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ORIGINAL ARTICLE

Petrogenesis and Geochemical Properties of Dome-shaped Subvolcanic Complexes in Southwest of Shahrab (Northeast of Isfahan)

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The studied area is located in southwest of Shahrab village near Ardestan city. This zone is part of Uremia- Dokhtar magmatic belt. Outcrops composed of rhyolite and rhyodacite dome-shaped volcanic complexes are scattered in the studied area; some of which are exploited as ornamental stone. The main rhyolite minerals include quartz, plagioclase and alkali feldspar. Minor minerals include Apatite, Sphene and opaque minerals and of the secondary minerals in these rocks Christie, Chlorite, Epidote and calcite could be mentioned. Calcite exists in rocks in form of filler of micro-fissures. The ignimbrite presence in this group of rocks in form of xenolith is one of the features of this rock group. The main primary texture in rhyolite and rhyodacite is porphyritic and the secondary texture includes pull-apart, snow flake and spherulitic textures. Geochemical evidences indicate that these rocks are sub-alkaline, Calc-alkaline compositions with high potassium and meta-alumina. These rocks have negative EU anomaly that is the feature of acidic igneous rocks. The studied rocks show high enrichment of LREE and LILE elements. The primary magmas constituting these rocks have mantel origin raised under extreme compressional conditions on continental crust in a tectonic environment of volcanic arc. It seems that these rocks are formed in connection with continuance of volcanic activities associated with subduction of Neolithic oceanic plate beneath continental plate of Iran.
Key words: Ardestan; sub-volcanic rocks; Calc-alkaline; Volcanic arc

Introduction

The distribution of these sub-volcanic groups is mostly in southwest of Shahrab village in southeast of Ardestan in Isfahan province. The geographical coordination of the studied area is 33° 04′ 08′′ to 33° 11′ 15′′ N latitude and 52° 23′ 10′′ and 52° 32′ 18′′ altitude (figure 1). The studied zone is part of Uremia- Dokhtar belt (figure1).
Sub-volcanic outcrops dating Oligocene have discontinued Eocene volcanic rocks of mainly basaltic to dacite compositions. In terms of composition, Eocene volcanic rock is in range of basalt to dacite; however, it has more andesite (Nasr Isfahan and Ahmadi, 1999). These outcrops are reported to be in southeast of Zafarqand or west of Rangan village and also in south Ardestan (northeast of Baqam villge) (Radfar, 1997). Generally, in Ardestan area, Oligocene volcanic activities are mainly acidic (Emami et al, 1992). With this group of rocks, Zeolite roundish shapes of ignimbrite can be observed. In this area of Aedestan, mining works on constructional and ornamental stones are under operation in form of opencast mining on outcrops of studied stones. In this study, petrologic characteristics and tectonic pattern governing sub-volcanic dome-shaped outcrops formation will be studied in south area of Shahrab village.

Geology of the area

The outcrop place of these sub-volcanic rocks is in southwest of 1:100000 geological map of Shahrab (northeast of Isfahan). Based on this map, the lithology composition of rhyolite and rhyodacite studied stones are reported to be in white color and porphyritic texture. Based on Bahroudi studies (1997) inside these stones, phenocrysts in form of quartz, alkali feldspar and plagioclase could be seen. Parts of this sub-volcanic unit are in form of rhyodacite, tuff and ignimbrite. The more acidic parts of this unit have been injected in mid and high Eocene stones, (Middle and upper Eocene) that is the subject of this study (Figure1).

