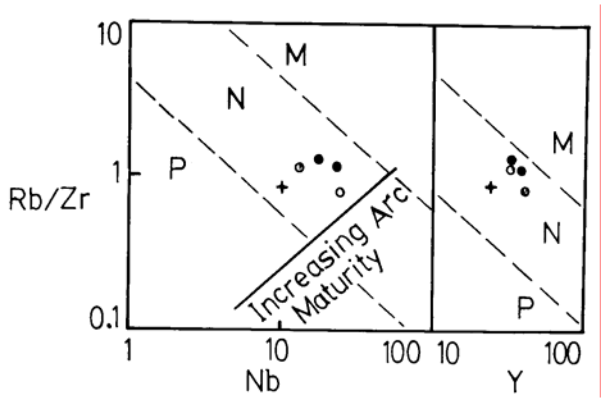

Figure 7. Plot of Rb/Zr against Nb and Y for Deh Siahan granitic rocks (after [11]). Dash lines: inferred boundaries between mature continental arcs (M), normal continental arcs (N), and primitive island arcs and continental arcs (P).

be derived by partial malting of normal mantle peridotite, but require heterogeneous mantle sources which have been metasomatically enriched in LILE (high-ion lithophile elements) and LREE [20,22]. Burnham [11] has attributed porphyry copper deposits to the high Cu abundances in I-type sources, such as metamorphosed oceanic basalt or lower crustal amphibolites. In these aspects, it is possible that dehydration and partial melting of hydrated oceanic crust (southern Neotethys) in the subduction zone, in southeast Central Iran, can give rise to basic magma with significant fluids [26,29]. Its emplacement under the mantle wedge provoke partial melting in the sub-continental lithosphere which is considerably metasomatized and enriched [42]. This led to generation of siliceous magma enriched in LILE, LREE and low HFS/LIL ratios. Low pressure crystal fractionation of such magma can account for observed rock types in Deh Siahan. Finally, though there are intrusive bodies similar to Deh Siahan granitoids rocks in the Central Iranian volcanic belt, more data are required in order to contemplate the same consideration for those intrusives.

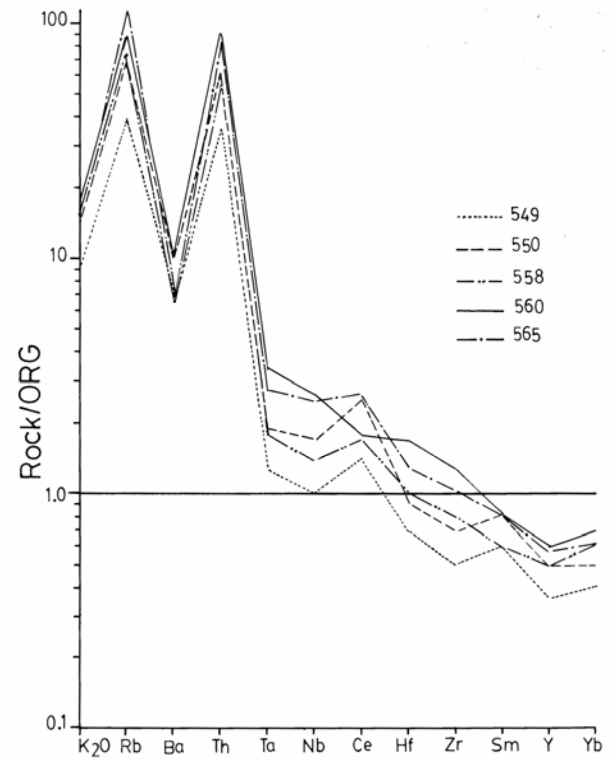

Figure 8. Ocean ridge granite (ORG) normalized geochemical patterns for Deh Siahan granitic rocks (normalization factors from [33]).

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