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Petrogenesis and Tectono-Magmatic Setting of Meso-Cenozoic Magmatism in Azerbaijan Province, Northwestern Iran

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1. Introduction

There are widespread Cenozoic magmatic rocks in the prei-Arabian part of northern Zagros suture zone, which form the continental crust of this part of Alpine – Himalayan orogenic belt (Fig. 1). Although the age of these rocks ranges from Cretaceous to Quaternary, but the main magmatic phases belong to Cretaceous, upper Eocene- Oligocene, upper Miocene-Pliocene and plio-Quaternary. The magmatism occurred in Meso-Cenozoic periods due to convergence of the Arabian and Eurasian plates. The time and space distribution of Meso-Cenozoic magmatism in Azerbaijan between Arabian and Eurasian plates and their tectonic setting, are the major question in geodynamics of the eastern Mediterranean and Eastern Alpine-Himalayan belt.

In this paper, new geochemical data of Cenozoic magmatic rocks of Arasbaran region (analyzed by XRF method in Miami University) are used for interpreting petrogenesis of these rocks and determining their origin, nature of magma and its evolution. The time and space distribution of Late Mesozoic- Cenozoic magmatic rocks of the study area are also compared with the adjacent region in Azerbaijan, Armenia and Eastern Turkey. The authors try to find the relationship between magmatism and mineralization in time and space and to locate the probable occurrence of different types of mineralization associated with various magmatic events in the study area.

2. Regional geology

The broad Tethyan orogen had been evolved during a series of successive collisions between Eurasia and the rifted fragments of Gondwana land (Shengor and Natal'in, 1996). Rifting of ribbon-like continental fragments (i.e. Central Iran, South Armenia and Tauride blocks) from Gondwana occurred in the late Paleozoic-early Mesozoic, and discrete Tethyan ocean

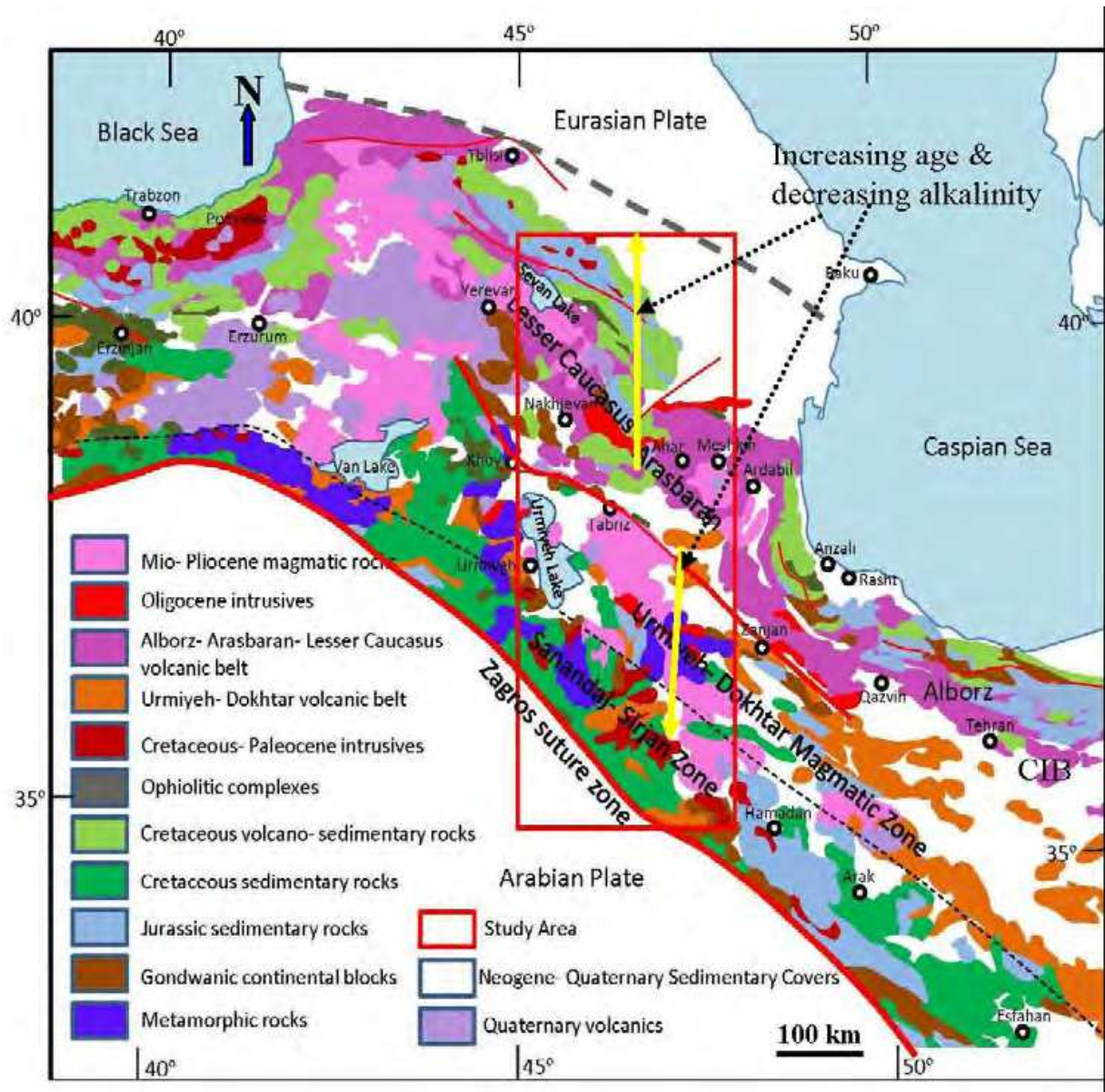


Fig. 1. Geological map of Tethyan belt from Central Iran to Eastern Turkey (modified from Aghanabati, 1993).

basins developed in the wake of these northward-migrating continental blocks (Dilek et al., 2010). The results of the collided segments of Gondwana land and Arabian plate with Eurasian plate were the construction of Zagros thrust mountain range trending NW- SE in the western part of Iran, and Alborz-Azerbaijan mountain range in the northern to northwestern parts of the country. Four major tectono-magmatic zones; Sanandaj-Sirjan zone (SSZ), Urmieh- Dokhtar magmatic belt (UDMB), Central Iran Block (CIB) and Alborz-Arasbaran- Lesser Caucasus Belt (AALCB) in northwest of Iran are the result of geodynamic evolution of Tethys belt formed between Arabian and Eurasian plates during Early Mesozoic to Late Cenozoic (Fig. 1).

These Tectono-magmatic zones could be divided into smaller magmatic-metallogenic subzones such as Songhor-Baneh subzone, Sanandaj Cretaceous volcanic subzone and Tabriz-Hamadan subzone situated in the tectono-magmatic zone between Tabriz fault and

Zagros thrust fault (Azizi, 2009). Blourian (1994) divided the magmatism of northern Iran into two subzones: Alborz subzone and West Alborz- Azerbaijan subzone. Jamali et al. (2010) recognized three magmatic-metallogenic subzones in the Ahar-Arasbaran-Lesser Caucasus area.

2.1 Sanandaj-Sirjan Zone (SSZ)

Sanandaj-Sirjan metamorphic-magmatic zone trending NW-SE is extending from south of Iran to southeast of Turkey parallel to the main Zagros thrust fault. Many geologists believe that the subduction of Arabian plate under the SSZ had been occurred in the place of main Zagros thrust fault where the ophiolites are situated along the thrust (Takin, 1972; Dewey et al., 1973; Berberian and Kings, 1981; Shengor, 1990; Hesami et al., 2001; Talebian and Jackson, 2004). On the other hand, Alavi (2007) believes that the suture zone between the Arabian plate and Iran lies between the SSZ and UDMB.

