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GEOCHEMISTRY AND PETROGENESIS OF SILLS IN LAVASANAT REGION, TEHRAN, IRAN

GEOQUÍMICA E PETROGÊNESE DE SOLEIRAS NA REGIÃO DE LAVASANAT, TEERÃ, IRÃ

GEOQUÍMICA Y PETROGÉNESIS DE UMBRALES EN LA REGIÓN DE LAVASANAT, TEHERÁN, IRÁN

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ABSTRACT

The study area is located in Lavasanat region in the east of Tehran Province in the Central Alborz zone. The outcrops in this region are mainly associated with Karaj formation and belong to the upper Eocene to Oligocene periods. These outcrops consist of two intrusions: one in the north and the other in the northeast of Lavasanat. These outcrops are scattered over an area of approximately 337km^2. In the study region, there are various intrusive igneous rocks, while numerous intrusive igneous rocks are scattered in the form of sills and dikes. These rocks include a range of rocks from diorite gabbro to diorite, monzonite, and syenite. The weathered colors of these rocks are black, brown and gray. The outcrops of these sills are mainly present in the middle-northern part of the quadrangle geological map of the east of Tehran. In different diagrams of the magma series, the study rocks are classified as alkaline, calc-alkaline, and shoshonite, which may indicate magma contamination. An analysis of the variations of the classical elements and trace elements, the spider plots, and interpretations of these plots confirms the relationship of these rocks with the subduction zone and continental arc. To find the tectonic position of the sills in the study area based on the geochemical diagrams, we selected samples from the within-plate (WIP) and arc zones.
Keywords: Geochemistry. Petrogenesis. Lavasanat Region. Magma contamination. Iran.

RESUMO

A área de estudo está localizada na região de Lavasanat, no leste da província de Teerã, na zona central de Alborz. Os afloramentos nessa região estão principalmente associados à formação de Karaj e pertencem aos períodos do Eoceno Superior ao Oligoceno. Esses afloramentos consistem em duas invasões: uma no norte e outra no nordeste de Lavasanat. Esses afloramentos estão espalhados por uma área de aproximadamente 337 km^2. Na região de estudo, existem várias rochas

ígneas intrusivas, enquanto inúmeras rochas ígneas intrusivas estão espalhadas na forma de soleiras e diques. Essas rochas incluem uma variedade de rochas, desde o diorito gabro até o diorito, monzonita e sienito. As cores resistidas dessas rochas são preto, marrom e cinza. Os afloramentos dessas soleiras estão presentes principalmente na parte centro-norte do mapa geológico de quadrângulos do leste de Teerã. Em diferentes diagramas da série de magma, as rochas do estudo são classificadas como alcalina, calcálcali-alcalina e shoshonita, o que pode indicar contaminação por magma. Uma análise das variações dos elementos clássicos e oligoelementos, as parcelas de aranha e as interpretações dessas parcelas confirmam a relação dessas rochas com a zona de subducção e o arco continental. Para encontrar a posição tectônica das soleiras na área de estudo com base nos diagramas geoquímicos, selecionamos amostras das zonas de placa interna (WIP) e de arco.
Palavras-chave: Geoquímica. Petrogênese. Região de Lavasanat. Contaminação por Magma. Irã.

RESUMEN

El área de estudio se encuentra en la región de Lavasanat, al este de la provincia de Teherán, en la zona central de Alborz. Los afloramientos en esta región se asocian principalmente con la formación de Karaj y pertenecen a los períodos del Eoceno superior al Oligoceno. Estos afloramientos consisten en dos intrusiones: una en el norte y la otra en el noreste de Lavasanat. Estos afloramientos se encuentran dispersos en un área de aproximadamente 337 km^2. En la región de estudio, hay varias rocas ígneas intrusivas, mientras que numerosas rocas ígneas intrusivas están dispersas en forma de alféizares y diques. Estas rocas incluyen una gama de rocas desde diorita gabro hasta diorita, monzonita y sienita. Los colores desgastados de estas rocas son negro, marrón y gris. Los afloramientos de estos umbrales están presentes principalmente en la parte norte-media del mapa geológico cuadrangular del este de Teherán. En diferentes diagramas de la serie de magma, las rocas de estudio se clasifican como alcalinas, alcalinas calcáreas y shoshonitas, lo que puede indicar contaminación por magma. Un análisis de las variaciones de los elementos clásicos y oligoelementos, las gráficas de araña y las interpretaciones de estas gráficas confirman la relación de estas rocas con la zona de subducción y el arco continental. Para encontrar la posición tectónica de los umbrales en el área de estudio basada en los diagramas geoquímicos, seleccionamos muestras de las zonas de placa interior (WIP) y arco.
Palabras-clave: Geoquímica. Petrogénesis. Región de Lavasanat. Contaminación por magma. Irán.

