

Geochemistry and Petrogenesis of Tertiary Volcanic Rocks of the Eastern Roodbar, Alborz Mountain, North of Iran

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Abstract

In the Alborz Mountains of the eastern Roodbar (north of Iran), Tertiary volcanic rocks have a variety of composition between olivine basalt, basaltic andesite, pyroxene andesite and andesite. The presence of different xenoliths and xenocrysts is among the evidence of crustal contamination of these rocks. The positive correlations of CaO/Al₂O₃ vs to MgO and Al₂O₃ vs. SiO₂ are of signs of the olivine and clinopyroxene fractionation in the variation trend of the area rocks. Positive correlations K₂O/P₂O₅ vs with SiO₂ and La/Sm vs. K₂O/P₂O₅ demonstrate contamination of magma with the continental crust. The incompatible trace element patterns and their comparison with crustal contents indicate contamination of the rocks of the area with the lower and upper continental crust. Linear trends in the variation diagram of Nb/Y vs. Zr/Y, introduce two different source regions: a MORB source and the other continental crust for the rocks which are the genesis. The variations of Y/Nb vs. Zr/Nb and Rb/Y vs. Nb/Y reveal a crustal contamination of the magma originated from the MORB source. Geochemical studies represent that the area's rocks were derived from the 15% melting of a mantle source of MORB type with spinel facies within a continental environment, which was contaminated by varying degrees of continental crustal rocks.

Keywords

Volcanic Rocks, Tertiary, MORB Source Mantle, Crustal Contamination

1. Introduction

One of the most important applications of the igneous petrology is to determine the

role of asthenosphere and lithosphere mantle in producing the melt and its relationships with geotechnical events, which has the most importance for genesis of continental and oceanic basalts of mantle composition [1]. But what should be considered in continental regions is that the primary magmas from partial melting of the mantle would be varied and modified, due to the interaction with the continental crust during ascent [2]. Thus, it should always consider the role of crustal contamination in petrogenesis of the continental within-plate magmas. Because, for example, the crustal contamination can change the geochemical properties of the continental within-plate basalts, and misleadingly show the geochemical characteristics of rocks in subduction zones [2]. Consideration of geochemical and isotopic signs of rocks allows the identification of the mantle composition and magmatic processes such as mixing, contamination and assimilation. All the continental basalts show enriched trace elements patterns. This enrichment has been generated either through metasomatic fluids penetration or explained by accepting enriched components such as crust or lithosphere by the asthenosphere and depleted mantle materials [1]. On the other hand, it can establish the relationship between the mantle source and tectonic setting of rocks: for example, the mantle type EM is in fact the lithospheric enriched mantle [3], which is possibly generated due to the subduction of crustal materials into the mantle [4]. The upper mantle wedge metasomatism has led to incompatible elements enrichment in these rocks through fluids released from the subducted plate [5]. But in the intra-continental rift regions, the asthenospheric mantle of OIB and MORB sources plays an important role in petrogenesis of basalts [2]. On the other hand, the sub-continental lithospheric mantle has been often hypothesized in the petrogenesis of basalts and both lithospheric crust and mantle are considered as the contaminant in asthenospheric magmas [6]. In this article, it is tried to investigate the characteristics of mantle source and the role of continental crust in the magmatic evolutions of Tertiary volcanic rocks through geochemical evidence and determine its relationship with the governing geodynamic setting at the time of the formation of these rocks. This could help us in better understanding of the tectonomagmatic setting of Tertiary rocks in Alborz and generally, Iran. In **Figure 1**, the satellite image of the studied area would be seen.

2. Geology of the Area

The study area is located in the East of Roodbar and Northeast of Lushan city in Gilan province, in north of Iran (**Figure 2**). According to division [7], this area falls in the Paleogene volcanism zone (**Figure 3**). The studied area is in the sheet of Jirande at a scale of 1:100,000 between 49°30' and 50°00' east longitude and 36°30' and 37°00' north latitude. In this part, outcrops of volcanic and pyroclastic rocks of Paleogene and especially middle Eocene age have widely extended. The Jirande sheet at a scale of 1:100,000 encompass a part of Central Alborz zone in which rock units of Paleozoic to present are exposed. The volcanic-sedimentary units of Mesozoic are mainly exposed in the northern region as thrust sheets. But a large part of the region covered by volcano sedimentary units of Cenozoic, in particular Tertiary [8]. The units have mostly cut by dykes



Figure 1. Satellite image of the studied area, the study area marked as a rectangle (Google Earth, 2016).