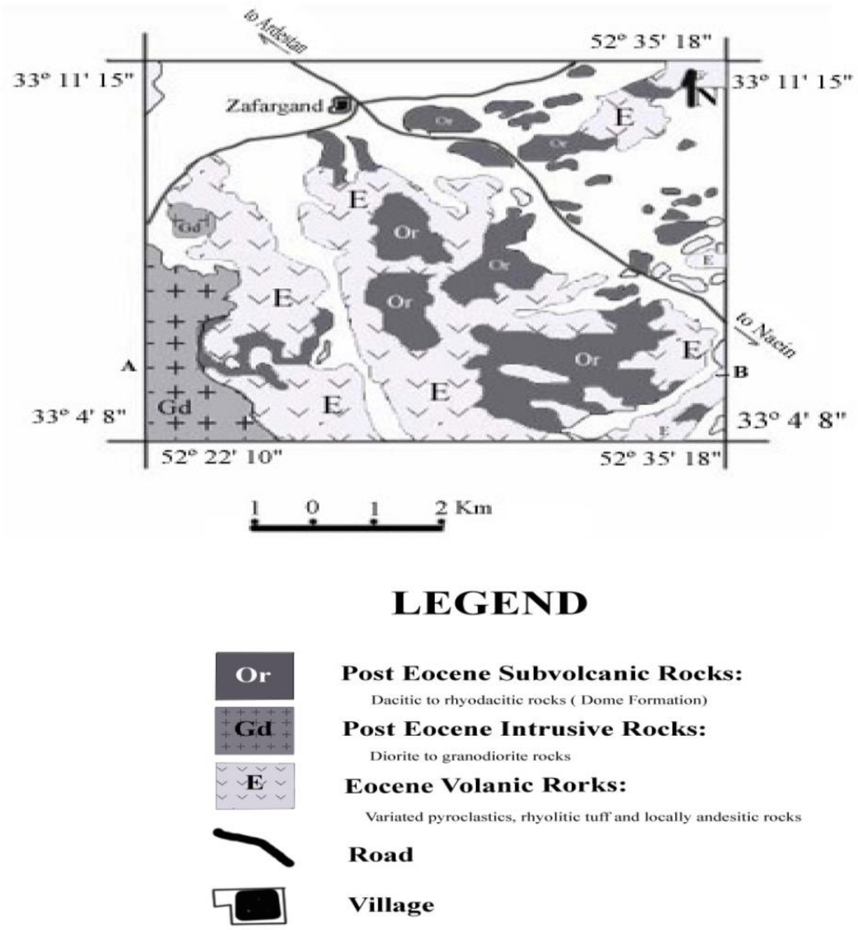

Fig.1. Geological map of studied zone (quoted from Radfar 1997 with changes)

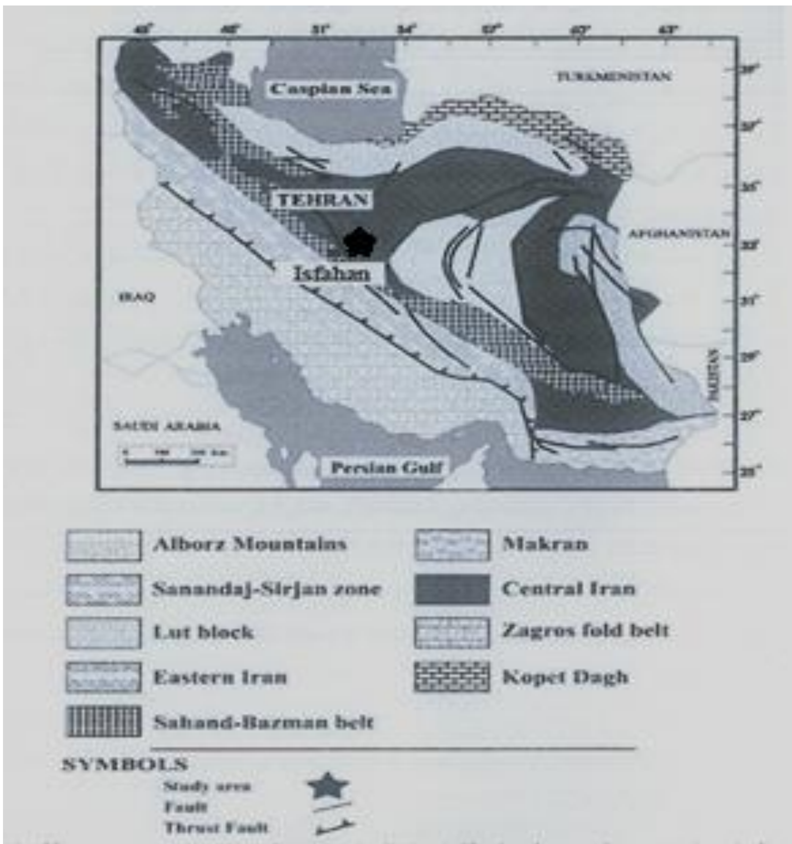

Fig. 2. Geological and constructional units (adopted from Eftekharnejad 1980) and the studied zone situation that is specified by star

Methodology

During field visits, 40 stone samples were extracted from various parts of dome-shaped sub-volcanic outcrops of rhyodacite and dacite. After investigation of manual samples, 34 thin sections were selected and after preparation with polarization microscope they were studied. 11 samples of healthy rhyolite and 2 xenoliths were chemically analyzed using ICP-MS and XRF in the Canada SGS laboratory (Table 1 and 2).