The northern part of the SSZ includes upper Paleozoic and Mesozoic metamorphic rocks with Meso-Cenozoic intrusive bodies. The age of these intrusions (Fig. 2) ranges from 170 to 40 Ma (Ghahamghash, 2009; Mehrabi et al., 2009; Ghaderi et al., 2009). These bodies are composed of granite, granodiorite, syenite and diorite that belong to medium potassium calc-alkaline series, and from genetic point of view, they belong to I, A and S type granitoids, and are formed during syn- to post-collision environments in subduction zones (Ghahamghash, 2009; Mazhari et al., 2009). In addition to intrusive events, two volcanic subzones were also recognized in SSZ (Azizi, 2009). Songhor-Baneh subzone (5 to 10 km wide and extending about 200 km) is composed of volcanic-sub-volcanic facies including basalt, gabbro and diorite with tholeiitic to calc-alkaline characteristics. In some places, the rocks are metamorphosed to greenschist and amphibolite facies. The age of these volcanic rocks using K-Ar dating method (Moinvaziri et al., 2008) is Late Eocene-Miocene (42-27 Ma). Azizi et al. (2009) believed that the Baneh-Songhor subzone that formed between the ophiolite suture zone (Campanian-Maastrichtian) and the SSZ belongs to an oceanic arc and it is the result of subducted Neo-Tethys oceanic crust under another fragment of the oceanic crust.

Another volcanic subzone belongs to the Late Cretaceous including mafic to intermediate rocks of calc-alkaline affinity. This subzone with 15-20 km width and 300 km length extends from Saghez to Piranshahr.

Differentiated REE pattern (Fig. 5), low Ti, high Al and negative Nb anomaly are indicative of continental margin subduction zone (Azizi, 2009). Barika barite- and gold-rich massive sulfide deposit is associated with this volcanism (Tajeddin, oral communication).

According to Ghahamghash (2009), the subduction of Arabian plate under the SSZ had been started in the Early Cretaceous, and the first magmatic activities are related to the subduction zone. He believes that the magmatism that occurred after Campanian (80 Ma) is not related to subduction and it is originated from the crust, formed due to the collision between Arabian margin and the SSZ. Mazhari (2009) believes that the Piranshahr intrusive bodies of 41 Ma belong to post collision event and the age of the collision between Arabian plate and the SSZ occurred in Late Cretaceous, while Omrani et al. (2008) and Azizi (2009) think that the collision was much younger and it occurred in the Late Miocene.

Gold mineralization (55.7-38.5 Ma) in metamorphic rocks (schist and amphibolite) of the SSZ (e.g. Muteh deposit and Saghez region) shows intrusion-related characteristics rather than orogenic mineralization. Magmatic phases, which are simultaneous with mineralization, are reported in the SSZ (Moritz et al., 2006; Tajeddin, oral communication).

There is no mark about the porphyry and epithermal mineralization associated with Mesozoic-Paleogene magmatism in the SSZ.

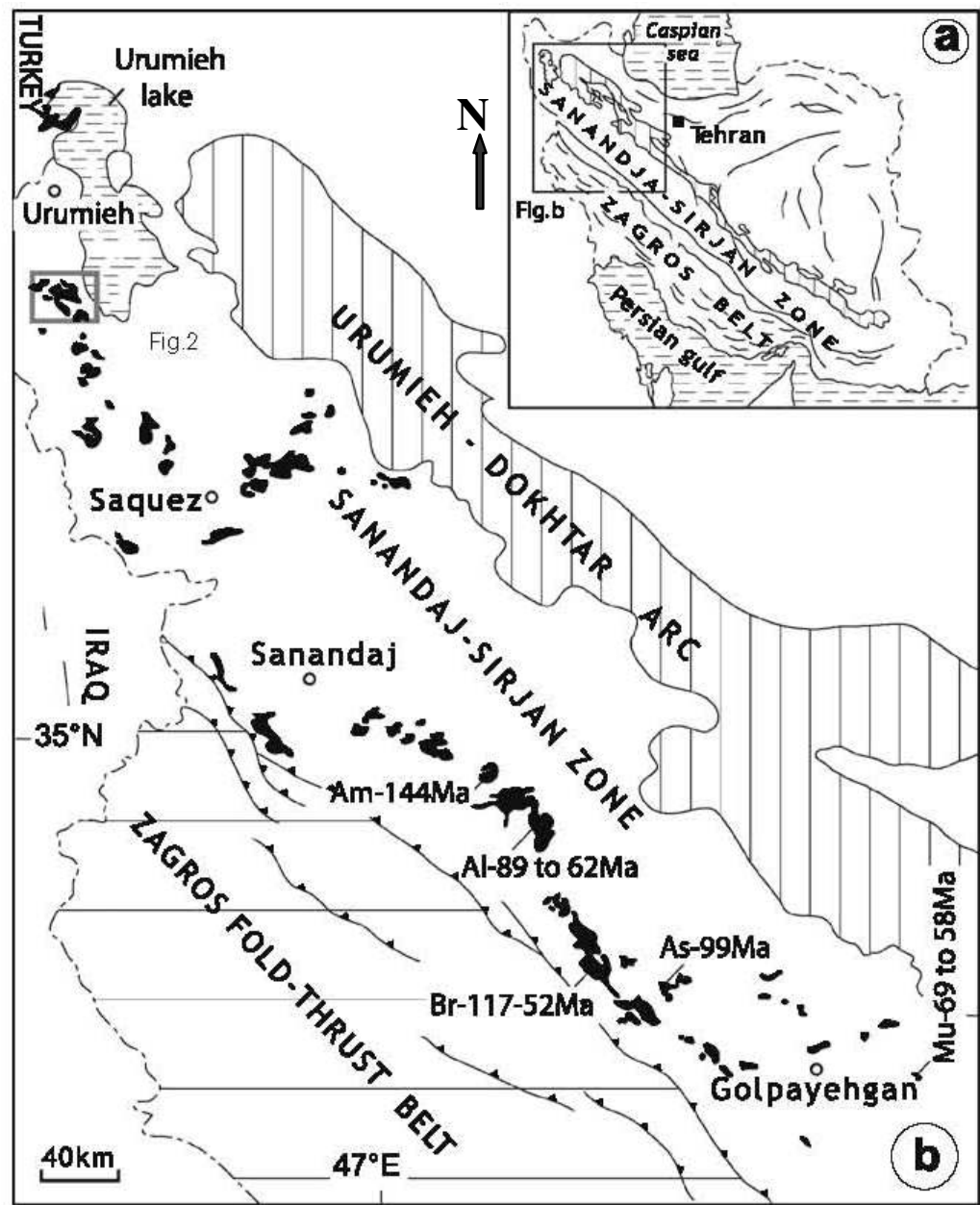


Fig. 2. (a) Tectonic setting of the Zagros orogenic belt in western Iran (b) Distribution of the Urumieh-Gholpaiegan plutonic belt (in black) in the SSZ. The ages of plutonic bodies are given in Ma, (Ghalamghash, 2009).