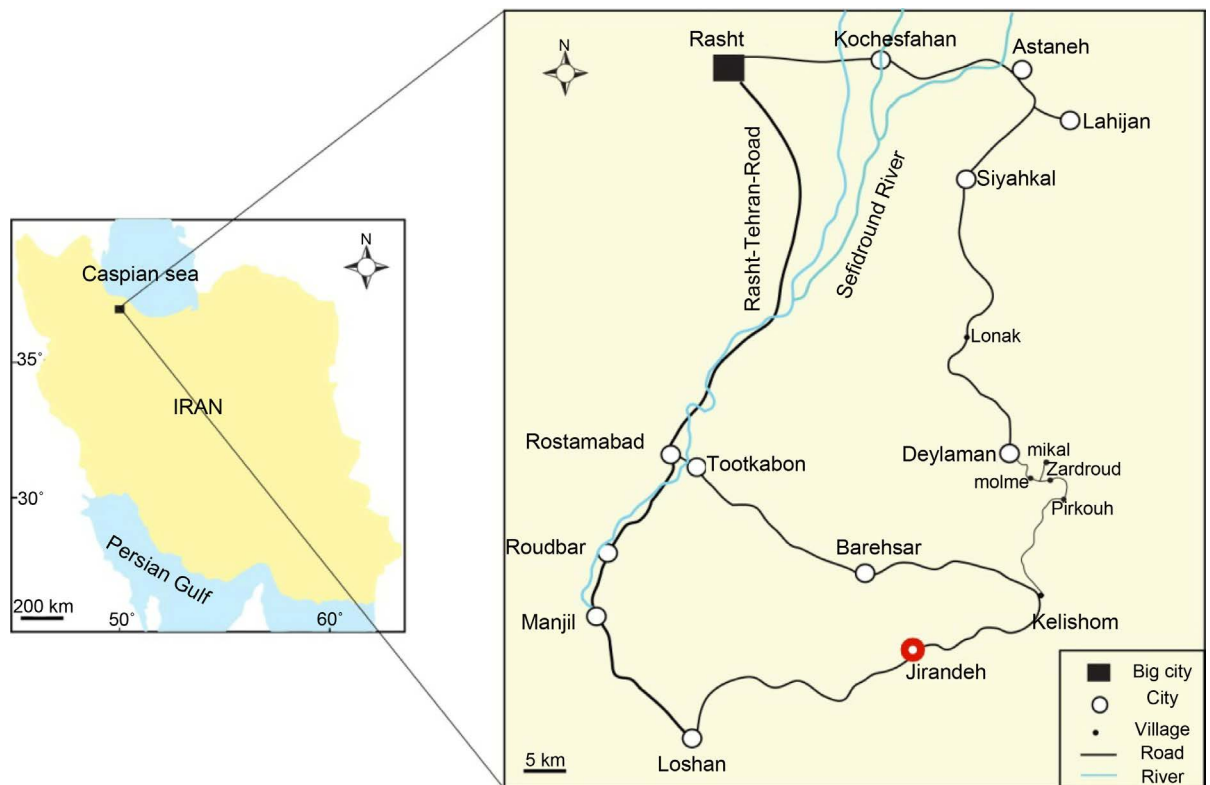


Figure 2. Access paths to the area in the east of Roodbar in Gilan province, north of Iran.

and small intrusive and subvolcanic bodies. Based on field studies, outcrops of rocks in the region from old to present include: limestone unit containing the fossil assemblages of lower to middle Eocene, olivine basalt to basaltic andesite unit with clear bedding and dark color, basic bedded pyroclasts unit comprising the collapse pyroclasts in lapilli size, heterogeneous tuffs and volcanic breccias which follow well the surface topography of olivine basalt unit. The last unit is a thick sequence consists of basaltic andesite