INTRODUCTION

Alborz mountain range in the north of Iran has a length of approximately 900km and a width of approximately 100km. This mountain range is an area housing active deformations in the southern bank of the Caspian Sea. This mountain range is also a branch of the active Alpine-Himalayan orogenic belt in Western Asia. The active deformation of this mountain range originates from the convergence and collision of the Arabian Plate with the south of Eurasia and the movement of the southern Caspian Sea plate (BARATIAN *et al.*, 2018., YAZDI *et al.*, 2019a).

The study region, which has a surface area of 337km^2, is located approximately 10km east of Tehran in the north of Jajrood. This area is located between longitudes 51°35`, 51°50`E and latitudes 35°45`, 35°53` (Figure 1).

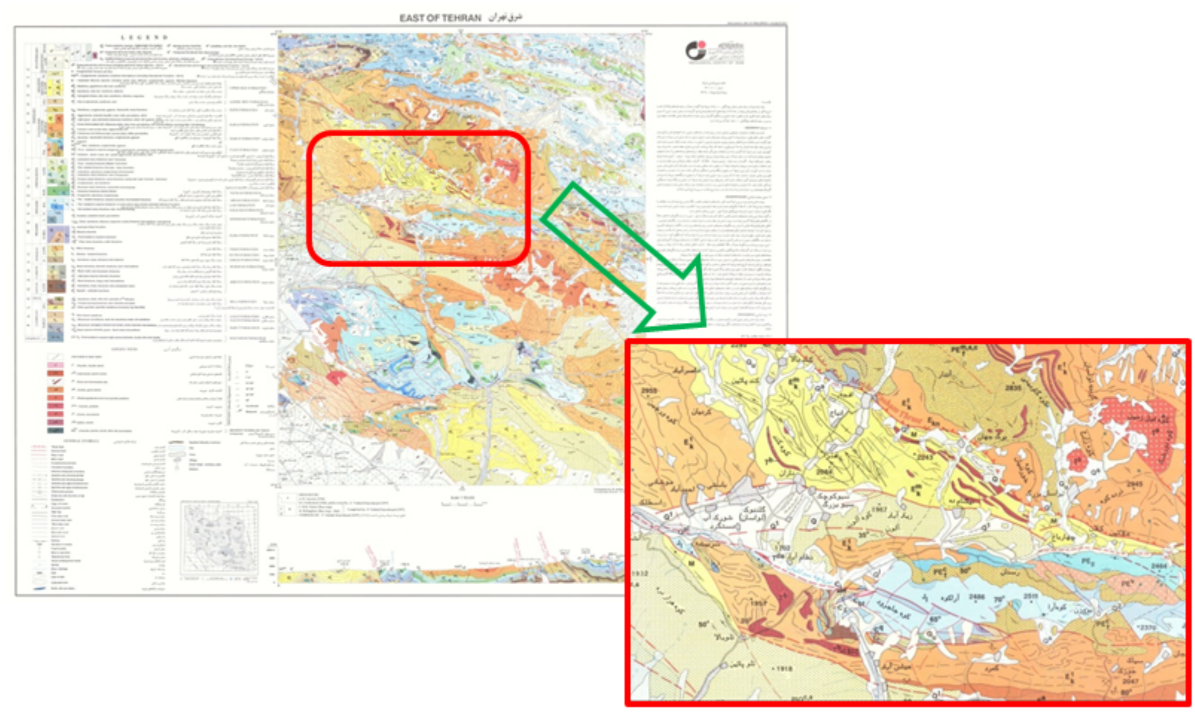
The study area has mountainous geomorphology. It is composed of large and small anticlines and synclines with a northwest-southeast strike. These anticlines and synclines are displaced by faults with the aforesaid strike. It includes a wide range of mountainous reliefs formed under the influence of tectonic and climatic conditions.

This quadrangle is part of the Central Alborz zone and the outcrops mainly belong to Karaj formation. These outcrops consist of two intrusions: one in the north and the other in the east of Lavasanat. Moreover, different rock units with different ages are juxtaposed in the study area. The Eocene rocks are manifested as folds and younger units are locally placed on top of them.

In the study area, igneous rocks are found as intrusions formed in between deposits. The intrusions in Lavasanat region are a mixture of gabbro and syenite or a combination of both. These intrusions are classified into the groups of sills and dikes. We study the sills in the study area in this paper, which is penned to attain the following goals.

