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Petrogenesis of volcanic rocks from Razei region in Northwest Ardabil, Iran

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Abstract

The Razei region in the northwest of Ardabil is considered a part of West Alborz-Azerbaijan. Rocks in this area were created by Eocene volcanic activities. These rocks range from andesite to olivine basalt. The common texture of these rocks is Porphyritic with microlithic matrix. The phenocrysts of these rocks are often clinopyroxene, plagioclase, and olivine. The texture is made of microlithic plagioclase and fine crystals of pyroxene. The studied rocks have clear desire to alkali basalts in terms of chemical nomenclature. Disequilibrium factors between liquid and crystal show the processes of magmatic evolution in an open thermodynamic system. The mixed climate in this region has probably contributed the most to changing the chemical composition of these rocks. In the spider diagrams, enrichments often include some LIL elements and depletions usually include some HFS elements. Enrichment of LILE is probably accompanied with the contamination of the basic magma with materials from continental lithosphere. The volcanic rocks in Razei have mainly geochemical characteristics of back arc basin, and the magmas that created the rocks in this region have an origin of lithospheric mantle.

Keywords: *Petrogenesis, Eocene, Volcanic rocks, Razei, Ardabil*

1. Introduction

The Razei region is located in the northwest of Ardabil and the south of Germi. This region is considered a part of the West Alborz Mountains that are almost along the north–south direction in this region. As the studied region has not experienced a systematic study yet, the scientific resources related to this topic are very limited, and these resources can be used partially. 1:250,000 geological map of Ardabil's sheet and 1:100,000 geological maps of Ardebil and Razei's sheet within the Geological survey of Iran's maps are some considered limited resources that a brief mention to the volcanic rocks of Razei region is done on them.

2. Method of the study

The research was conducted in four stages. The first level involved collecting resources related to the plan's subject. The second stage of the operation phase was for studying the volcanic rocks from deserts. At the third stage, microscopic sections were prepared from the taken samples. After the removal of similar rocks, 60 samples were surveyed in exact macroscopic and microscopic method. Then, 20 selected samples were dispatched to SGS laboratory in Toronto, Canada, for chemical analysis to determine the main oxides with ICP-AES method and rare elements with ICP-MS analysis. At the fourth and final stage, using petrographic studies and charts gained using various software such as Petrograph, Igpet, Minpet, and Excel, petrological and geochemical results as well as tectonomagmatic of the studied rocks were derived.

3. Field studies

The studied zone is considered a part of the structural zone in West Alborz-Azerbaijan. The most studied rock units are the Eocene volcanic rocks. Volcanic rocks in the Razei zone are formed after lava flow, and pillow and prismic structures are often seen in them. Geologic map and situation of the studied region is provided in Fig. 1. The oldest studied rock unit is Eocene basaltic olivine lava (E^{b1}) that auto-clastic breccia is according with it locally. On these lavas, there are outcrops of hyaloclastite breccia (E^{h}). At the base, its pieces often are pyroxene andesite and pitted basalt. Sometimes, mild pillow lava forms can be seen in these hyaloclastite (Fig.2a). In this unit, a set of breccia and tuff are formed with andesite composition (E^{p1}). Megaporphyric andesite and trachyandesitic lavas (E^{a1}) are placed gradually with intermediate sections with megaporphyric parts in the previous part. Lavas of such units are sometimes seen as pseudo-prismic (Fig.2b). On these lavas, basaltic rocks and basaltic olivine (E^{b2}) are placed. From the base towards the top, lavas have more cavities. Cavities are mostly occupied by zeolite and calcite. Olivine and pyroxene are the main phenocrysts of these rocks and can be identified in the

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manual sample easily. In this unit, andesite pyroxene with red pyroclastic breccias are placed (E^{p2}). The main difference of these rocks from the E^{b2} unit rocks is the gradual appearance of plagioclase phenocryst in them. Megaporphyry andesitic lavas (E^{a2}) are placed in two units of E^{p2} and E^{b2}. Inside these rocks and locally, red tuffs can be seen that show the explosive eruptions. Besides, interrupted and narrow bands including red tuffs (E^{t}) can be seen. The newest rock unit from the Razei zone are new alluvial terraces and sediments of the Ardabil plains (Q^{t}) and are considered quaternary units.