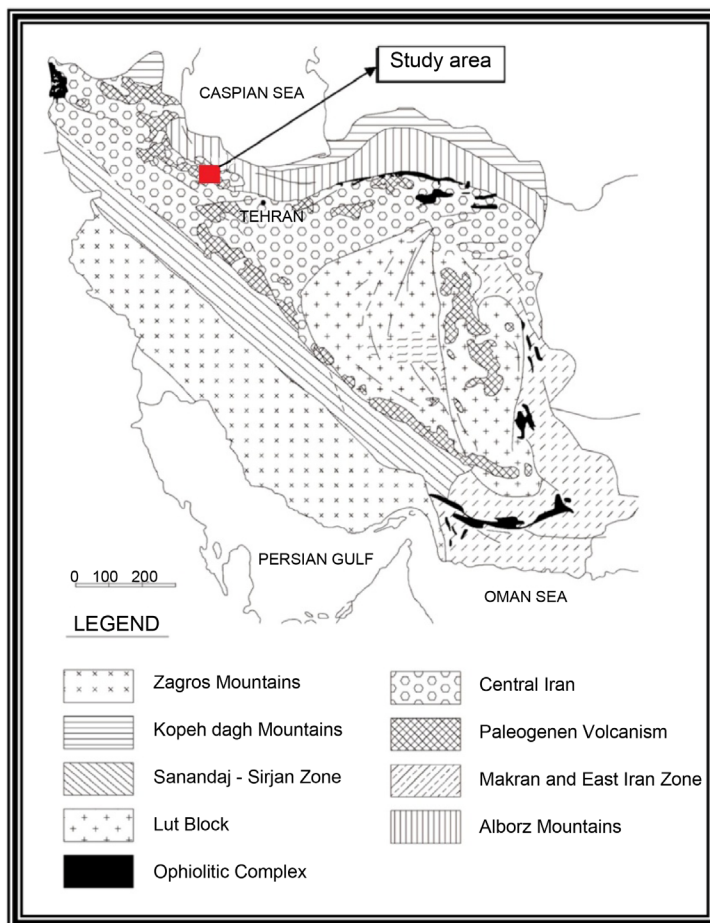


Figure 3. Structural zones division of Iran [7], the approximate location of the studied area show as quadrangle.

lavas, pyroxene andesite and andesite, which comprise the most part of the region.

3. Methodology

After field studies, notice to lithological varieties of the volcanic units in the region, 50 samples caught and thin sections were prepared and studied in terms of petrography using polarizing microscope. Then, among the above samples, 22 samples with the lowest weathering and most lithological variety were selected to analyze the major elements using XRF method and the trace and REE elements by ICP-MS at SGS laboratory in Toronto. In order to analyze data, the software Igpert 2007 and GCD kit are used.

4. Discussion

In this section, petrographic, geochemical and petrogenesis studies are explained:

Based on petrographic studies carried out on the lavas units, three rock units were distinguished: 1) olivine basalts, 2) andesitic basaltic and basaltic andesite, 3) pyroxene andesites and andesites. The first group: olivine basalt has often porphyritic texture and sometimes glomeroporphyritic. The major minerals of the rock: olivine, augite pyrox-

ene and plagioclase. Secondary minerals: chlorite, bowlingite and iddingsite which is a product of the olivine alteration in the rock (**Figure 4(a)**). In some crystals of augite (**Figure 4(b)**) and plagioclase, zoning can be observed. The second group: andesitic basalt to basaltic andesite: These rocks have microliticporphyritic to hyalo porphyritic and glomeroporphyritic texture (**Figure 4(c)**). Given the diversity of rock, the major minerals of the rock include olivine, augite, plagioclase and hornblende (**Figure 4(d)**).

The third group: pyroxene andesite and andesite: These rocks have microliticporphyritic and sometimes glomeroporphyritic texture (**Figure 4(e)**). The major mineral of pyroxene andesite rock include: plagioclase, amphibole, which andesites lack pyroxene mineral. Plagioclase mineral in these rock has sieve texture and zoning and burned margins (opacitic) can be seen in amphibole (**Figure 4(f)**), which hornblende can be observed only in some andesites.

In most investigated rocks, there are different types of xenoliths and xenocrysts (**Figure 5**). Xenoliths are composed of gabbro, diorite and sometimes basalt. This xenoliths