1. Carry out a petrographic analysis of the rocks constituting the sills in the region
2. Conducting a geochemical and petrologic study on the sills in the region

Figure 1 - The geological position of the study section



Source: Vahdati Daneshmand F. (1995).

STUDY METHOD

- Gathering information, using local and foreign scientific-research articles, and using theses and reports on the study area at the university libraries, the Geological Survey and Mineral Exploration Organization of Iran, and Internet sources;
- Using different information layers such as the 1:100000 quadrangle geological maps, topographic maps, aerial photographs, and satellite images of the study area to select regular survey routes in field operations;
- Paying field visits and making proper marks on the petrologic diversities using GPS; and properly sampling the healthy less-altered outcrops in the study area for petrographic studies, mineral chemistry analyses, and geochemical studies of the entire rocks;
- Conducting experimental studies classified into the following categories ;

1. Collecting 17 samples for a mechanized analysis using the alkaline fusion technique
2. Conducting geochemical ICP-MS analyses and measuring the oxides of classical and rare earth elements in 17 samples
3. Studying and analyzing the results of geochemical analyses after drawing petrologic diagrams using geochemical data
4. Determining the genesis of rocks
5. Summarizing the data obtained from field and experimental works
6. Drawing conclusions from the geochemical and petrogenesis results

SUB VOLCANIC INTRUSIONS

These rocks are present in the upper parts of the crust and at the less crystalline depths mainly in the form of sills, dikes, and stocks. Sills, which are sometimes called sheets, are layered intrusions lying in parallel to the surface of the strata or schist of their country rocks.

The sills in the study area have basic to neutral compositions. Since these sills are injected in between the Fajan sedimentary layers (which belong to Paleocene period) as well as the sedimentary layers and pyroclastic layers in Karaj formation (which belong to middle Eocene period), they can be attributed to the upper Eocene or Oligocene period. There are either a considerable number of sills or sills with significant lengths on the ground, which include a range of rocks from gabbro to syenite. In the south of Barge Jahan village, there are many sills on the ground in parallel to each other (SAFARI, 2017; DABIRI *et al.*, 2018; ASHRAFI *et al.*, 2018; YAZDI *et al.*, 2019b; NAZEMI *et al.*, 2019).

Figure 2 - The boundary between the sills and host rocks in the region

GEOCHEMISTRY

The results of the geochemical studies revealed that all samples collected from the region fall into the alkaline series category according to the alkaline-silica series diagram (Figure 3). They also fit into the category of calc-alkaline series in the diagram provided by Irvin and Barager (1971) (Figure 4).

Figure 4 - Determining the calc-alkaline and tholeiitic series (Irvin and Barager, 1971)

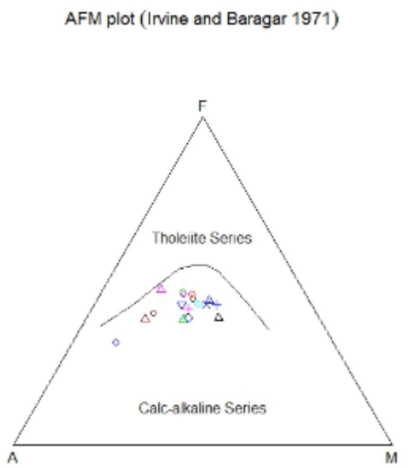
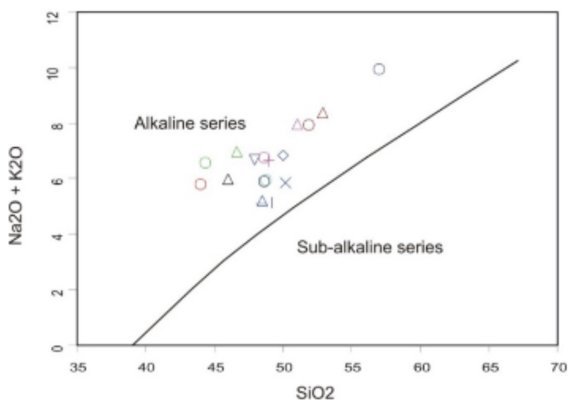
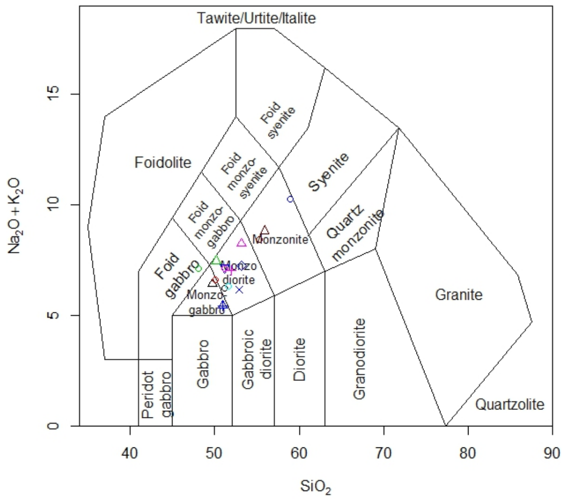


Figure 3 - The alkaline and sub-alkaline series curves



Middlemost's chemical classification (MIDDLEMOST, 1994) is based on the SiO_2 concentration and the alkalinity degree (Na_2O+K_2O). The samples analyzed in this study are also in the monzonite, monzodiorite, and monzogabbro groups (Figure 5).