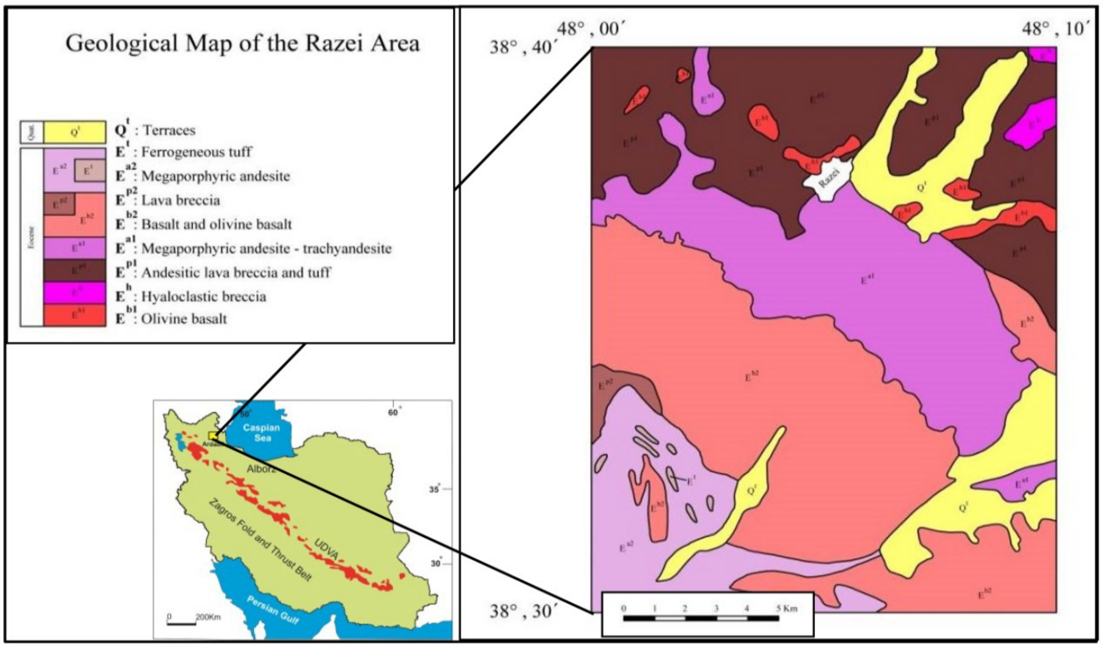

Fig.1: Geological map of the Razei region and the state of the studied region in Northwest Ardabil

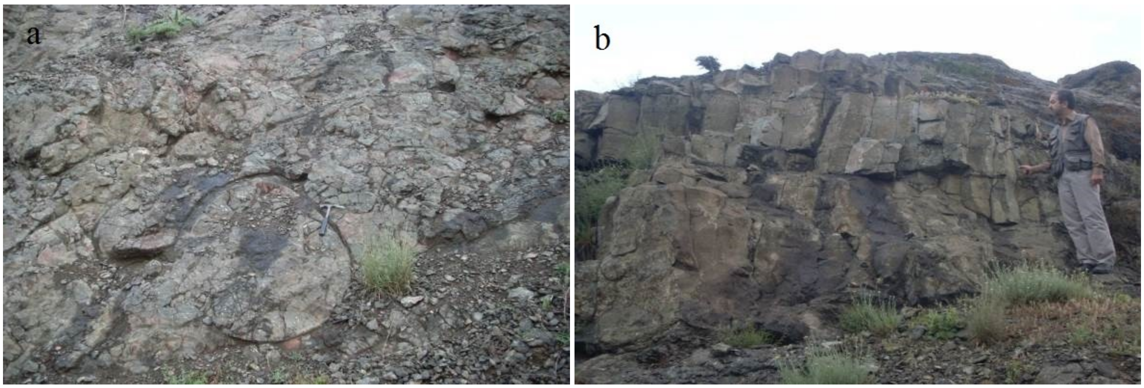

Fig.2: a) Mild pillow lava forms in E^{h} unit as nearly circular (looking northeast). b) Prism-like landscape made by lavas in E^{a1} unit in Northeast Razei (looking northeast)

4. Petrography

Andesite: The texture of these rocks is mostly porphyric with a glassy microlithic matrix and sometimes porphyric with a microgranular matrix. In the matrix of these rocks, plagioclase can be seen more than other minerals as microlithic and fine-grained. Microlithics rarely display a flow manner. Pyroxenes, another mineral of matrix, are fine-grained. Glass can be also seen in the matrix of some samples. Fine opaque minerals can be seen in the rock's matrix, too. The phenocryst of these rocks includes plagioclase and pyroxene in order of frequency.

Andesitic Basalt: Andesite basalts in the studied region have various textures. The major texture is porphyric with microlithic and microlithic vitric. In the samples with glass in their matrix, the amount of glass is less than crystal. Microlithics are from plagioclase and needles of pyroxene. The phenocryst of these rocks includes pyroxene and plagioclase in order of frequency.