2.2 Urumieh-Dokhtar magmatic belt(UDMB)

Urumieh-Dokhtar magmatic belt trending NW-SE parallel to the SSZ (50 to 80 km wide) extends from south to northwest of Iran, situated next to Tabriz fault in northeast of this zone. There are some volcanic rocks cropping out in the south of Sarab. Magmatic activities in this belt started in the Eocene and continued until Quaternary (Omrani, 2008; Azizi, 2009). Magmatic activities are divided into two phases: a) volcanic activities in Eocene followed by

intrusive activities in Oligocene, and b) magmatic activities started in the Late Miocene and continued to Quaternary. Data of major and trace elements in UDMB indicate the characteristics features of calc-alkaline magmatism related to continental margin subduction zones. REE pattern of these rocks is also indicative of mantle origin for the Eocene volcanic rocks (Omrani, 2008). On the contrary, the patterns of major and minor elements of the Late Miocene volcanic rocks, with adakite characteristics, are indicative of the break off of subducted slab and post collision process (Omrani, 2008). Omrani (2008) also believes that the Late Miocene collision and breakage of subducted slab in UDMB is simultaneous with the same event in the southeast of Turkey that occurred in 5-10Ma ago (Keskin, 2003).

Eocene volcanic rocks are associated with manto-type copper mineralization (e.g. Sarab and Mianeh regions). Recent studies indicate the probable existence of porphyry type mineralization in the Hashtrud- Mianeh region accompanying Oligocene plutonism that intruded the Eocene volcanic rocks (Jamali, 2011; unpublished data). Miocene magmatism with an adakitic signature and mildly alkaline affinity is accompanied with epithermal and Carlin type gold mineralization in Ghorveh and Takab regions (Mehrabi et al., 1999; Richards, 2006 and 2009).

2.3 Central Iran Block (CIB)

There are scattered exposures of the CIB, overlain by the Cenozoic volcanic rocks in northeast of UDMB and Alborz-Azerbaijan mountain ranges. These rocks, cropping out in the study area, are pre-Triassic sedimentary rocks that are similar to those of the south Armenia and Tauride blocks in Turkey. According to Sosson et al. (2005) and Dilek et al. (2010), Central Iran, Armenia and Tauride blocks were formed the northern margin of the Gondwana land prior to Triassic rifting. These three blocks include Precambrian crystalline basement overlain by Paleozoic-Mesozoic sedimentary sequences (Dilek, 2009; Roland, 2009; Sosson, 2005), separated from Gondwana land in the Late Triassic and joined the southern margin of the Eurasian plate during Late Cretaceous-early Paleocene (Dilek, 2009; Roland, 2009). Paleomagnetic investigations on Middle Triassic igneous rocks in Sumkhit- Gharebagh (Azerbaijan) and south Armenia indicate that the latitude was at about 22° N for the time of their formation (Sosson, 2005). The Paleo-Tethys Ocean started closing as the Neo-Tethys Ocean opened during separation of Central Iran, Armenia and Tauride blocks from the Gondwana land moving northwards. According to Bazhenov et al. (1996), the site of paleo-Tethys ocean enclosure is the present place of Sumkhit-Gharabagh-Black Sea area.

2.4 Alborz-Arasbaran-Lesser Caucasus Belt (AALCB)

The Transcaucasian Massif includes Pan-African orogenic crust intruded by latest Proterozoic to Palaeozoic granitoids, experienced multiple deformation and migmatitization, and the Jurassic to Early Cretaceous plutons representing a magmatic arc (Zakaridze et al., 2007). This arc continued into the Eastern Pontide blocks in the west.

A Cretaceous island arc complex with calc-alkaline to alkaline extrusive rocks, and pyroclastic deposits, flysch units and marl-limestone rocks occurs north of the Sevan-Akera suture zone (Dilek et al., 2010).

Cenozoic magmatic rocks of the AALCB are mainly acidic to basic volcanic rocks and acidic to intermediate intrusive bodies, with calc-alkaline to alkaline affinities trending NW-SE and located in the northwestern Iran and Caucasus mountain ranges (Moayed, 2001; Jamali et

al., 2010). Similar to UDMB, magmatic activities in this belt have been started in the Eocene and continued to Quaternary.

Azizi et al. (2009) and Alavi (2007) believe that the scattered pieces of ophiolites around Tabriz fault are the remnants of UDMB back-arc oceanic crust (basin) and its subduction was the cause of the formation of Alborz-Arasbaran magmatic belt. There are scattered exposures of ophiolites and metamorphic rocks from Anzali to Sevan- Akera at northern margin of the AALCB (Fig. 1) (Galoyan et al., 2009; Berberian et al., 1981; Jamali et al., 2010). Based on isotopic data, the formation of Sevan-Akera ophiolites have started in the Middle-Late Jurassic and continued to Early Cretaceous (Galoyan et al., 2009). According to Sosson (2005), based on interlayering of radiolarites and pillow basalts, the age of ophiolites in the northern Armenia is proposed to be Late Jurassic. The exposure sites of these ophiolites could be the site of the Mesozoic ocean that was closed in Late Cretaceous-Early Paleocene causing the AALCB magmatisms. Jurassic to Cretaceous magmatic rocks with alkaline to calc-alkaline affinities in the north Lesser Caucasus indicates arc magmatism characteristics and continued to the west joining the Pontide magmatic belt in northeastern Turkey (Dilek, 2010; Zakaridze, 2007). Intense volcanic activities with acidic to basic composition were started in the AALCB during Eocene. Eocene volcanic rocks with alkaline to calc-alkaline nature (Figs. 3 and 4) indicate continental margin magmatism. Distribution patterns of the