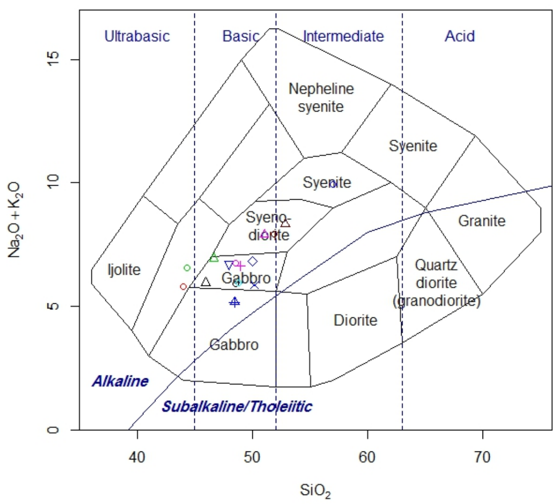
Figure 5 - Middlemost classification



Source: Middlemost (1994).

The results of Cox's chemical classification (COX *et al.*, 1979), which is known as the TAS diagram, partly comply with the results of Middlemost's diagram (Figure 5). According to this diagram, the study area consists of gabbros, syenodiorite, and syenite rocks (Figure 6; Table 1).

Figure 6 - The classification of the rocks in the study area



Source: Cox *et al.* (1979).

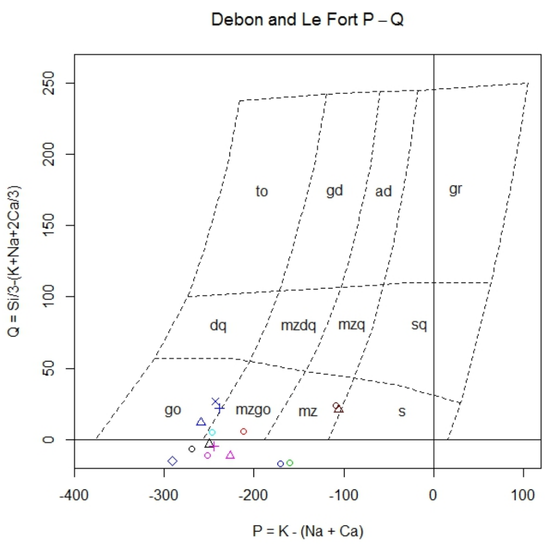
Table 1 - Naming the rocks in the study area based on the essential elements

	SiO_2	Sampe	TAS Middlemost,1994	TAS Middlemost,1985	TAS Cox et al,1979
Sill	<52	S-1-8	Monzo diorite	Monzo diorite	Gabbro
		S-1-10	Monzo gabbro	Monzo diorite	Gabbro
		S-2-27	Monzo gabbro	Monzo diorite	Gabbro
		S-3-52	Foid gabbro	Monzo diorite	Gabbro
		S-3-60	Monzo diorite	Monzo diorite	Gabbro

		S-4-63	Monzo gabbro	Monzo diorite	Gabbro
		S-4-65	Monzo gabbro	Monzo diorite	Gabbro
		S-4-68	Monzo diorite	Monzo diorite	Gabbro
		S-4-71	Monzo diorite	Monzo diorite	Gabbro
		S-4-90	Monzo diorite	Monzo diorite	Gabbro
		S-5-80	Monzo diorite	Monzo diorite	Gabbro
		S-6-83	Monzo diorite	Monzo diorite	Gabbro
		S-6-84	Monzo diorite	Monzonite	Syeno diorite
		S-6-86	Monzo diorite	Monzo diorite	Gabbro
		S-8-94	Monzonite	Monzonite	Syeno diorite
	>52	S-4-62	Monzonite	Syanite	Syanite
		S-8-95	Monzonite	Monzonite	Syeno diorite

According to the classification by Debon and Le Fort P-Q, most samples fit into the following categories: monzonite, monzogabbro, and gabbro. These results reveal that the sills in the study area belong to the family of basic rocks (Figure 7; Table 2).