Table 1. Chemical analysis data related to main oxides through ICP-MS

Element	Rj A1	Rj 1	Rj 2	Rj 8	Rj 11	Rj 14	Rj 15	Rj 16	Rj 21	Rj 24	Rj 28	Rj C1	Rj C2
SiO2	68.4	67.9	67.9	67.3	67.4	69.8	69.0	68.8	61.7	70.6	58.8	68.2	69.3
P2O5	0.06	0.06	0.05	0.05	0.06	0.05	0.06	0.05	0.05	0.06	0.16	0.07	0.07
Na2O	5.0	4.9	6.6	3.0	2.3	3.1	3.5	2.9	3.8	4.0	4.4	4.4	4.5
MnO	0.04	0.09	0.08	0.08	0.06	0.05	0.05	0.06	0.33	0.05	0.11	0.04	0.04
MgO	0.40	0.26	0.24	0.68	0.54	0.15	0.34	0.61	5.24	0.16	1.86	0.52	0.52
K2O	4.36	3.82	4.12	4.24	4.70	6.73	5.26	6.31	4.53	6.59	3.20	3.77	3.81
Fe2O3	2.75	2.82	2.81	2.67	2.73	2.64	2.53	2.63	4.94	2.55	3.63	2.76	2.84
Cr2O3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CaO	1.26	1.26	1.24	1.55	1.20	0.36	1.61	0.42	0.41	0.39	1.35	0.54	0.56
Al2O3	13.0	13.7	13.5	13.4	13.2	12.8	12.5	13.0	12.6	12.8	16.8	13.2	13.4
TiO2	0.35	0.36	0.37	0.34	0.35	0.34	0.32	0.35	0.38	0.34	0.52	0.35	0.35
LOI	1.69	2.24	1.88	2.43	1.92	0.87	2.46	1.39	4.47	0.90	2.59	1.18	1.17
Total	97.32	97.42	99.99	97.96	98.93	98.99	90.98	94.99	93.92	97.99	98.97	97.93	97.91

Moreover, specialized software such as Minpet and Igpet were used for analysis, calculation of norm and drawing of figures.

Table 2. Chemical analysis data of minor elements through ICP-MS

Element	Rj C2	Rj C1	Rj 28	Rj 24	Rj 21	Rj 16	Rj 15	Rj 14	Rj 11	Rj 8	Rj 2	Rj 1	Rj A1
Ba	730	710	680	920	660	850	840	890	800	940	750	670	720
Sr	120	110	210	100	100	100	130	90	130	110	100	100	130
Zn	38	38	125	32	365	24	20	30	34	56	34	36	34
Sum	97	9/55	95/7	9/37	97	97/6	9/67	96/7	95/9	96/7	9/76	9/96	96/8
Ag	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ce	49/1	4/49	64/2	4/90	53/7	38/8	4/27	46/9	45/4	46/2	4/86	4/75	45/3
Co	3/5	3/5	5/3	3/4	33/7	4	3	2/9	3/8	5/2	3/8	3/9	3/8
Cs	1/6	1/5	2/3	3/9	3/9	2/5	2/4	3/8	4/1	4/9	4	4/5	1/3
Cu	15	16	47	10	10	131	25	9	25	31	33	38	8
Dy	3/96	/024	5/59	/514	4/51	3/57	/783	4/27	3/73	3/94	/993	4	3/61
Eu	0/73	/730	1/34	/670	0/67	0/45	/670	0/62	0/71	0/74	/740	/780	0/65
Er	2/47	/572	3/6	/962	2/96	2/34	/452	2/86	2/45	2/41	2/6	/582	2/56
Ga	15	15	22	14	14	16	12	14	14	17	16	16	15
Gd	3/92	/793	5/43	/094	4/09	3/22	/583	3/78	3/7	3/52	/853	/682	3/42
Hf	6	6	6	6	6	6	6	6	5	6	6	6	6
Ho	0/75	0/8	1/17	/930	0/93	0/71	/790	0/86	0/81	0/76	/810	/770	0/78
La	25/4	26	33/4	1/39	19/3	15/8	2/93	24/2	52/3	26/8	2/54	2/64	24/4
Lu	0/36	/390	0/55	/420	0/42	0/37	/380	0/41	0/39	0/39	/390	/380	0/41
Mo	<2	<2	<2	<2	<2	<2	<2	<2	<2	2	<2	<2	<2
Nb	11	11	12	13	13	12	11	12	11	11	11	11	12
Nd	19/6	1/89	29/3	1/88	18/8	16/8	1/29	20/7	19/5	18/3	1/19	1/69	18/7

Ni	5 <	<5	<5	<5	<5	<5	12	<5	<5	<5	<5	<5	<5
Pr	5/43	/42 5	7/62	/81 4	4/81	4/39	/09 5	5/48	5/39	5/25	/17 5	/27 5	5/12
Rb	109	111	90/5	184	184	166	144	184	135	136	133	120	124
Sm	3/7	3/7	5/8	¼	¼	3/2	3/5	¼	7/3	3/7	3/9	3/8	3/6
Sn	1	1	2	2	2	2	2	<1	1	<1	<1	2	<1
Ta	0/7	0/7	0/8	0/9	0/9	0/8	0/7	0/9	0/7	0/8	0/7	0/7	0/8
Tb	0/6	/65 0	0/91	/68 0	0/68	0/54	/59 0	0/69	0/54	0/6	0/6	/62 0	0/57
Th	11/6	1/7 1	11/8	1/7 2	12/7	12/6	1/3 2	13/5	11/3	11/7	12	1/3 1	12/5
Tl	0/5<	</5 0	<0/5	</5 0	<0/5	<0/5	</5 0	<0/5	<0/5	<0/5	</5 0	</5 0	<0/5
Tm	0/35	/32 0	0/49	/41 0	0/41	0/33	/35 0	0/4	0/37	0/37	/34 0	/38 0	0/37
U	2/59	/65 2	3/07	/09 3	3/09	3/13	/98 2	3/05	2/68	2/88	/76 2	/53 2	2/78
V	29	29	53	36	36	40	33	35	34	37	33	36	26
W	1	1	2	2	2	2	1	2	1	2	2	2	1
Y	22/3	2/7 2	31/5	2/1 7	27/1	22	2/4 2	25/5	22	22/1	2/9 2	2/9 2	22
Yb	2/5	2/4	3/7	3	3	2/5	2/7	2/7	2/7	2/5	2/6	2/6	2/7
Zr	216	213	225	240	240	214	211	216	201	212	226	23	232