Basalt: The texture of this rock is mostly porphyric with microlithic matrix and sometimes porphyric with a microlithic matrix, microgranular, and rarely vitric. In the matrix of these samples, pyroxene is more than plagioclase, and if it has glass, the amount of glass is less than that of crystals. Moreover, secondary minerals such as calcite, quartz, and zeolite, as well as fine-grained opaque minerals, are a part of this matrix in some samples. The phenocrysts of these rocks include pyroxene and plagioclase in order of frequency. Longitudinal and cross sections of needle apatites as inclusion can be seen in some phenocrysts.

Olivine basalt: The texture of these rocks is porphyric with microlithic and microgranular matrix, and sometimes has a few glasses. The microlithics of plagioclases are fine and short. The phenocryst of these rocks includes pyroxene, olivine, and plagioclase in order of frequency.

5. Geochemistry

According to the classification of Le Bas et al. (1986), most of the rocks in the samples are in the domain of basalt, trachy basalt, and basaltic trachy-andesite (Fig.4a) (Le Bas et al. 1986). In the classification of Middlemost (1994), most samples are in the domain of basalt, trachy basalt, and basaltic trachy-andesite (Fig.4b) (Middlemost 1994). According to the classification of Winchester and Floyd (1977), which is based on the ratio of SiO_2vs.Zr/TiO_2, most of the samples are in the domain of alkali basalt (Fig.4c) (Winchester and Floyd 1977). Based on the classification of Winchester and Floyd (1977), i.e. according to the ratio of Nb/Y vs. Zr/TiO_2, most of the samples are in the domain of sub-alkali basalt and alkali basalt (Fig.4d). As determined in these diagrams, there is a clear tendency towards alkali basalts that can be seen in these rocks.

5.1. Determining the magmatic series:

For determining the magmatic series, some diagrams are used that are based on the oxide of main elements and sometimes trace elements. In the diagram of Irvine and Baragar (1971), samples are in alkaline magmatic series (Fig.5a) (Irvine and Baragar 1971). Most of the samples in the diagram of Winchester and Floyd (1977) are in the range of alkali basalt, and some of them are in the territory of tholeiitic basalts (Fig.5b) (Winchester and Floyd 1977). The region's rocks, according to the diagram of Middlemost (1994), are spread mostly in a potassium-rich range (Fig.5c). According to the mentioned diagrams, the dependency of the studied rocks on potassic alkaline series is determined.

5.2. Spider diagrams:

In spider diagrams, rare elements are normalized with the composition of primitive mantle, chondritic meteorite, and MORB. For surveying the normalized diagrams with the composition of primitive mantle, the diagram of Sun and McDonough (1989) is used. In this diagram, positive anomalies of K and Sr and negative anomalies of Nb, and to some extent Tican, be seen. Positive anomaly of K is probably relative to the origin of the producer magma. A bivalent element, Sr can be the substitute of Ca in plagioclase and creates positive anomaly (Mason and Moore 1982). The most possible reason for negative anomaly of Nb and Ti is contamination with crustal rocks. Moreover, depletion of Ti may relate to the existence of Ti in nuclear network of minerals as ilmenite and titanaugite, as well as the differentiation of these minerals in the early stages of crystallization from magma. This diagram can be seen in Fig. 6a.

For surveying the normalized diagrams with chondrite meteorite, the diagram of Sun (1980) is used. In this diagram, a positive anomaly of K and negative anomalies of Nb, and to a certain extent Ti and Ta, can be seen. Negative anomaly of Nb, Ti, and Ta can be in relation to crustal contamination. Meanwhile, the concentration of these elements is controlled by the crystallization of ilmenite. Fractional crystallization of this mineral at the first stage of crystallization can cause this element to deplete. Positive anomalies of K can be reasonable as the previous diagram. This diagram is shown in Fig. 6b.

For surveying the normalized diagram with the composition of MORB, the diagram by Pearce (1983) is used. In this diagram, positive anomalies of Th, Ba, Rb, K, Sm, and Ce and negative anomalies of Ti, Nb, as well as Zr, are seen. Positive anomalies of Th, Ba, and Ce and negative anomalies of Nb and Ti can be relative to the crustal contamination. Ce is a rare-earth element with low ionic potential and high basicity, and its aggregation in the rocks of basic alkaline and ultrabasic is logical (Smirnov and Beus 1983). Moreover, the existing secondary mineral of apatite in the studied rocks that is a suitable carrier for Ce. This diagram is shown in Fig. 6c.

According to the gained results from the spider diagrams, enrichments mostly include elements of LIL and depletions mostly include some elements of HFS. Magmatic evolution such as the impact of percentage of limited partial melting and factors such as contamination with the crust, the impact of fluids or fractional crystallization process is probable and within these, the contamination with the crust has more evidences.