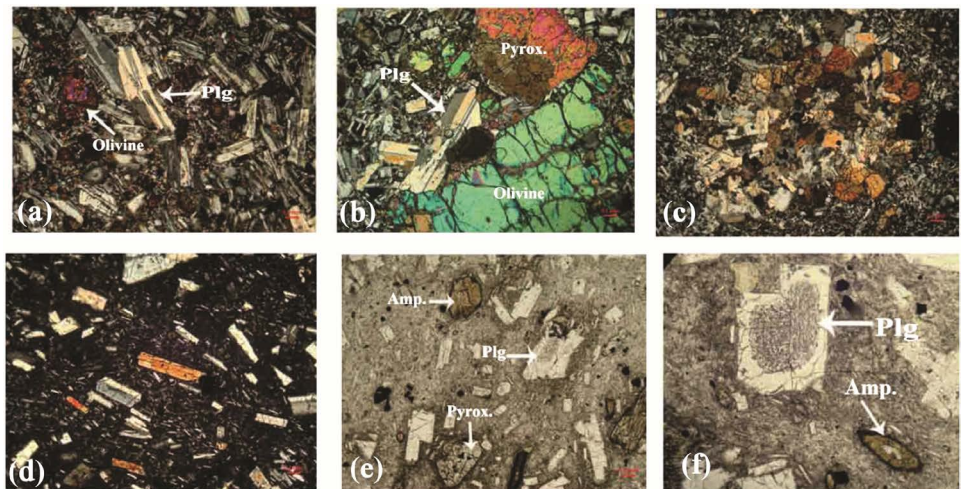


Figure 4. Microscopic images of rocks of the area with magnification $\times 40$. (a) An image of the iddingsite olivine in olivine basalt (XPL); (b) A view of the olivine basalts and zoning of the clinopyroxene mineral (XPL); (c) A view of the glomeroporphyritic texture in basaltic andesite (XPL); (d) A view of the basaltic andesite (XPL); (e) The presence of amphibole, pyroxene and plagioclase in the pyroxene andesite rock (PPL); (f) A view of the opacitized amphibole with burned edges and plagioclase with sieve texture in the andesite rock (PPL).

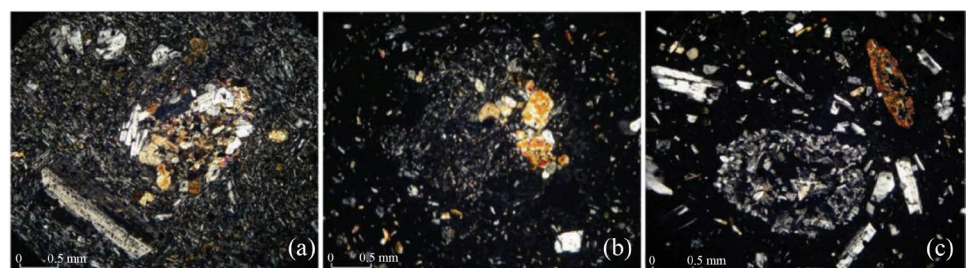


Figure 5. Xenoliths in volcanic rocks of the area. (a) Gabbroic xenoliths; (b) Dioritic xenoliths; (c) Basaltic xenoliths.

and xenocrysts are of petrographic evidence for magmatic contamination. SiO₂ content of the rocks in area is in a wide range of 45.3% to 68.1%. Seven samples have a silica content of 45% - 52%, which are considered as a part of the basic rocks in the region. Also, two samples have more than 63% silica which are part of acidic rocks, and the other rocks are in the range of intermediate rocks. In the logarithmic plot of Zr/TiO₂ vs. Nb/Y from [9], the samples show a trend of basalt, basaltic andesite and trachyandesite (**Figure 6**).

Reference [10], the contents of oxides SiO₂, MgO, CaO and Fe₂O₃ decrease and the contents of Na₂O, K₂O increase with increasing silica content (**Figure 7**). Also, along with increasing the trend of differentiation, namely decreasing MgO content, the ratio of CaO/Al₂O₃ regularly decreases (**Figure 8**). Olivine fractionation does not change the ratio of CaO/Al₂O₃ and only with the use of Mg in its structure, reduces the content of MgO in the remaining melt. But, on the other hand, CaO/Al₂O₃ ratio was low in plagioclase so that the content of this ratio in clinopyroxene is about tenfold of plagioclase, so the ratio of CaO/Al₂O₃ decreases with the clinopyroxene fractionation [11].

On the Al₂O₃/CaO vs. SiO₂ variation diagram (**Figure 9**), a linear positive correlation was observed between the samples and follows the vector of clinopyroxene fractionation [12]. On the other hand, along with decreasing MgO content, namely increasing differentiation, the content of Al₂O₃ remains constant that this indicates the lack of plagioclase fractionation (**Figure 10**). The major elements variation diagrams indicate olivine and clinopyroxene fractionation in the magma evolution trend of rocks in the area. In **Figure 11**, a linear positive correlation was observed between incompatible elements and interestingly passed through the coordinate origin. According to [2], constant remaining of the incompatible elements concentration is possible only as a result of fractional crystallization and from his view, this is a distinct feature found in many volcanic series of the intracontinental rift in eastern Africa. Of course, in her opinion, it should be cautious to interpret samples correlation and generated trends as the actual line of liquid descend, because these trends are also maintained in series which exposed to the