Petrography

Petrologically, this stone is in the group of rhyodacite stones and constituted from main minerals including quartz, Plagioclase and feldspar alkali. Quartz crystals are abundantly seen in form of Phoenocrystal and microcrystal in stones. Phoenocrystal are usually Subhedral to Euhedral with corrosion gulf (figure3-a). The interesting phenomenon seen in these sections, are absorbed quartz that are also known as armored quartz. In such state, quartz is in the middle and feldspar alkali and quartz are in surrounding (figure3-b).

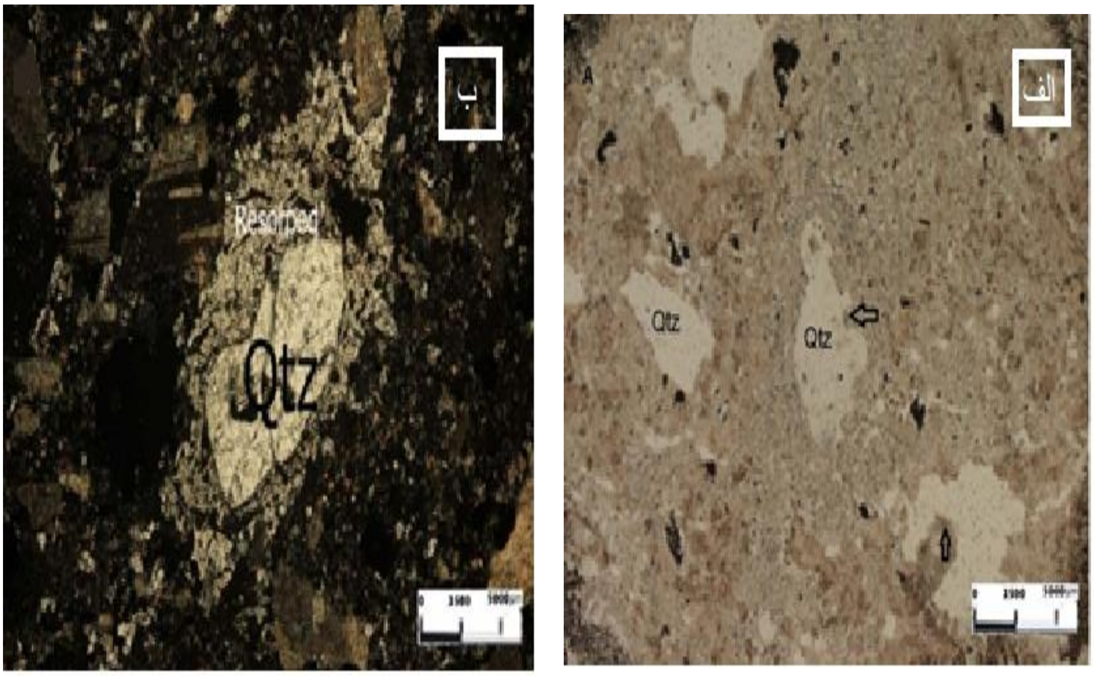

Fig. 3. Microscopic images of studied area: a. Quartz phenocrystal with Porphyritic texture suffering from corrosion gulf (PPL light), b) Quartz phenocrysts with reabsorption margin in the rhyolites of zone (XPL light)

In this group of stones, Microcytic Porphyritic to hyaluporphyritic could be observed (figure 4-a); moreover, Calcite of sponge texture is also seen (figure4-b). Tectonic forces lead to crushing and expansion of fractures and tracks in plagioclase phenocrysts and tracks parallel to traction-separation tissue are clearly obvious in plagioclase phenocrysts (figure4- c). Quartz has welded plagioclase crushes and other feldspars as cement and made shear texture (figure4-d).