6. Tectonomagmatism

The diagram of Floyd et al. (1991) is drawn according to two variables of Y against the ratio of La/NB, and it is used for determining tectonomagmatic environment of oceanic basalts.

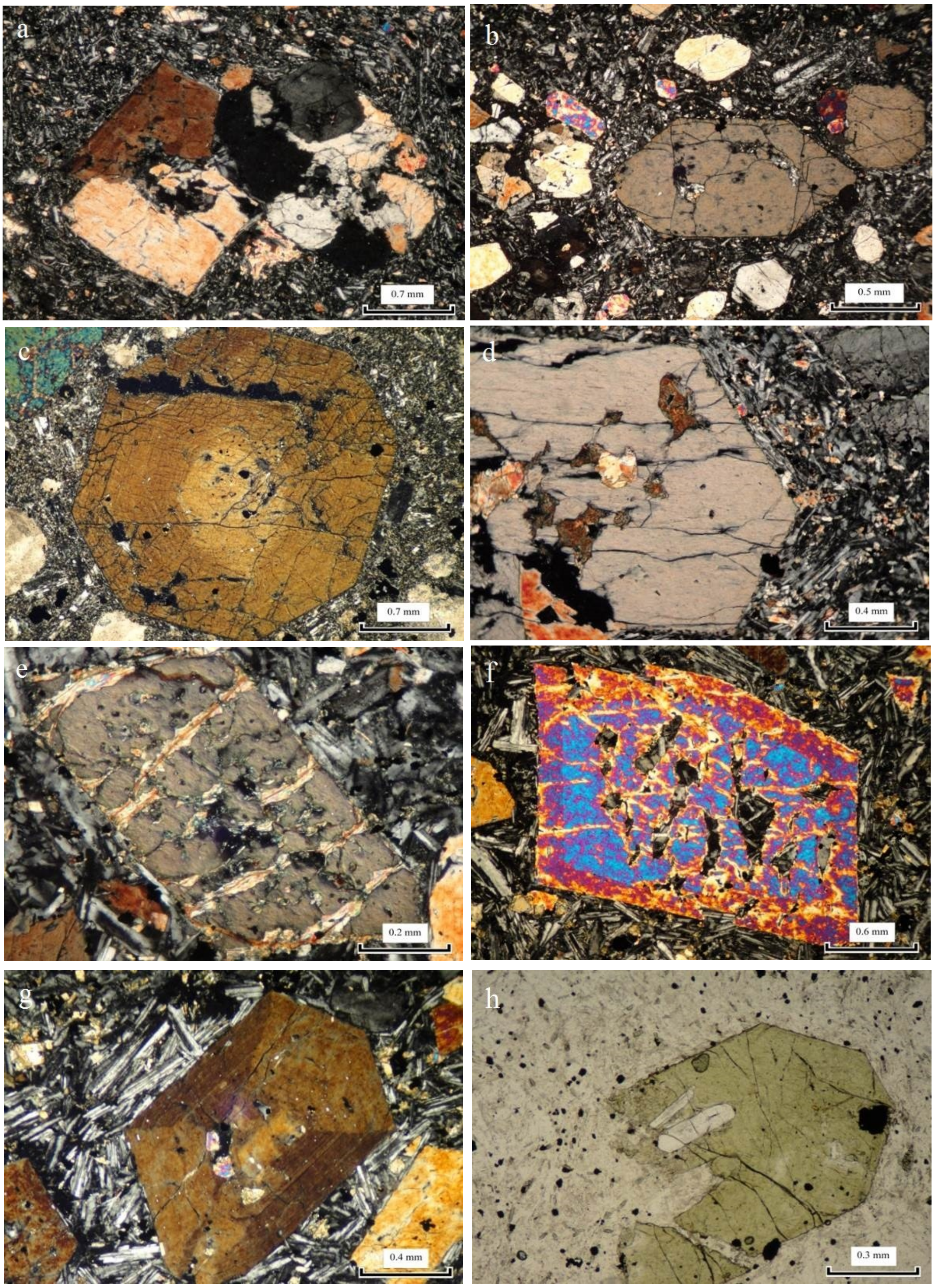

Fig. 3: a) Glomeroporphyritic texture gained from aggregation of clinopyroxene with microlithic matrix in olivine basalts (XPL). b) Porphyric texture with olivine phenocrysts and plagioclase with microlithic matrix in olivine basalts (XPL). c) Clinopyroxene automorph and octagonal phenocryst with zoning texture and determined cleavage in microlithic matrix in basalt (XPL). d) Clinopyroxene phenocryst with inclusion of consumptive olivines in a matrix of plagioclase microlithics and fine pyroxene crystals in olivine basalt (XPL). e) Serpentinization at the fractures of olivine phenocryst in the microlithic matrix of olivine basalt (XPL). f) Zoned clinopyroxene phenocryst with brown margin as a sign of titanium and iron increase in microlithic matrix of olivine basalt (XPL). g) Clinopyroxene automorph crystal with sand-clock twin and oscillatory regional textures in a matrix of flow plagioclase microliths in olivine basalt (XPL). h) Consumptive clinopyroxene phenocryst with inclusions of elongated crystals of plagioclase and opaque minerals in andesite basalt (PPL).