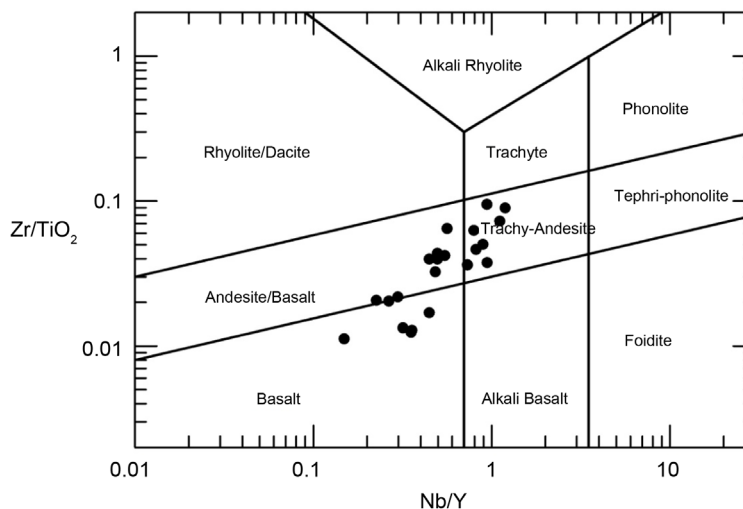


Figure 6. Position of the area rocks in logarithmic diagram Zr/TiO₂ vs. Nb/Y [9].

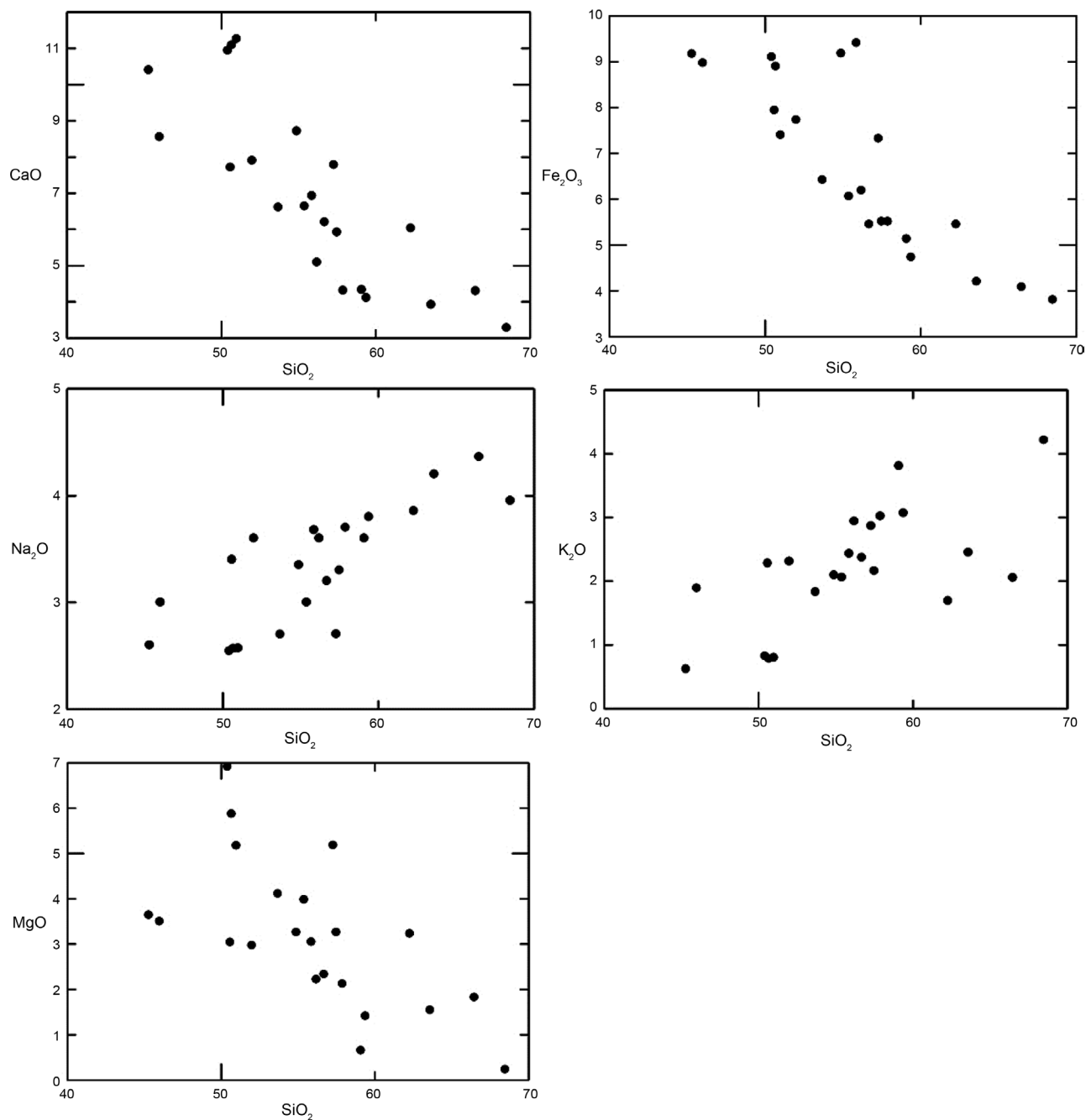


Figure 7. Variations of the main elements against the silica in the volcanic rocks of the area [10].