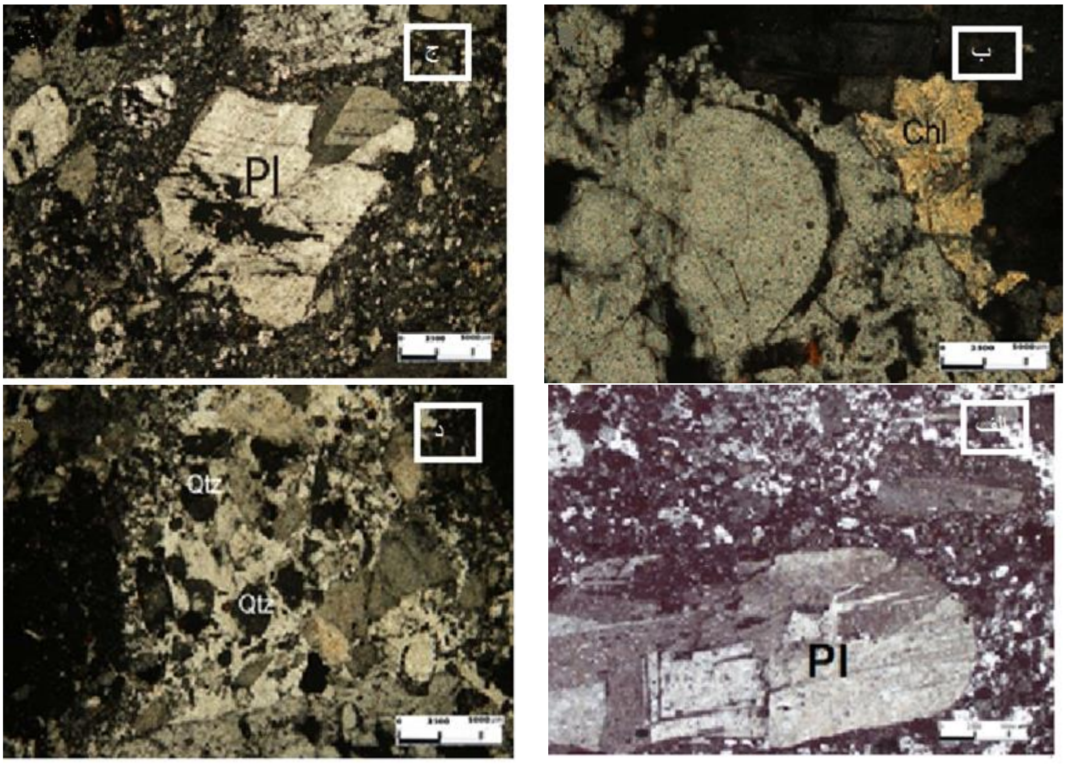

Fig. 4. Microscopic images of the textures of zone: a) Microcytic Porphyritic to hyaluporphyritic (XPL light), b) sponge texture (XPL light), c) traction-separation texture (XPL light), d) shear texture (XPL light).

In terms of alteration studies, it can be said that some of the plagioclase phenocrysts are characterized by complete fading that is probably due to alteration (Fig. 5a). In some parts, feldspar alkali which is due to alteration has developed in the form of cement material and welded phenocrysts. In addition, the formation of calcite in the field indicate carbonation phenomenon (which is a kind of alteration) (Fig. 5b)

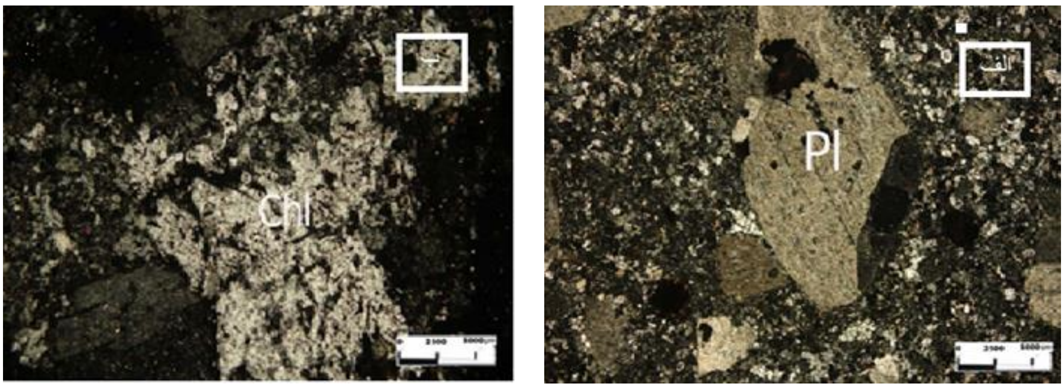

Fig. 5. Microscopic images of secondary textures; a) plagioclase phenocrysts with complete fading are clear (XPL light); b. Calcite formation in the background shows carbonation phenomenon (XPL light).