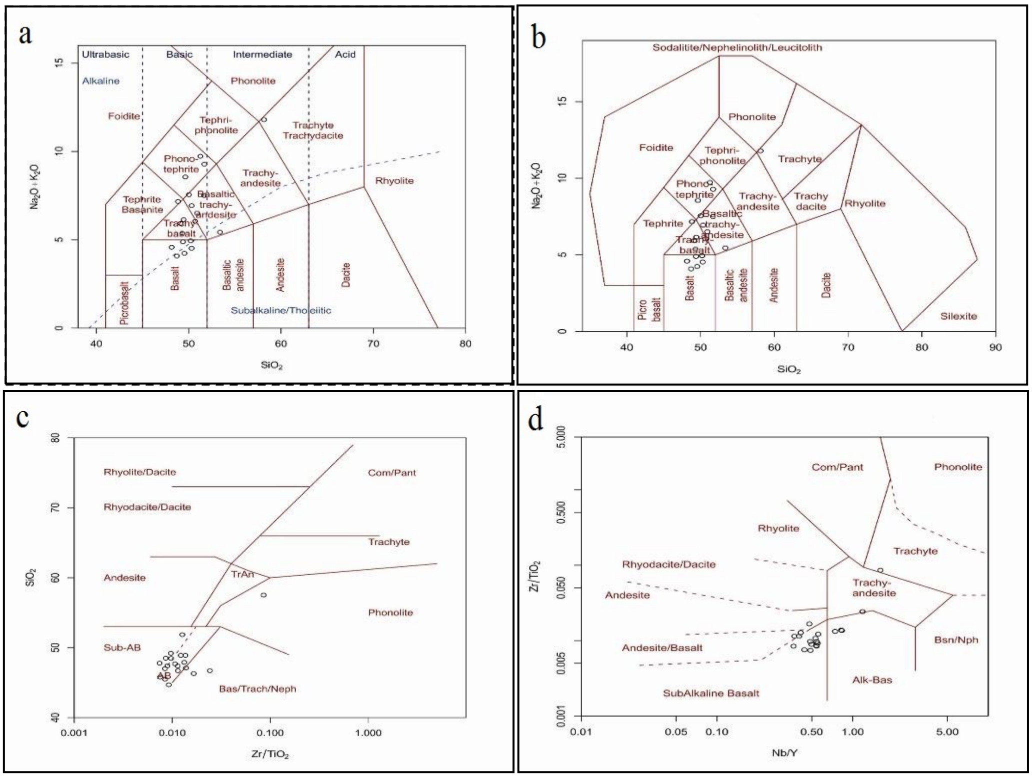

Fig.4: Chemical classifications by (a) Le Bas et al. (1986) (b), Middlemost (1994) (c and d), and Winchester and Floyd (1977).