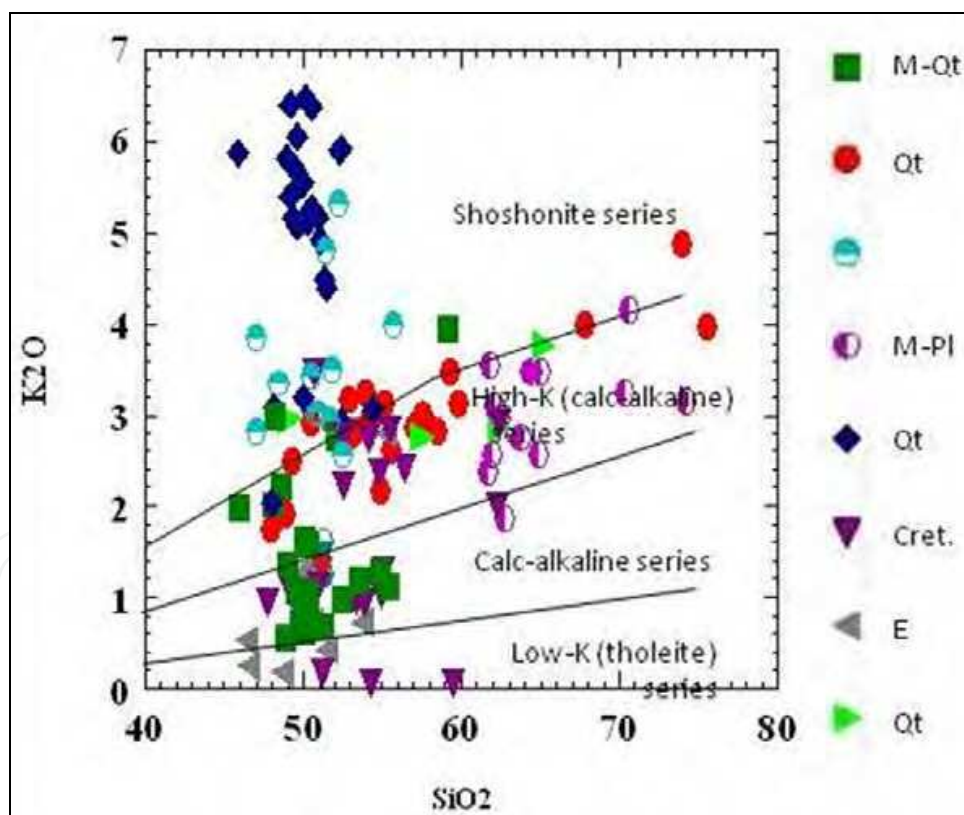


Fig. 3. K_2O (wt%) versus SiO_2 (wt%) diagram for classification of NW Iran volcanic rocks (Peccarillo and Taylor, 1976). The abbreviations are as follow: M-Qt: Mio-Pliocene to Quaternary (Kheirkhah et al., 2009), Qt: Quaternary (Dilek et al., 2010), E: Eocene (Dilek et al., 2010), M-Pl: Mio-Pliocene (Dilek et al., 2010), Qt: Quaternary (Ahmadzadeh et al., 2010), Cret: Cretaceous (Azizi et al., 2009), E: Eocene (Azizi et al., 2009), Qt: Quaternary (Ahmadzadeh et al., 2010).

REEs (weak or absent Eu negative anomaly and more differentiated pattern of REEs) also are indicative of continental subduction zones (Fig. 5). Most of the samples (except some Cretaceous volcanics in SSZ) plotted in $(\text{Nb}/\text{Zr})_n\text{-Zr} - \text{Zn}$ diagram clustered in the collision related and within plate fields (Fig. 6). In $\text{Rb} - \text{Y} + \text{Nb}$ and $\text{Nb} - \text{Y}$ diagram (Pearce, 1996, 1984) they mainly plotted in the field of post collision granitoids (Fig. 7). In the Hf, Nb, Ta and Rb diagrams of Harris (1986), most of the samples plotted at the border of VAG, WPG and Post-Collision fields (Fig. 8).

Following to the Eocene intense volcanic activities, Oligocene magmatic activities occurred in the form of intrusive bodies, in the AALCB. The composition of Oligocene intrusions is mainly acidic to intermediate with lesser amounts of mafic rocks (Fig. 9). They include granite, granodiorite, quartz monzonite, monzonite, syenite, syeno-diorite and gabbro which are intruded by lamprophyric to dacitic dykes. Based on the geochemical studies, the intrusive rocks are of different origins. Monzodiorites, gabbros and syenites show alkaline and shoshonitic nature and probably were originated from partial melting of lithospheric mantle, while the acidic rocks (granites, granodiorites and quartz monzonites) with high-K, calc-alkaline affinities (Fig. 8) show C type adakitic magma characteristics. They also show high amounts of Ba and Sr and originated from partial melting of lower mafic and potassic crust due to increase of the crust's thickness. Finally, the lamprophyrs are alkaline type and formed from the melting of OIB type metasomatized lithospheric mantle (Aghazadeh, 2010).

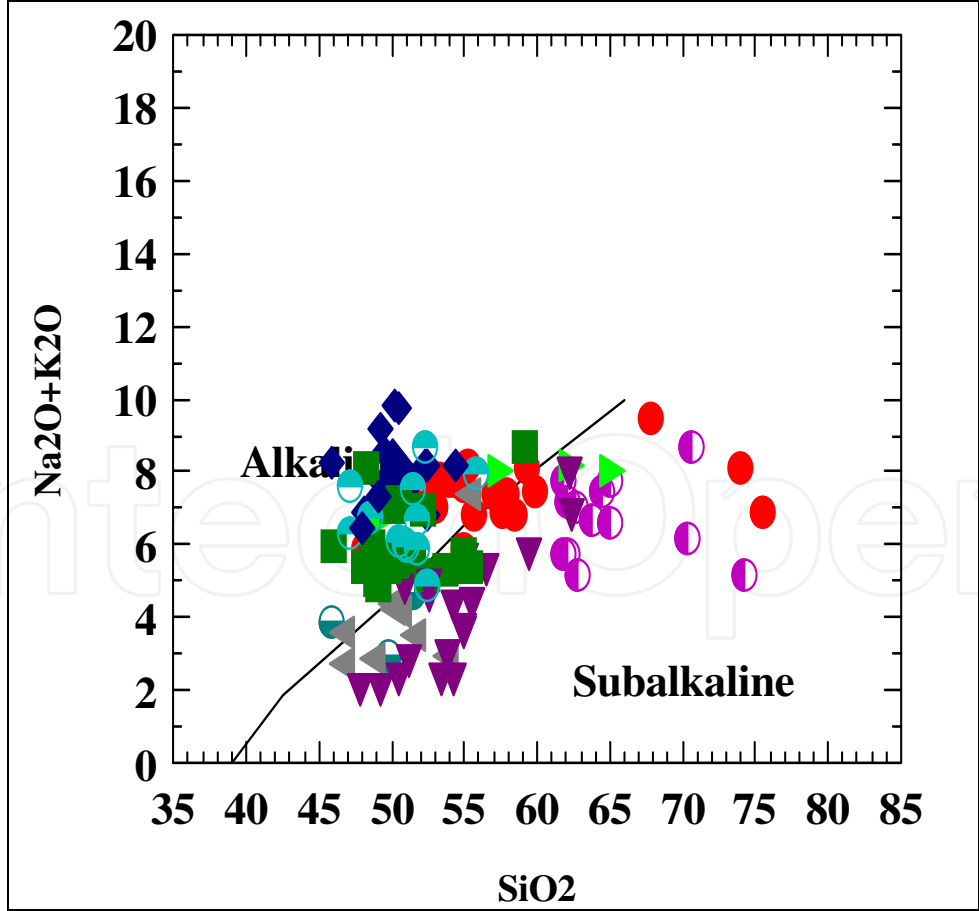


Fig. 4. Total alkali (wt%) versus SiO_2 (wt%) clasification of volcanic rocks (after Le Bas et al., 1986). (symbols as in Fig.3)

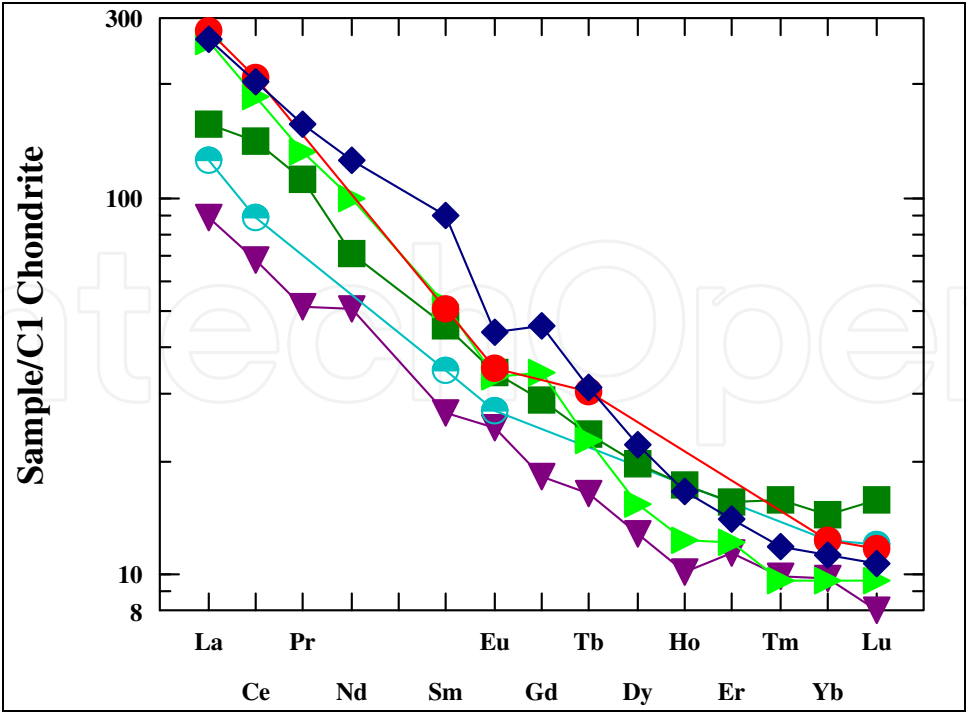


Fig. 5. C1 Chondrite normalized REE patterns for Meso-Cenozoic volcanic rocks in NW Iran. Mean values of REE used for each rock group. (symbols as in Fig. 3).