AFC process (assimilation with fractional crystallization).

5. Crustal Contamination

In petrogenesis studies of all within-plate continental provinces, it should pay attention that magmas during ascent how much interacted the continental crust rocks. Therefore, in the genesis of magmas in these regions, it should be always considered the role of crustal contamination [2]. The K₂O/P₂O₅ ratio in samples of the area is variable from

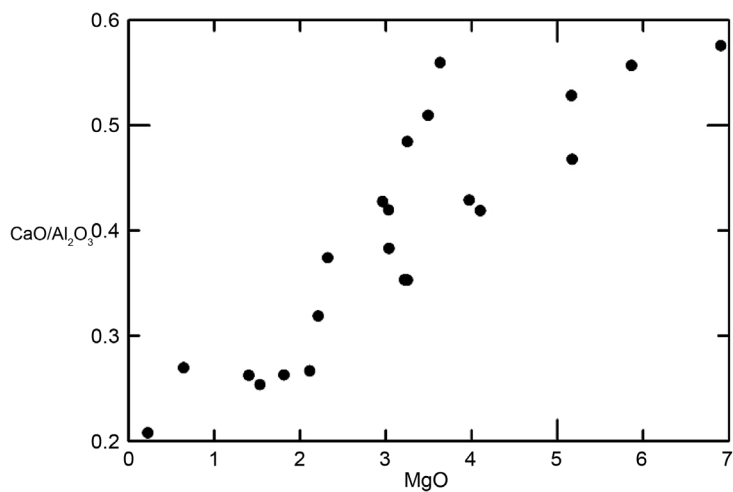


Figure 8. Variations diagram of CaO/Al₂O₃ vs. MgO in the volcanic rocks of the area.

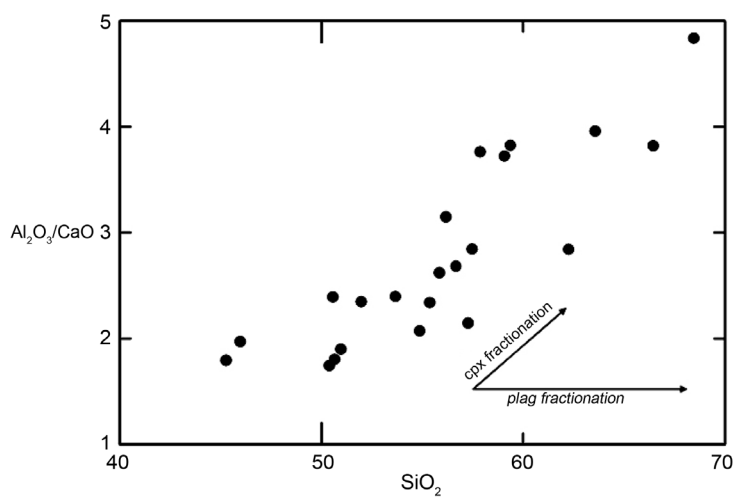


Figure 9. Variations diagram of Al₂O₃/CaO vs. SiO₂ in the volcanic rocks [12].

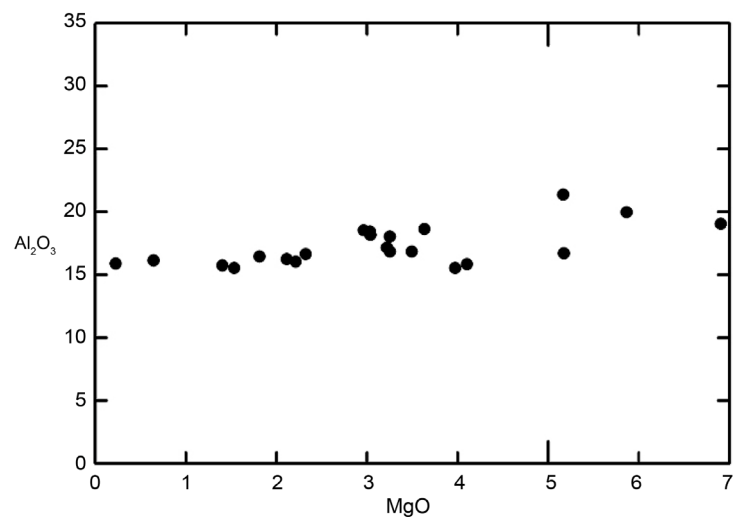


Figure 10. Variations diagram of Al₂O₃ vs. MgO in the volcanic rocks of the area.