Geochemistry

One of the geochemical features of these rocks is enrichment from LILE elements similar to Rb (109-184 ppm) and Zr (201-232 ppm) and enrichment from mobile elements such as Cs and Ba.
Based on classification figures of igneous rocks, the samples are placed in rhyolite zone in terms of chemical composition of stones (figure 6-a). In the proposed figure, Le Maitre et al (1989) show the samples of behavioral zone of semi-alkali or sub-alkali (figure 6-b). The samples placement in AFM figure (Irvine and Baragar, 1971) indicates their calc-alkaline feature (figure 6-c). According to the studies carried out on the stones of studied area and drawing of potassium rate determination figure, these samples are located in the range of stones of high potassium which in the figure, the zone of these stones is determined in K_2O versus SiO_2 (figure 6-d). The location of felsic specimens in A/CNK vs. A/NK and ACF figures (figure 7) shows their Metaloumin nature and their similarity with I-type granite. To investigate the patterns of minor elements and REE, normalized figures in respect to initial crust and chondrite are used. Normalized figure in respect to chondrite (figure 8-a) indicates a uniform smooth trend and undifferentiated pattern in distribution of JREE elements. While LREE has enrichment and differentiation $(La/Yb)_N$=4.21-7.2), $Gd/Yb)_N$=1.01-1.26 and Eu shows negative anomaly (Eu/Eu^*= 0.48- 0.61). The separation of Feldspar from

felsic melt leads to negative anomaly of Eu (Sun and McDonough, 1989). The presence of enrichment and abundance of LREE elements could be due to melting of a small part of these stones or relatively enriched origin of alkali elements associated with Subduction areas. LREE enrichment to HREE might be associated with the minor minerals of Zircon and apatite (Pearce et al., 1984).

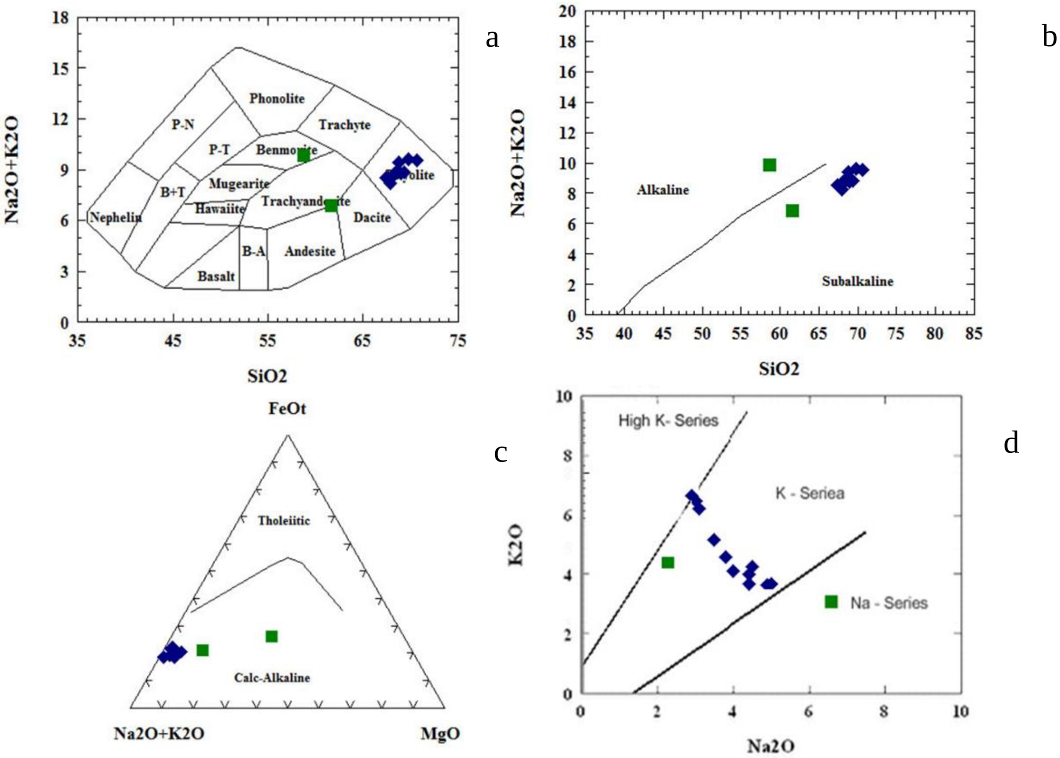

Fig. 6. a) Cox et al classification (1979) for igneous rocks, b) alkali vs. Silica alkali ((Le Maitre et al.,1989) for distinction of alkali and sub-alkali series zone, c) triangular figure of AFM where calc-alkaline series are separated from tholeiitic (Irvine and Baragar, 1971), d) weight percentage of K_2O against weight percentage of Na_2O of magma series of high potassium, containing potassium and containing sodium (Middlemost, 1985).