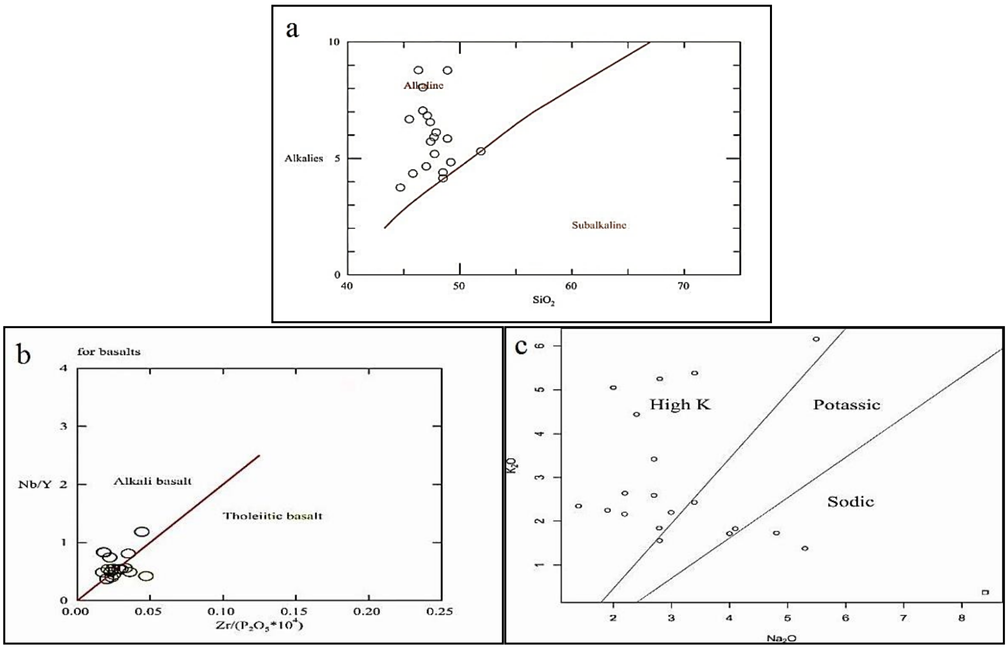

Fig.5: a) Diagram for determining magmatic series of Irvine and Baragar (1971). b) Diagram for determining magmatic series of basalts from Winchester and Floyd (1977). c) Diagram for separation sodic and potassic magma from Middlemost (1975).

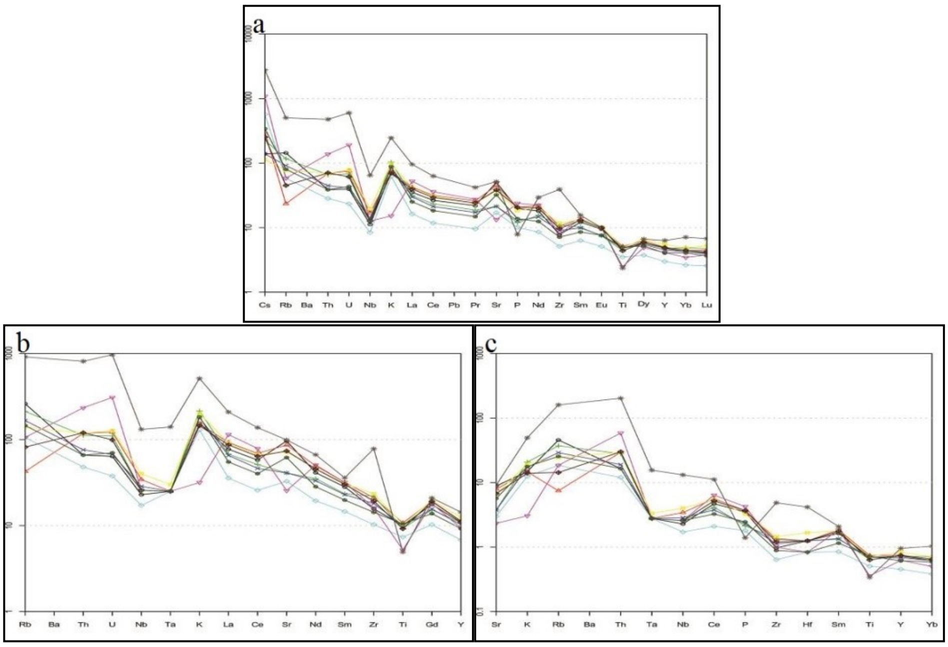

Fig.6: Spider diagram of the studied rocks, normalized with primitive mantle (Sun and McDonough 1989) (a) Chondrite meteorite (Sun 1980) (b) and MORB composition (Pearce 1983).

In this diagram, most of the studied rocks are back-arc basin basalts (Fig.7a). In the diagrams of Hollings and Kerrich (2004), which are drawn according to the ratio of Ti/Zr against Zr and separate the status of forming oceanic basalts, the studied samples are generally in the ranges of volcanic arcs and back-arc basin (Fig.7b). The diagram provided by Pearce and Gale (1977) is used for separating the intraplate basalts from other basalts called plate margin basalts. This diagram is drawn according to the enrichment of Ti and Zr in intraplate basalts. The studied rocks fall in the domain of plate margin basalts (Fig.7c). The diagram of Hooper and Hawkesworth (1993), which is in line with the ratio of N/Ba against Nb/Zr, separates the asthenosphere (A) origin and sub-continental lithospheric mantle (SCLM). Most of the rocks are in the range of sub-continental lithospheric mantle (Fig.7d). The ratio of Nb/La for the asthenosphere mantle is more than 1, and for the lithospheric mantle it is lower than 0.5. As can be seen in the common diagram of Fitton et al. (1991), as well as that by Chen and Arculus (1995), the magmatic origin of the studied rocks is in the domain of lithospheric mantle (Fig.7e).