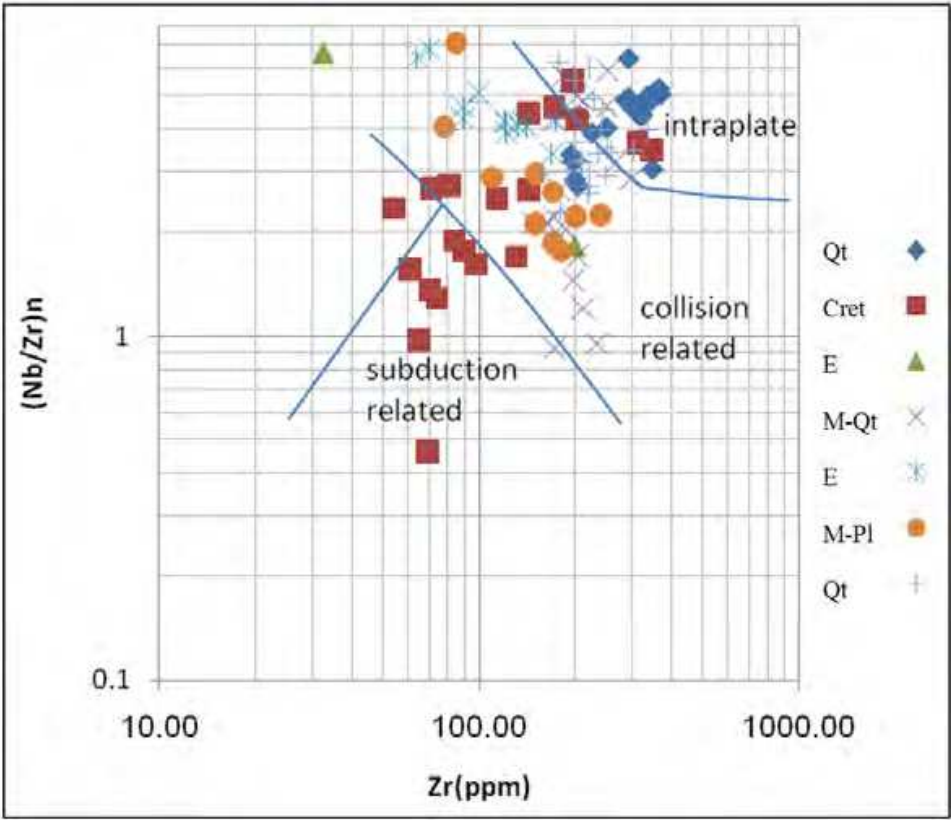


Fig. 6. $(Nb/Zr)_n$ versus Zr (ppm) diagram (Thieblemont and Tegye, 1994) for volcanic rocks. Most of the samples plotted in the collision related field. (Abbreviations as in Fig. 3).

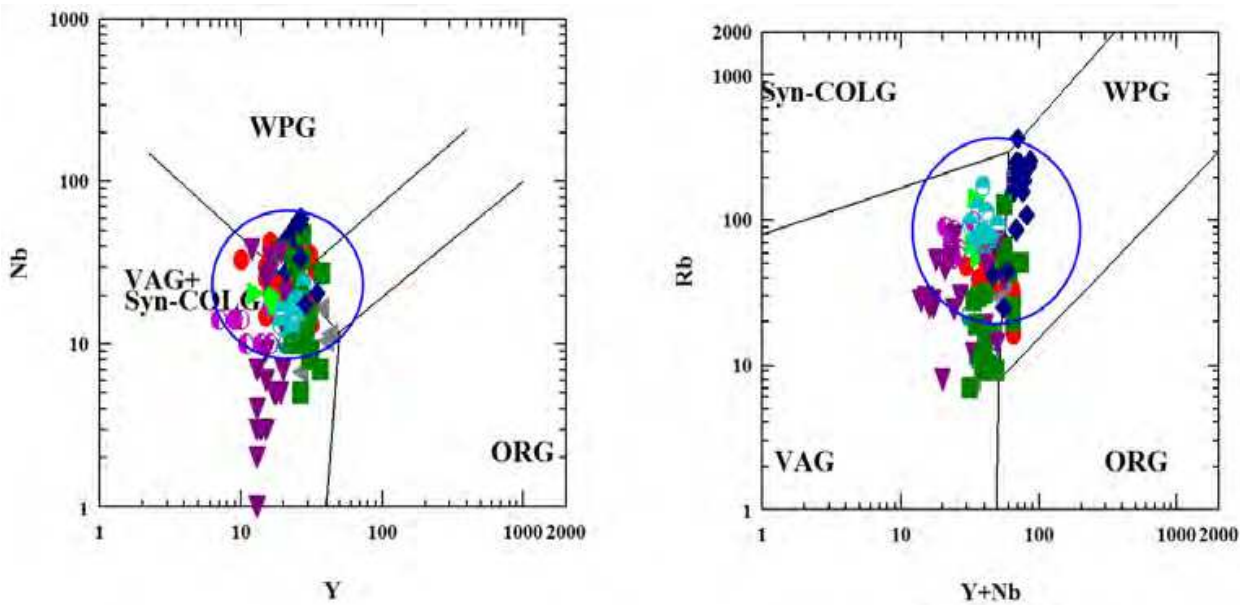


Fig. 7. Tectonic discrimination diagram of Rb versus Yb + Nb and Nb versus Y (after Pearce et al., 1984 and 1996). Most of the samples plotted in the post collision field (blue circles). (symbols as in Fig.3)