3.87 in the most acidic samples to 24 in the most basic samples. Generally, the mantle-derived basalts have the ratio of $K_2O/P_2O_5 \leq 2$ [13]. Crustal assimilation or apatite fractionation results in increasing the mentioned ratio [13]. In **Figure 12**, positive correlation of K_2O/P_2O_5 against SiO_2 can be seen.

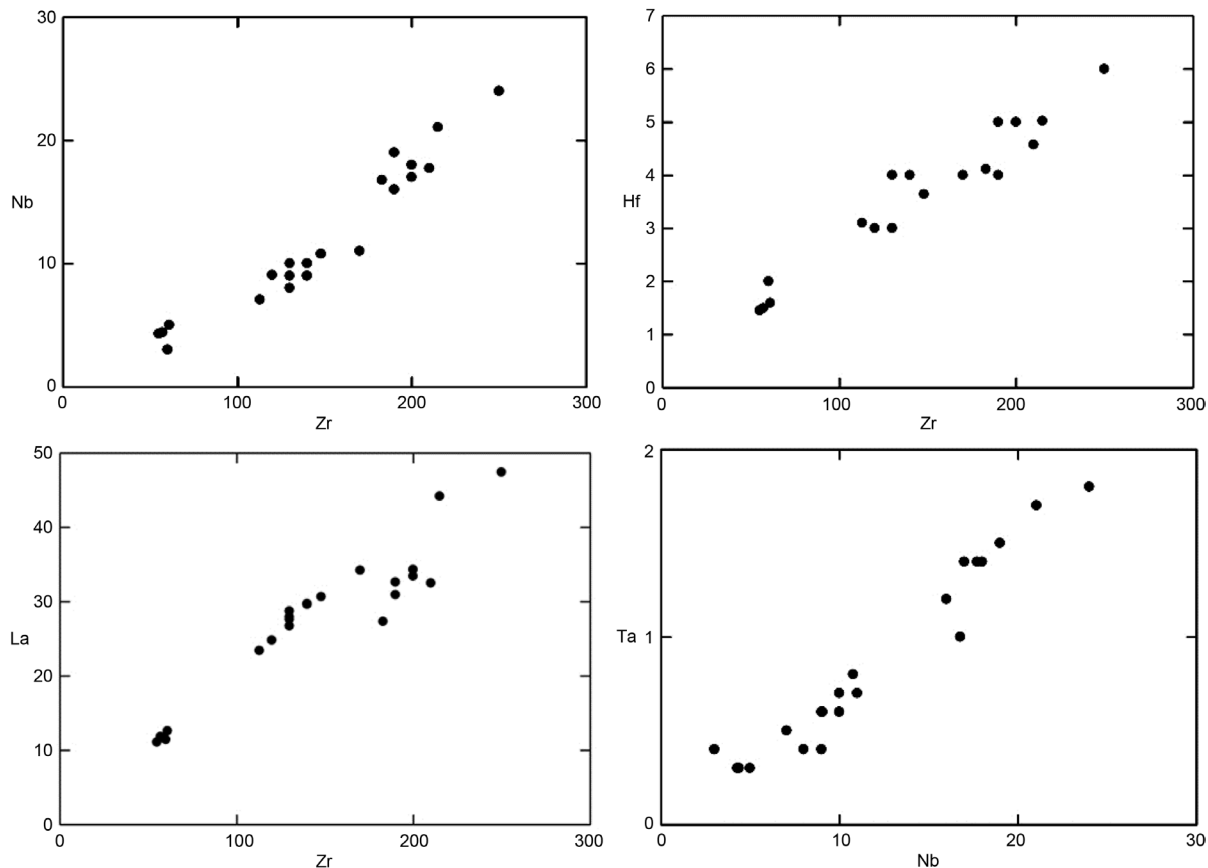


Figure 11. Variations diagram of incompatible trace elements in the volcanic rocks of the area.