Figure 7 - The classification of the sills in the study area based on the accessory elements



Source: Debon (1983).

Table 2 - Naming the rocks in the study area, accessory elements

	SiO₂	Sampe	Pearce,1996 (Nb/Y-Zr/Ti)	TAS Debon (1983)
Sill	<52	S-1-8	Monzonite	Gabbro
		S-1-10	Monzonite	Monzo gabbro
		S-2-27	Monzonite	Monzo gabbro
		S-3-52	Monzonite	Monzonite
		S-3-60	Monzonite	
		S-4-63	Gabbro alkali	Gabbro
		S-4-65	Monzonite	Gabbro
		S-4-68	Monzonite	Gabbro
		S-4-71	Grano diorite	Gabbro
		S-4-90	Grano diorite	
		S-5-80	Monzonite	Monzo gabbro
		S-6-83	Grano diorite	Monzo gabbro
		S-6-84	Granite	Monzo gabbro
		S-6-86	Monzonite	Monzo gabbro

		S-8-94	Granite	Monzonite
	>52	S-4-62	Grano diorite	Monzonite
		S-8-95	Grano diorite	Monzonite

In general, it could be stated that:

1. The igneous rocks in the study area are available in the form of sills, dikes, and stocks. Considering the geochemical diagrams presenting the results of analyzing the essential and accessory elements, the rocks in the study area can be classified as rocks with basic to neutral composition ranging from gabbro to syenite. The variations in the silica content of these rocks are also small but their K_2O content varies considerably.

2. In different diagrams of magma series, the rocks in the study area fall into the categories of alkaline magma, calc-alkaline, and shoshonite series, which may be indicative of magma contamination. These samples are also meta-aluminate samples. The diagrams of the variations of the oxides are indicative of the magmatic differentiation, while the diagrams of the silica accessory elements confirm the magmatic differentiation. However, there are expansions in the diagram series, which are caused by magma contamination.

3. The sills in the study area include various intrusive rocks. However, the rocks include thin sills or extremely shallow sub-volcanic rocks with respect to texture. Moreover, the sills in the study area belong to a subvolcanic environment and they are classified into the following categories based on their silica content: basic (SiO_2=52-45) and neutral (SiO_2=52-66).

4. Considering the geochemical diagrams of the results of the essential and accessory elements, the rocks in the study area are classified as gabbro, monzogabbro, monzonite, and syenite. The magma is also alkaline and it could be associated with a subduction zone from the tectonic point of view. Our analysis of the variations of the essential and accessory elements, the spider plots and their interpretations confirms the relationship of these rocks with the subduction zone and continental arc.

5. The Harker diagrams of the variations of oxides in relation to SiO_2 in Lavasanat region indicate that the essential oxides decrease with an increase in silica in relation to SiO_2 while the K_2O content increases. From the geochemical point of view, the Na and K essential elements both are considered incompatible elements, which increase with an increase in silica. In the final stages of crystallization, the concentrations of these two oxides rise in the silicate lava, resulting in the production of more acidic feldspars.

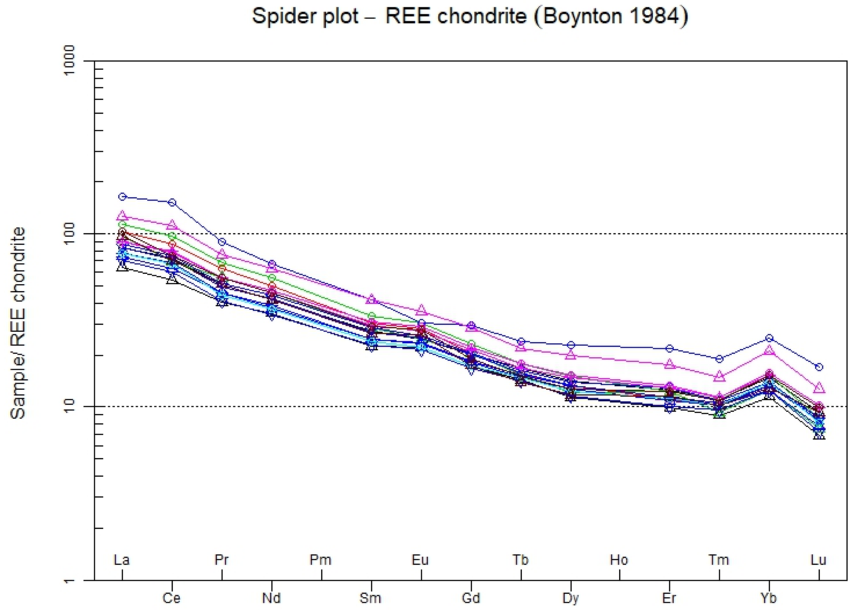
6. The rocks in this region show a degree of richness in LILE and LREE as compared to HFSE, while they are richer in LILE/HFSE and LREE/HFSE than MORB.