Pearce (1983) at the normalized spider diagram with MORB determined the patterns of tectonomagmatic for kinds of basalts (Fig.7f). As can be seen in this figure, intraplate basalts have a convex form and are enriched with incompatible elements. The most important difference of continental margin basalts and intraplate basalts is the significant decline of elements such as Ti, Nb, Ta, along with those continental margin basalts against the intraplate basalts. Comparing this diagram with the spider diagram of the studied region shows its similarity with the pattern of the spider diagram of continental margin basalts that is shown in Pearce's diagram with the symbol of CABM.

According to tectonomagmatism diagrams, the lavas in the studied region are dependent on marginal basin that shows a certain relationship with volcanic arc environment and especially back-arc basin. The chemistry of the elements of the studied rocks, especially rare elements, has a good conformity with the chemical composition of the formed rocks in the back-arc basin environment. Gill (1981) and Wilson (2007) believe that negative anomalies of Nb and Ta are due to the specifications of magma rocks in the arc regions. Based on the idea of these researchers, enrichment of LILE (Pb, Cs, Ba, and Rb) with relative depletion of HFSE (NB, Ta, Ti, Zr, and Hf) is usual in the lavas of the arc regions. Different models of enrichment of LILE compared to HFSE are stated in arc magmas (Cribb and Barton 1997). One separator characteristic of volcanic arc environments' magma is the ratio of Ba/Ta, which is more than 450 in arc magma. The average of this ratio is more than 1000 in the studied samples. The amount of TiO_2 in the rocks of arc regions is rarely more than 1.3% (Gill 1981). The amount of this oxide is 0.51–1.15 in the studied samples which show their dependence to the arc environment.

The origin of the producer magma of the studied rocks depends on the lithospheric mantle. Some of the HFS elements such as Nbhas exist in various amounts in lithospheric melts. Therefore, some researchers propose that the ratio of La/Nb can be affected by the metasomatic enrichment style (Abdel-Fattah et al. 2004). Bradshaw and Smith (1994) as well as Smith et al. (1999) show that HFS elements such as Nb in lithospheric mantle are depleted against the LRE elements such as La. Therefore, this amounts to more than the ratio of Nb/La (more than 1), thereby showing the origin of the Asthenospheric mantle. A ratio lower than this (lower than 0.5) shows the origin of the lithospheric mantle. The average of this ratio in the Razei rocks is 0.414, confirming the origin of lithospheric mantle of the producer magma of these rocks.