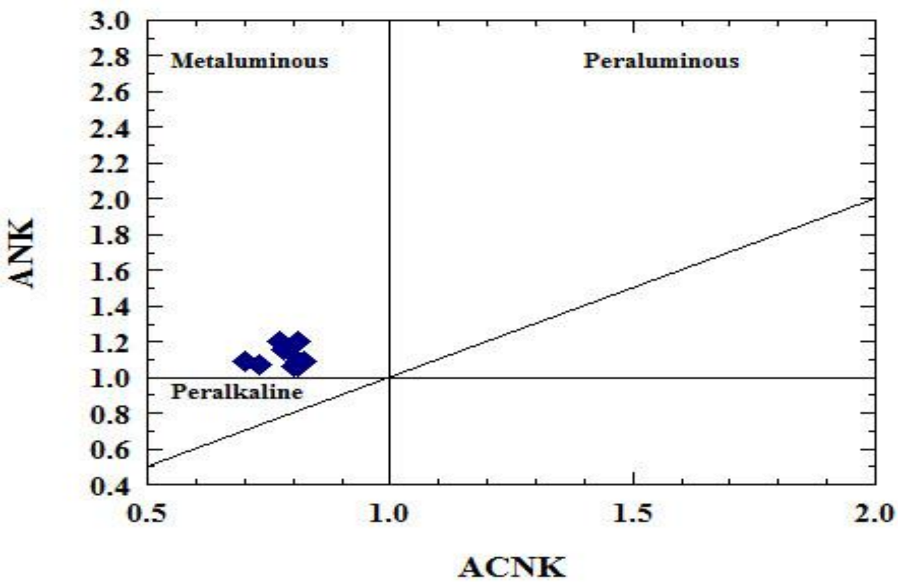

Fig. 7. A/CNK vs. A/NK diagram (Maniar and Piccli , 1989)

In distribution figure of minor normalized elements compared to chondrite (figure 8-b), elements U, Th, Ba and LILE show high enrichment (for example for Rb, there is 1000 times enrichment); instead, a fall is seen compared to Ta and Nb and Sr which indicates the crust origin or extreme pollution with crust. This distribution pattern is special for arc calc-alkaline felsic magma.

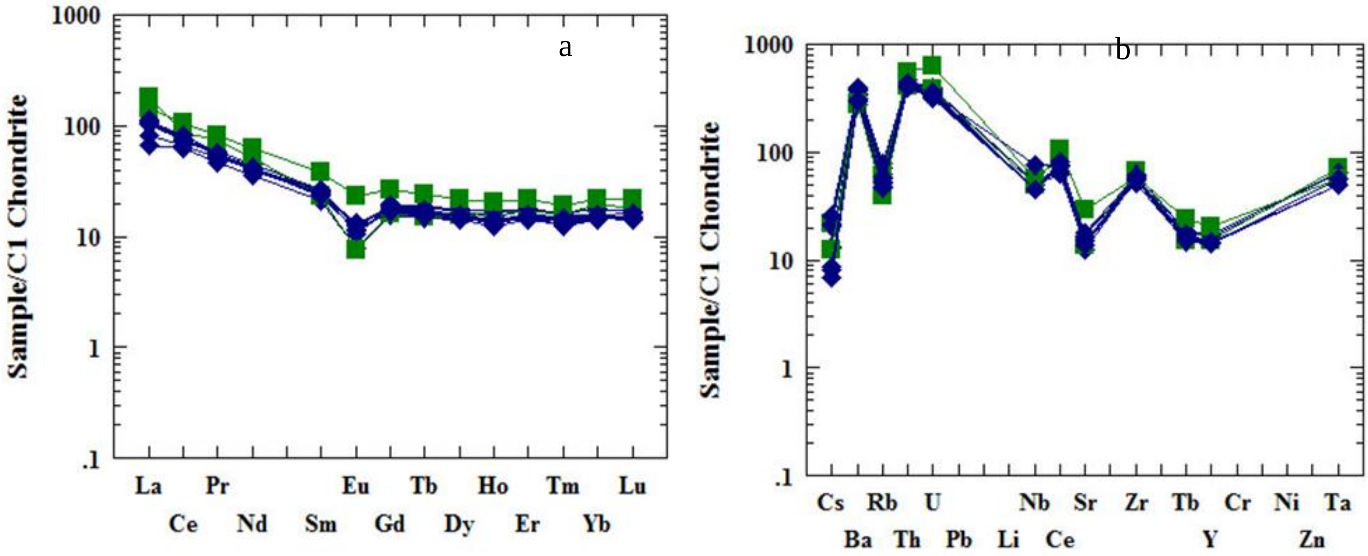

Fig. 8. Spider figures; a) The samples of rhyolite rare earth elements normalized in terms of chondrite; b) samples of minor and rhyolite rare elements normalized in terms of Chondrite.

Tectonic- magma position

Harris et al (1986) classified Granitoid Magma in terms of tectonic area using minor elements. In these figures, the studied samples are located in volcano arc magma (VA) and due to plate subduction (figure9).