7. The rocks in the region are rich in light rare earth elements (LREE) while they show depletion HREE-wise. There are two possible reasons for these LREE-rich the study samples. Firstly, LREEs are somewhat more incompatible than HREEs and can be attributed to the low melting percentage of the source rock. Secondly, it may result in the LREE-enrichment of the rocks in a region. This is why these rocks form in subduction zones.

8. In the diagram of the distribution of rare elements versus the primitive mangle, which is based on the spider plot, the Pb, U, Ba, K, and Cs elements show enrichment whereas elements such as Lu, Y and Ti show depletion. Enrichment in K can be associated with the metasomatism of the mantle or the continental crust contamination. The positive Nb anomaly may also reflect the effect of fluids in the subduction zone on the mantle resources. In the rocks in the study region, there is a negative Nb anomaly. Besides, these rocks are significantly rich in LILEs (such as U and K) and show depletion of the HFSE elements (such as Y). The high atomic radius and low capacity of LILEs show these elements are highly soluble in aqueous fluids and easily enter an aqueous phase. This is because aqueous fluids constitute an important part of the petrogenesis in subduction zones. The evident source of H2O that is extremely deep

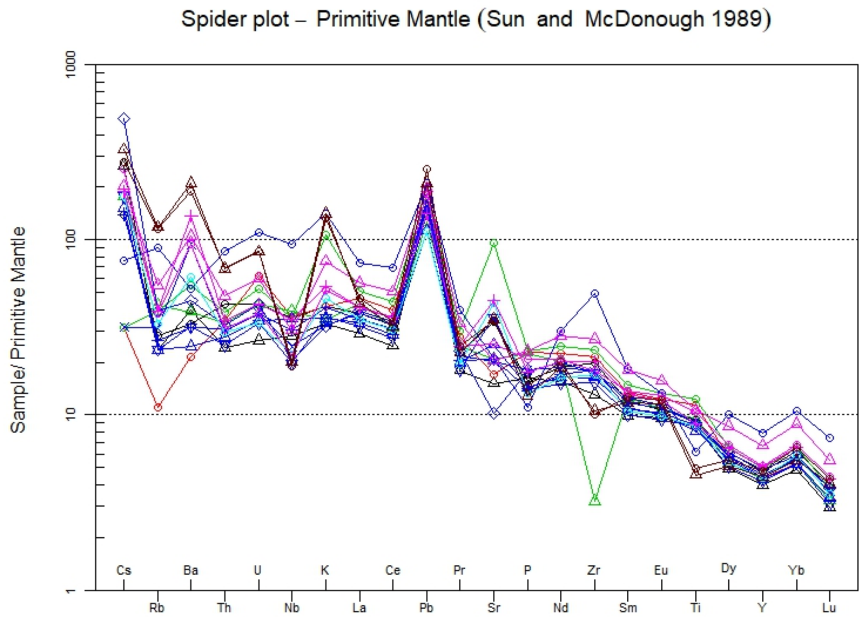
in the ground is the water in the deposits in the oceanic crust of the subducting plate (Figure 8 A and B).

Figure 8A - the rare earth elements in mafic and neutral rocks in the study area based on the REE chondrite data



Source: Boyenton (1984).

Figure 8B - Based on the primitive mantle



Source: Sun and McDonough (1989).

9. The HFSE elements that have a larger capacity are less soluble, and thus they are often called the immobile elements. The concentrations of these elements are controlled by the source chemical processes and the crystallization-melting processes during the genesis of the rocks. The high LILE/HFSE ratio is an evident indication of the magmas in the subduction zone (WINTER, 2001). Since the subduction zone is identified as a tectonic environment housing

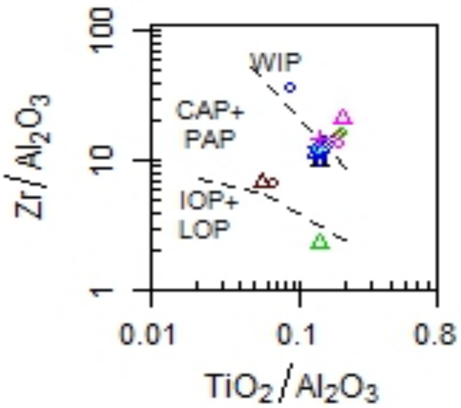
these rocks and the negative Ti anomaly is the characteristic of this zone, the lack of the negative Ti anomaly can be another evidence of the contamination of these rocks with the crust.