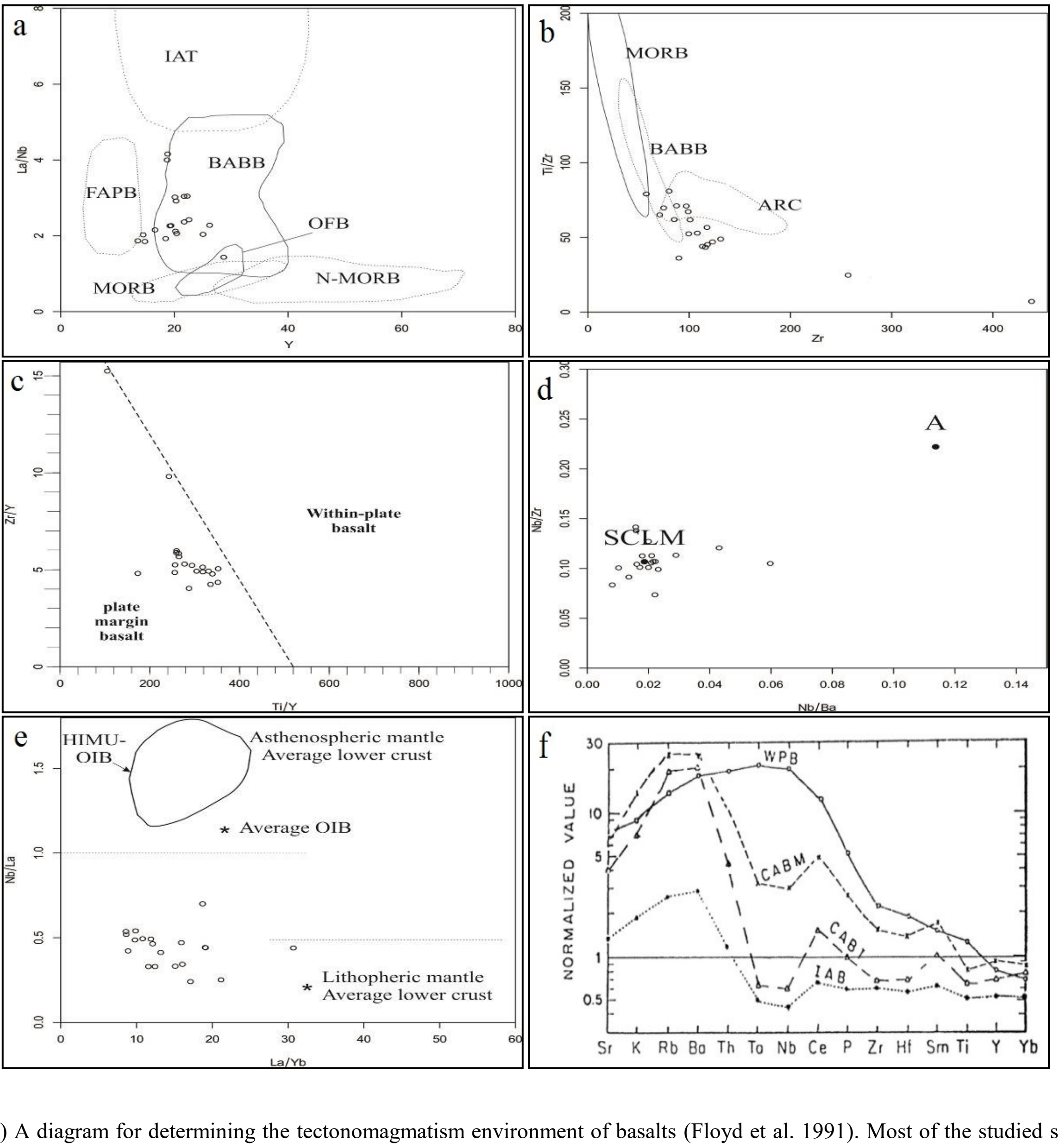

Fig.7: a) A diagram for determining the tectonomagmatism environment of basalts (Floyd et al. 1991). Most of the studied samples fall in the domain of back-arc basin basalts. b) A diagram for determining the tectonomagmatism environment of basalts (Hollings and Kerrich 2004). Most of the samples fall in the domain of volcanic arc basalts or back-arc basin or close to these ranges. c) A diagram for separating the intraplate and margin-plate basalts (Pearce and Gale 1977). The studied samples fall in the domain of margin-plate basalts. d) A diagram for separating the sub-continental lithospheric mantle (SCLM) of magma (Hooper and Hawkesworth 1993). The origin of the producer magma of the studied rocks is placed in the sub-continental lithospheric mantle. e) A diagram for separating the origin of magmas (Fitton et al. 1991; Chen and Arculus 1995). The samples of the studied region are placed in the lithospheric mantle. f) Spider diagram pattern of incompatible elements for determining the tectonomagmatism environment of basalts (Pearce 1983) that is normalized against MORB, showing the similarity of the studied basalts with continental margin basalts. (WPB: intraplate basalts, CABM: continental margin basalts, CABI: Calc-alkaline island arc basalts, IAB: Island arc tholeiite).

7. Conclusion

The volcanic rocks studied in this paper have basic composition, and their alkaline nature shows the index composition of volcanic belt of Alborz, Azerbaijan, and Ghafghaz. The presence of phenocryst in the most studied samples shows the stop of magma in the magma chamber before exit. Crystallization pattern in most of the samples are olivine → clinopyroxene → plagioclase. Different textural and mineralogical events show the mixing process in the producer magma of these rocks. The limitation caused by acidic magmas improves the probability of basic magma mixing with each other or basic magma with intermediate magma. The presence of intermediate rocks and the lack of acidic rocks near basaltic rocks also confirm this phenomenon. The producer magma of these rocks depends for the magmatic evolution such as contamination on continental-crust sialic materials, which sometimes lead them to sub-alkaline series. The distribution or unusual accumulation of samples in some of the diagrams may reinforce the impact of magmatic evolution, such as pollution. According to the gained results from spider diagrams, the effect of magmatic events, especially contamination with the crust, is obvious in the studied rocks. Enrichment mostly include some LILE such as K, Sr, Rb, Ba, and especially K and Sr, while depletions mostly include some HFSE such as Nb, Ti, Zr, and especially Nb and Ti. K is probably enriched from the initial origin of magma and the influence of the continental crust. Enrichment of Sr is probably related to this element's substitution with Ca in plagioclases. The depletion of Nb and Ti probably shows the contamination with the crust, the impact of fluids, or the fractional crystallization process. The phenomenon of contamination and mixing in the studied rocks may have played the most important role in chemical changes in the rocks. The studied rocks' enrichment from LILE in the spider diagrams shows a rare partial melting of a relatively K-rich origin or the partial melting of a rich and heterogeneous origin of deeper mantle, or a contamination of the initial magma with some continental lithospheric materials that the recent matter seems to be real. The lavas in this region generally have the geochemical characteristics of back-arc basin basalts, and were probably created on a spreading ridge in the marginal basin and above the subduction zone.

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