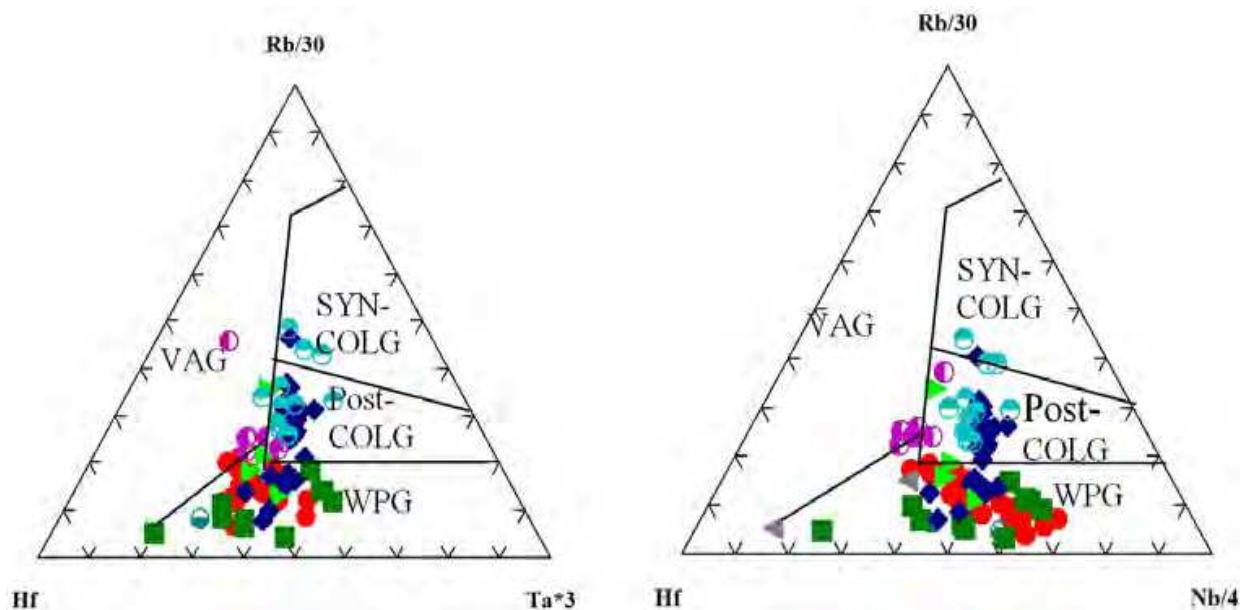


Fig. 8. Triangular diagrams of Harris et al. (1986), for various tectonic environments in collision zones. Most of the samples plotted at the border of VAG, WPG and Post-Collision field, which is characteristics of the post-collision magmatism. (symbols as in Fig. 3)

Field observations indicate that the acidic calc-alkaline rocks are older than intermediate to basic shoshonitic rocks. These observations are confirmed by zircon age dating of intrusive bodies of north and east of Ahar given by Aghazadeh (2010). The results of these dating indicate that the age of adakitic granodiorite is 31.8 Ma., gabbro-monzonite is 28 Ma and syenite and melasyenite is 24-26 Ma. In K₂O-SiO₂ diagram, lamprophyrs and syenites are plotted in shoshonite field and gabbros, monzonites and granites (resulted from their

differentiation) belong to the high potassium series. Granites, granodiorites and quartz monzonites are situated in medium to high potassium calc-alkaline field (Fig. 10). In diagram of trace elements of Pearce (1984, 1996) and Thieblemont and Tegye (1994), most of the samples belong to post collision environments and they have no direct relationships with subduction (Figs. 11 and 12).

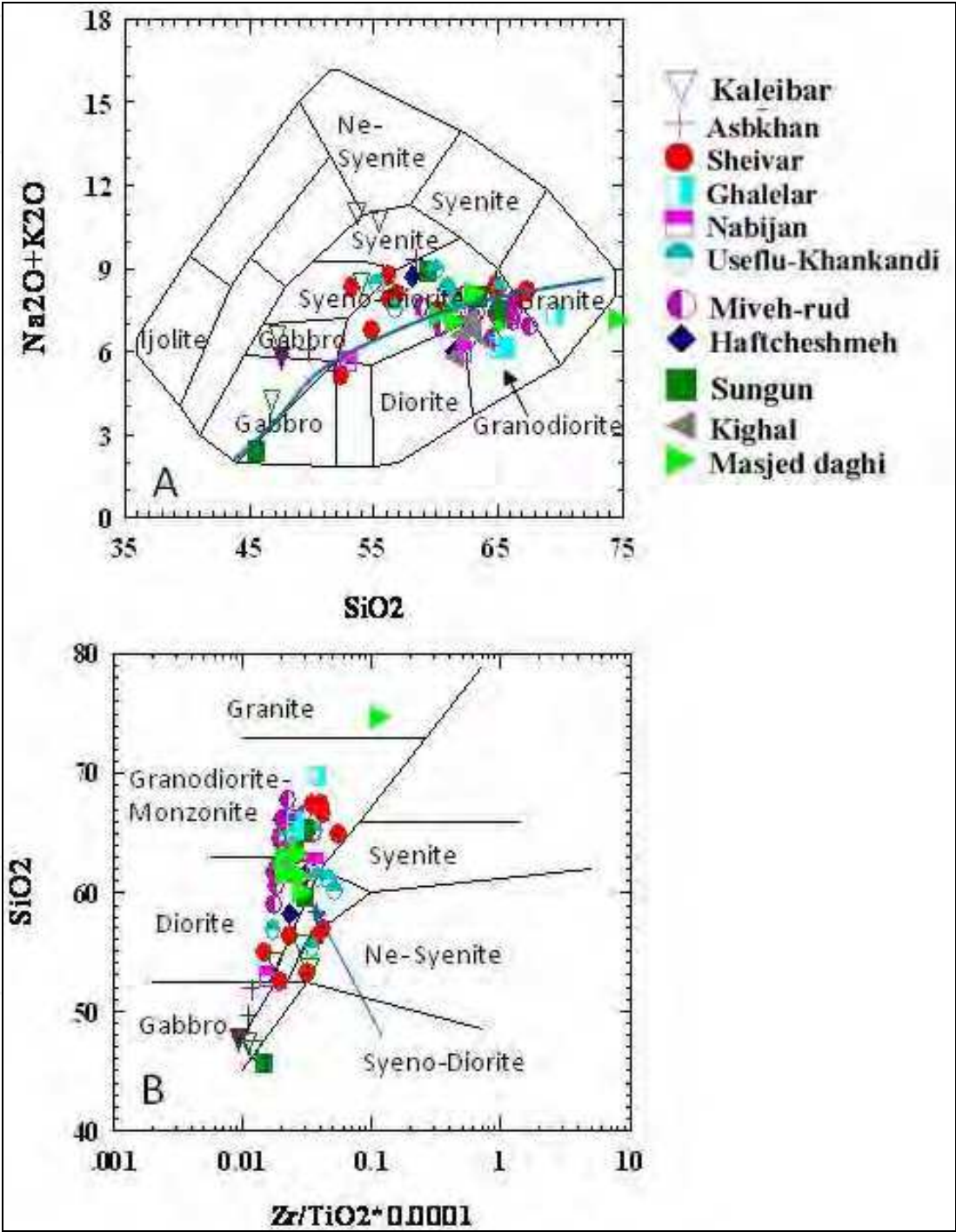


Fig. 9. Geochemical classification of the AALC plutons. (A) Using the total alkali versus SiO_2 (Wilson, 1989); the blue line separates alkaline rocks from sub-alkaline. (B) Zr/TiO_2 versus SiO_2 diagram of Winchester and Floyd (1977).