10. The rocks in the study region show a low Ba/La ratio (similar to the Aleutian islands), revealing that part of the oceanic crust melted before its dehydration. Stolz *et al.* (1996) argue that a high Nb/Ta ratio is indicative of a mantle source, which it will be free of HFSEs (originating from subduction) and rich in LILEs under the influence of fluids. In this case, we have Nb/Ta>1. This ratio varies between 15 and 20% in the rocks in the region. A high level of the Nb/Ta ratio is also characteristic of the magmas derived from a contaminated mantle.

11. Thorium and rubidium are used to model the assimilation and crystallization of part of the rare elements (KASKIN, 1998). These two elements are used because they are not affected by the crystallization of different minerals. According to this diagram, the study samples have undergone different degrees of assimilation and crystallization, and their compositions have become similar to the composition of the upper crust.

In the Zr/Al_2O_3-$TiO_2/Al2O_3$ diagram (MULLER; GROVES, 1997), the different types of rocks that belong to the arc can be differentiated from the within-plate rocks. As seen in Figure 9, all samples are in the within-plate (WIP) zone and the S94, S95, and S60 host rocks are in the arc zone.

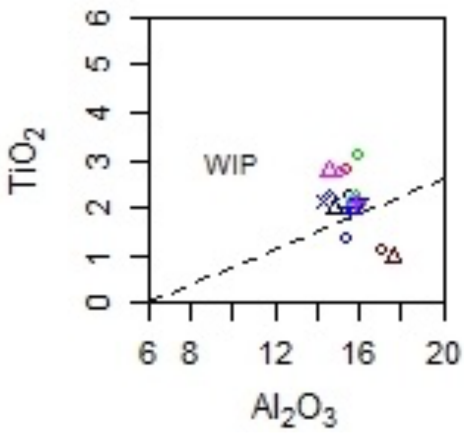
Figure 9 - The diagram of the tectonic position of the rocks in the study area



Source: Muller and Groves (1997).

In the TiO2-Al2O3 diagram (MULLER; GROVES, 1997), the rocks belonging to the arc area are separated from the within-plate rocks. According to Figure 10, most of the study samples except for S62, S95 and S94, which represent the host rock, are in the WIP (within-plate) zone.

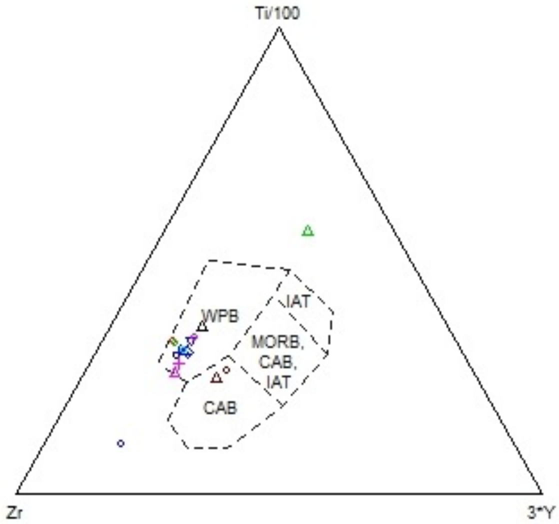
Figure 10 - The diagram of the tectonic position of the rocks in the study area



Source: Muller and Groves (1997).

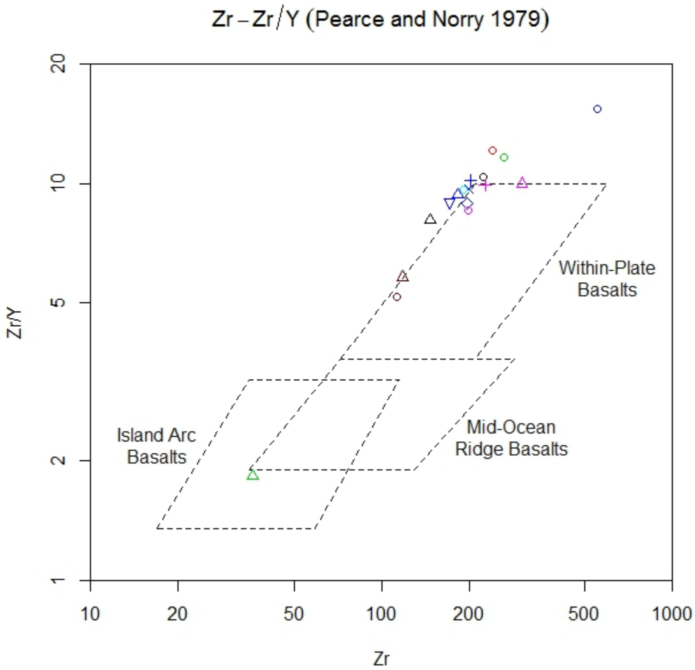
In the ternary diagram (PEARCE; CANNS, 1973) of the samples collected from the study region, these samples are classified as within-plate basalts (Figure 11).