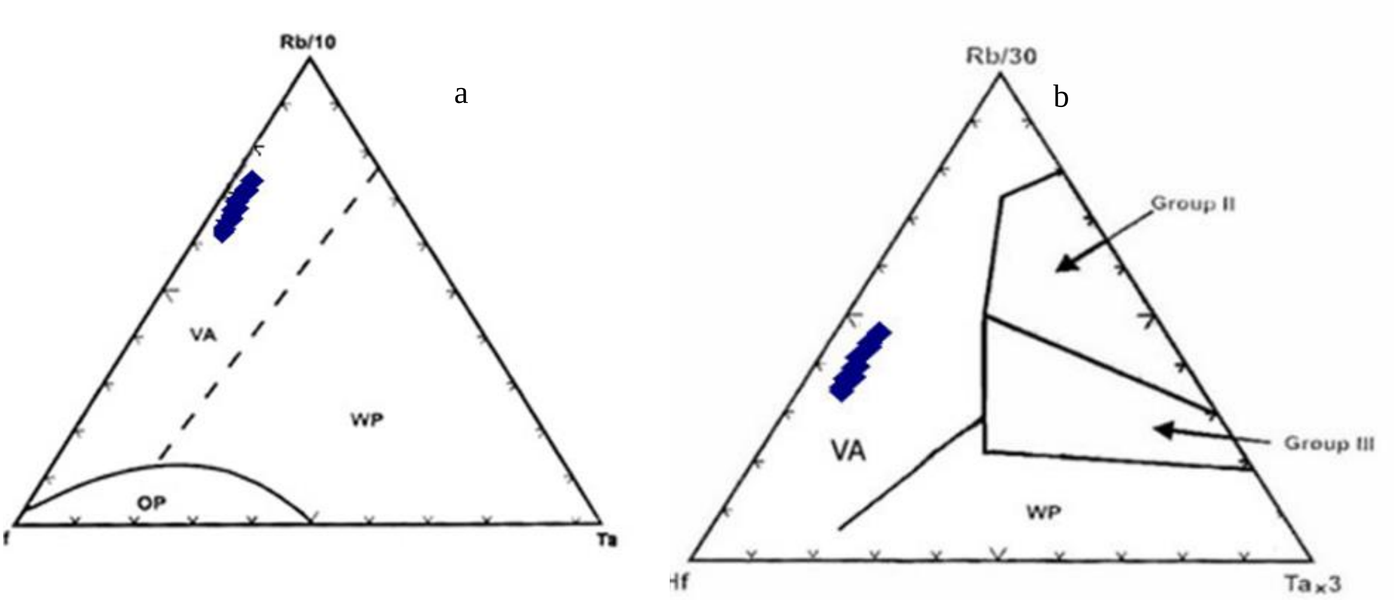

Fig. 9. The distinguishing figure of granite magma tectonic environment (Harris et al, 1986); a) based on Hf-Rb/10-Ta*3, b) based on Hf/Rb/30-Ta*3

Discussion and conclusion

Felsic sub-volcanic rocks in the studied area are classified in rhyolite rocks group in terms of mineralogy and chemical composition. The texture features in phenocrysts such as gulf texture in quartz, margined quartz, zoning in plagioclases and some corrosion in them and the presence of basic micropiles, all indicate chemical imbalance, magma quick swelling and sudden drop of pressure. These observations make clear the role of crust contamination or magma mix (Raymond, 2002). These sub-volcanic stones are geochemically sub-alkali with calc-alkaline nature, Metaloumin indicates negative EU anomaly, enriched of potassium. The studied rocks show high enrichment in terms of LREE and LILE elements.

Wilson (1989) believes that rhyolites of subduction zones are sub-alkaline. High potassium (K>4 weight percentage), iron enrichment (FeO/Mg>4.5) and silica are the signs of igneous rocks in thrust environment.

The specifications of subduction zone include enrichment of Ba, Rb, K and LREE compared to HREE and HFSE and decreasing Nb anomaly (Sajona et al, 1996). Nb values below 70 ppm are related to subduction zone (Green, 2006).

High potassium in these rocks might be due to increased contamination degree of crusts in continental active magma (Wilson, 1989; Brown et al, 1984). In the continental active margin zones, there is some relation between increased potassium and increased depth of Beniow plane (Miskovic and Francis, 2006). The researchers consider the reason as increased thickness of continental crust and its increased effect on changing initial magma composition (Scandl and Gorton, 2002). Tectonic-magma figures separating various tectonic environments confirm the formation in an active volcanic arc environment (Thompson, 1982; Martin, 1993).

Emami et al (1992) believe that Oligocene rhyolite in Ardestan are poured out due to continuation of Eocene rift in extend of Oligocene cracks; however, Moein Vaziri (2004) believes that extreme and expanded volcanism of Eocene and its continuation in a subduction regime led to mild magmatism in Oligocene and onward. He considers the origin of this magmatism as compression discharge of deep Eocene magma reservoirs. The studied sub-volcanic groups might also have been created in this way.

All evidences provide the possibility of proposing a probable origin of sub-volcanic outcrops with low melting temperature of metasomatism crust (enriched of silica and alkaline) affected by the solutions accompanying ocean crust beneath thrust in continuation of magma processes along with tectonic active regime. Swelling of rhyolite magma in extension of existing cracks in a tensile environment is similar to volcanic art backward from late Eocene to Oligocene. Although this proposed tectonic magma model requires geochemical and field evidences and isotopic data; this doesn't well reject the results of Emami et al (1992) studies in this area, indeed it is used to confirm the subduction regime model (Moein Vaziri, 2004) under the influence of a volcanic art at least in Ardestan area in Oligocene time later on.

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