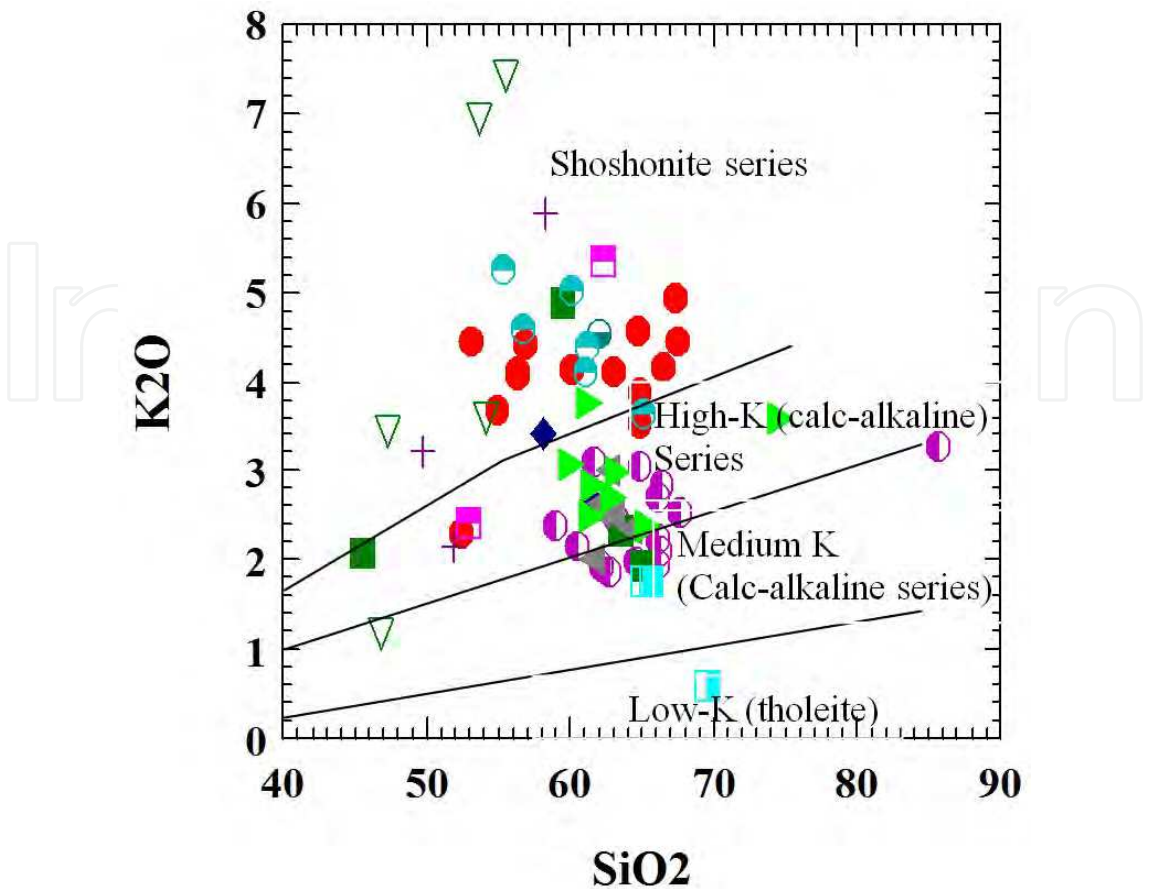


Fig. 10. K₂O (wt%) versus SiO₂ (wt%) diagram for clasification of the Arasbaran Oligicene plutonic rocks (Le Maitre et al.,1989; Rickwood, P.C., (1989). (symboles as in Fig.9).

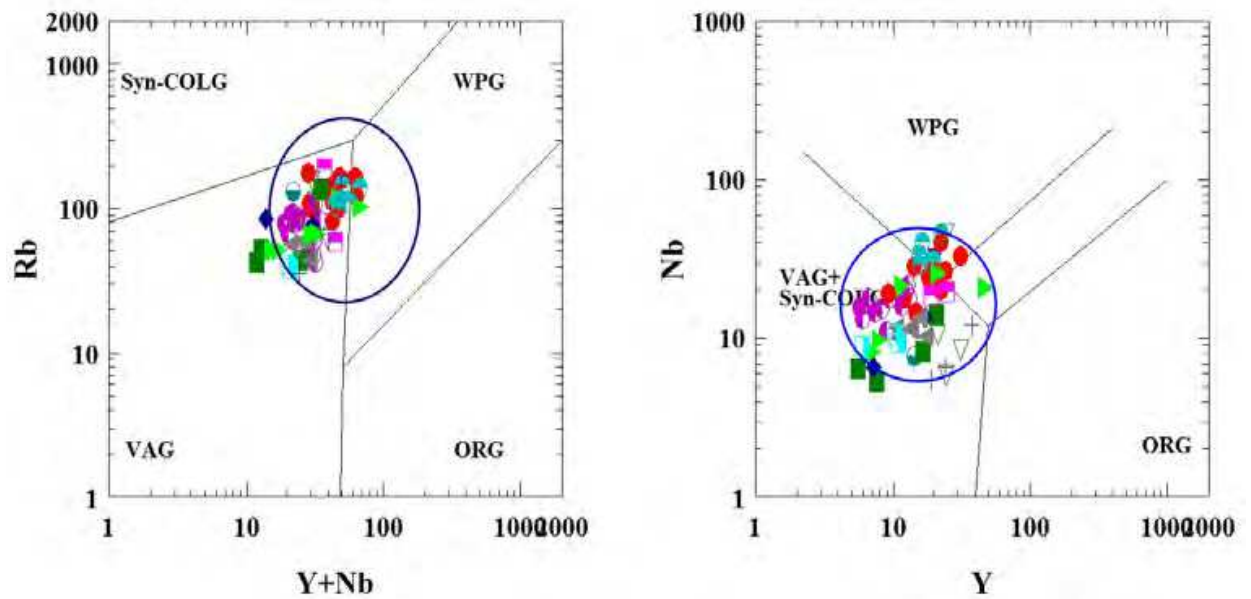


Fig. 11. Tectonic discrimination diagram of Rb versus Yb + Nb and Nb versus Y (after Pearce et al., 1984; Pearce, 1996). Most of the samples plotted in post collision field (blue circle). (symboles as in Fig.9).

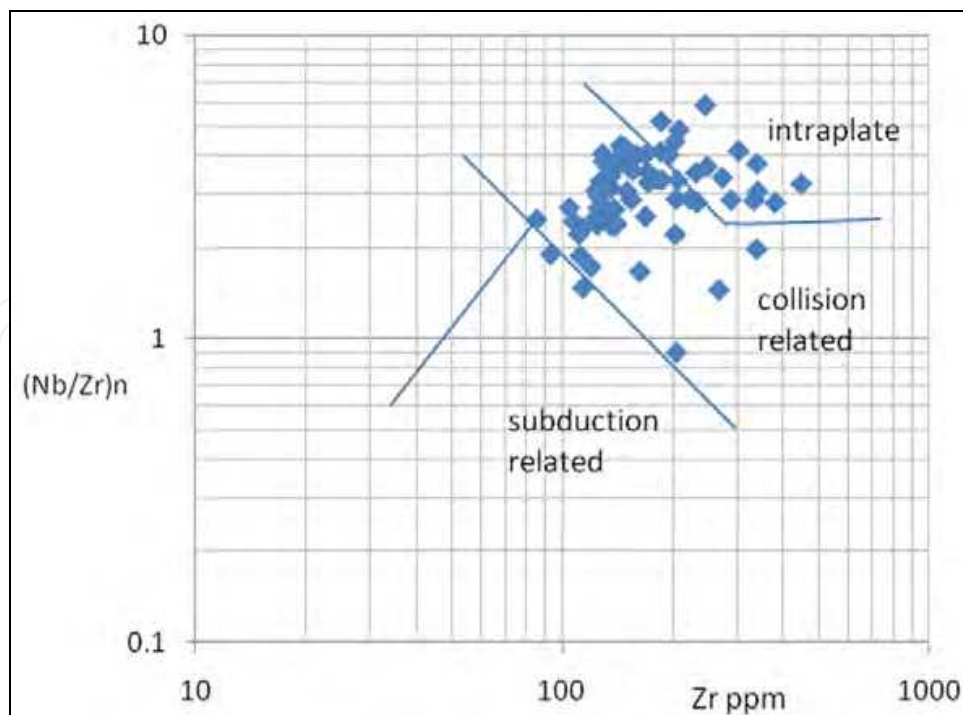


Fig. 12. $(\text{Nb}/\text{Zr})_n$ versus Zr (ppm) diagram (Thieblemont and Tegyey, 1994) for the volcanic rocks. Most of the samples plotted in the collision related field.