Figure 11 - The ternary diagram of the tectonic position of basalts for the differentiation of calc-alkaline, diagonal, island arc, and within-plate basalts



In the Zr-Zr/Y diagram (PEARCE; NORRY, 1979) shown in Figure 12, all samples are classified as within-plate basalts.

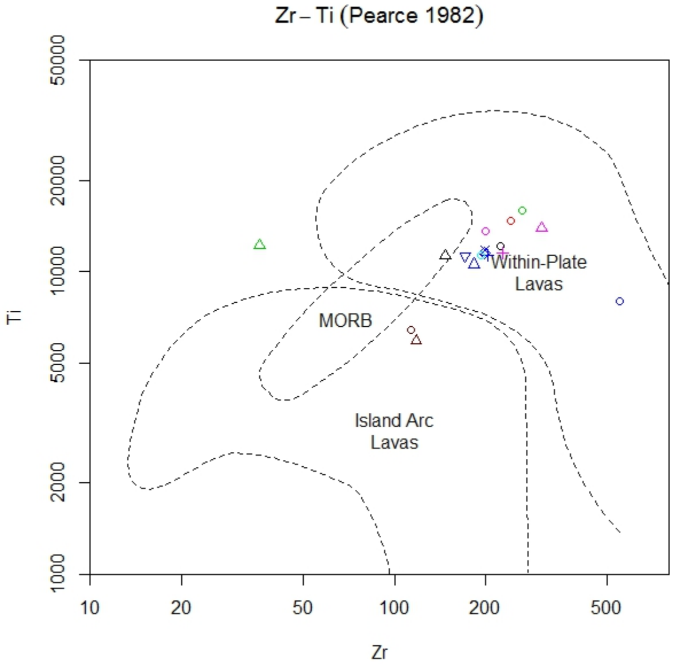
Figure 12 - The tectonic position of the rocks in the study area



Source: Pearce and Norry (1979).

In the Zr-Ti diagram (PEARCE, 1982), all samples are classified as within-plate rocks (Figure 13). The S94 and S95 samples, which originate from the host rock, are in the continental arc environments. The S60 sample is outside this range probably due to weathering and alteration.

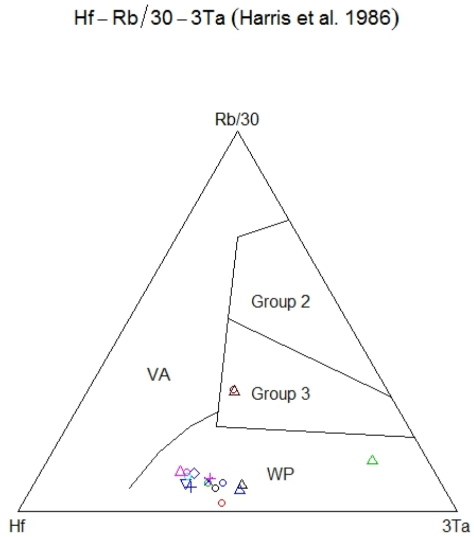
Figure 13 - The diagram of the tectonic position of the rocks in the region for the separation of island arc basalts, mid-ocean basalts, and within-plate basalts



Source: Pearce (1982).

In the ternary Hf-Rb/30-3Ta diagram (HARRIS *et al.*, 1986), the sills in the study area are in the WIP (within-plate) range while the host rock samples are in Group3 (Figure 14).

Figure 14 - The tectonic position of the sills in the region



Source: Harris *et al.* (1986)

CONCLUSION

The igneous rocks in the study area are present in the form of sills, dikes, and stocks. The geochemical diagrams of the results of analyzing the essential and accessory elements indicate that the rocks in the study area belong to a subvolcanic environment. These rocks include a range of basic to neutral rocks depending on their silica content. The composition of these rocks varies from gabbro to syenite. The study rocks also fit the alkaline, calc-alkaline, and shoshonite magma series categories, which may have magma contamination. An analysis of the variations of the essential and accessory elements, the spider plots, and interpretations of the spider plots confirms the relationship of these rocks with the subduction zone and continental arc. As regards the tectonic position of the sills in the study area, our samples are in the within-plate and arc zone according to the results of the geochemical methods and the related diagrams.

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