Oligocene intrusive bodies could be divided into two groups based on their structure, texture and the depth of emplacement: (1) Large intrusive bodies (batholites) with medium to coarse grained texture that formed at 3 to 4 km depth such as Sheivar Dag, Khankandi, Youseflu and Kaleibar are poorly mineralized, and mineralization associated with them mainly occurs in the contact zone with their host rocks or within the country rocks. These intrusive bodies show high K calc-alkaline to shoshonitic affinity. (2) Sub-volcanic bodies with porphyritic texture and calc-alkaline character formed at 1-2 km depth and are associated with remarkable mineralization such as Sungun, Mivehrud, Masjed Daghi and Haftcheshmeh deposits. Most of the mineralization occurs in quartz monzonite-monzonite. Microscopic investigations of rock samples of quartz monzonite-monzonite indicate that amphibole and biotite phenocrysts are paragenetically earlier than other minerals. This indicates that the amount of water in the original magma was more than 3% in the crystallization stage (Whitney, 1975; Burham, 1979; Whitney and Stromer, 1985). The lack of Eu negative anomaly may be assumed to be the result of high oxygen fugacity in the original magma, because the high oxygen fugacity oxidizes Eu^{2+} to Eu^{3+} and so it can not enter into the plagioclase structure (Hezarkhani, 2006). In addition to bearing water and oxidizing state of the primary magma, replacement in the lower depth caused water saturation and fluid separation in primary stages of crystallization of original magma followed by mineralization.

After Oligocene intrusion phase in the Arasbaran area the next magmatic activities occurred in the Late Miocene and continued to Quaternary. The Late Miocene-Pliocene magmatic rocks are mostly acidic in composition (granite-granodiorite) and they are in the form of sub-volcanic bodies and/or volcanic domes (such as Ghalehlar and Bohlul Daghi), that could be observed in the southwestern Arasbaran area. These magmatic rocks have alkaline

adakitic nature and they are probably related to post collision processes such as slab break off or delamination (Jahangiry, 2007; Karimzade, 2004). Adakitic magmatism in the Plio-Quaternary was followed by basic alkaline volcanism. At first, the alkali basic magma was sodic in composition changing upward to more potassic in composition, and bears leucite phenocrysts. The Plio-Quaternary volcanic rocks include andesite, basalt-andesite, tephrite-basalt, leucite basalt and tephrite. The amounts of K_2O and MgO and the K_2O/Na_2O ratio in these rocks are high enough to classify them as high or even ultra potassic rocks (Fig. 3). They characterized with significant enrichment in LILE and LREE and depletion in high-field-strength elements. So, the metasomatized lithospheric mantle composed of garnet lherzuite and high fugacity of CO_2/H_2O ratio played a significant role in their genesis (Ahmadzadeh, 2010 and Khezerlu, 2008).

2.5 Discussion and conclusions

Two oceanic island arcs magmatism, one in SSZ (Songhor-Baneh) and the other in the north Lesser Caucasus are distinguished. Except of these two oceanic arcs, all of the magmatic rocks in the SSZ, UDMB and AALCB are related to continental margins. As going toward north and south from Tabriz fault, the magmatism becomes older and its alkalinity decreases.

SSZ magmatic rocks that are mostly intrusive type were primarily related to an active subduction margin and later on about 80 million years ago reveals post-collision magmatic characteristics. There is no unanimity for the time of collision between the Arabian plate and SSZ. Some geologists believe that the collision had been occurred in the Late Cretaceous–Early Paleocene (Moaiyed, 2001; Ghalamghash, 2009; Mazhari, 2009), while some others think of the collision had been occurred during Middle–Late Miocene (Omran, 2009; Azizi, 2009). However, the rare earth and trace elements diagrams indicate that the major plutonic and volcanic rocks of the UDMB and SSZ belong to the post-collision environment. So, it may be concluded that the time of collision is more likely Late Cretaceous–Early Paleocene, and the following magmatism is not directly related to subduction. On the other hand they may be related to the post collisional magmatism such as slab break off and delamination.

From Tabriz fault toward north to Lesser Caucasus, a reverse zonation is observed, that means the age of magmatic rocks increases toward north. In the vicinity of Tabriz fault the magmatic rocks are of Miocene–Quaternary age, while in the Arasbaran region and southern part of Lesser Caucasus, the magmatism belongs to Eocene–Oligocene, and from Sevan-Akera suture zone toward north, the magmatic rocks are related to Jurassic–Late Cretaceous events. However, in the study area the older rocks (Late Mesozoic) show magmatic arc characteristics, while the younger rocks (Cenozoic) are indicative of post-collision environments.

In each side of the Tabriz fault, the zoning is reversed relative to the other side and it could not be justified to be related to one subduction zone. It is more likely to belong to two separate subduction zones. It seems that in the Zagros region the subduction relates to southern Neo-Tethys, while in Lesser Caucasus–Arasbaran, this event relates to the northern Neo-Tethys, and these two events justify the magmatism and geotectonic evolution of the region. On the other hand, a northern ocean was existed between the north of Central Iran, south Armenia and Tauride blocks with Eurasian plate, and a southern ocean was between

the above blocks with Arabian plate. The oceans were closed during convergence of the Arabian plate moving northward towards Eurasian plate. The dip direction of subduction in southern ocean is supposed to be northeast, while there are many controversies about the dip direction of the subducting slab of the northern ocean, although magmatic and petrogenetic characteristics of the area and the distribution of the magmatic rocks in time and space are indicative of probable southwest dip direction for subducting slab of the northern ocean.

Gold Mineralization in the SSZ were previously supposed to be related to orogenic events, while recently it is believed that they are intrusion related type mineralization that belongs to the Eocene post collision events. Recent investigations have also indicated the probable existence of porphyry type mineralization in the Hashtrud, a part of northwestern UDMB.

Carlin and epithermal type gold mineralizations are associated with Miocene adakitic magmatism, i.e. in Ghorveh and Takab region. Oligocene magmatism in the Arasbaran zone is associated with remarkable porphyry, skarn and vein type Cu-Mo-Au mineralization. Epithermal gold mineralization is accompanying both Oligocene and Miocene magmatisms.

In general, the northern belt including the AALCB is highly mineralized compare to the southern belt including the UDMB and SSZ that have relatively poor mineralization.

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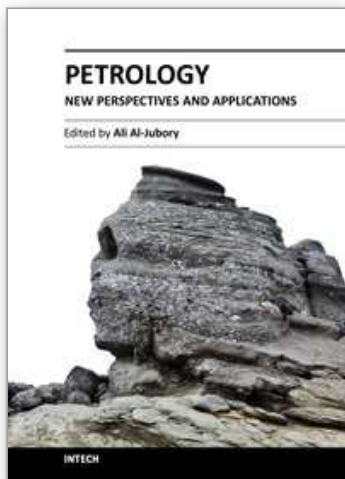
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