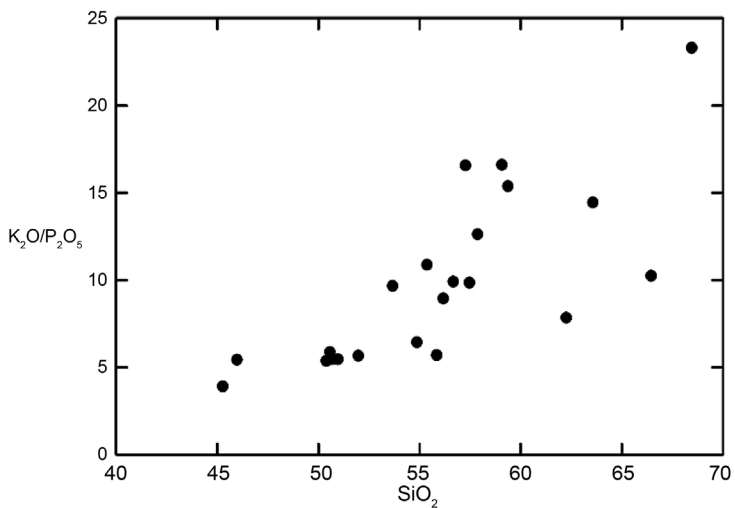


Figure 12. Variations diagram of K_2O/P_2O_5 vs. SiO_2 in the volcanic rocks.

According to [14], increasing the ratio of K/P along with increasing SiO_2 suggest crystal fractionation of mafic magma associated with silica crustal assimilation enriched in K. According to these researchers, this phenomenon has been hypothesized as the main factor of generating intermediate magmas in within-plate continental setting. The signature La/Sm is of sensitive crustal contamination indicators, too [15]. In **Figure 13**, there is a linear positive correlation between the ratios of La/Sm against $\text{K}_2\text{O}/\text{P}_2\text{O}_5$. The most basic sample has the lowest ratios of La/Sm and $\text{K}_2\text{O}/\text{P}_2\text{O}_5$ and the most acidic sample has the highest ratios of La/Sm and $\text{K}_2\text{O}/\text{P}_2\text{O}_5$.

6. Mantle Source

The ratios of incompatible elements in basaltic systems are used to distinguish mantle and crustal sources [3]. According to [16], the ratios of incompatible elements can act as the geochemical tracers in the source area. The binary diagram Y/Nb vs. Zr/Nb can be used to the effect of OIB plumes on MORB geochemistry [2]. In the Y/Nb vs. Zr/Nb diagram, the region's samples apparently place on the trend that is a melange of depleted MORB source and an enriched source (characteristic of Kenya rift or enriched source of OIB) (**Figure 14**). The most basic sample (N8) is close to MORB source and the samples exhibit a linear trend towards continental crust and OIB source.

According to [2], observation of this trend suggests being involved of MORB asthenospheric mantle source in petrogenesis of the rocks in the area. In the diagram of Rb/Y vs. Nb/Y from [17], the samples of the region from the basic to intermediate indicate the trend of a MORB source towards upper continental crust (**Figure 15**). Location of samples in the area is shown in the logarithmic plot of Nb/Y vs. Zr/Y (**Figure 16**). Generally, this diagram is almost insensitive to the effects of alteration processes, crystal fractionation and different degrees of partial melting [18]. According to [19], linear trends in the diagram at least purpose two different source regions in the petrogenesis of magmas. As observed, the most basic sample of the area (N8) has the lower ratios of Nb/Y and Zr/Y, which is of characteristics of depleted sources such as MORB

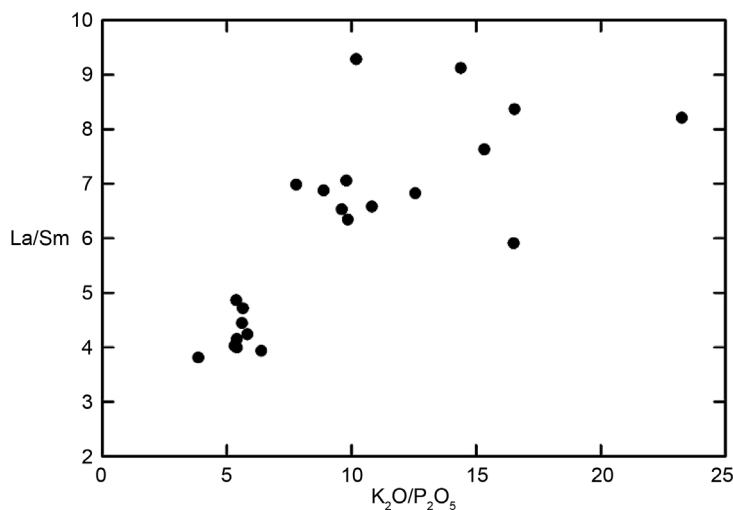


Figure 13. Variations diagram of La/Sm vs. $\text{K}_2\text{O}/\text{P}_2\text{O}_5$ of the area in the volcanic rocks of the area.

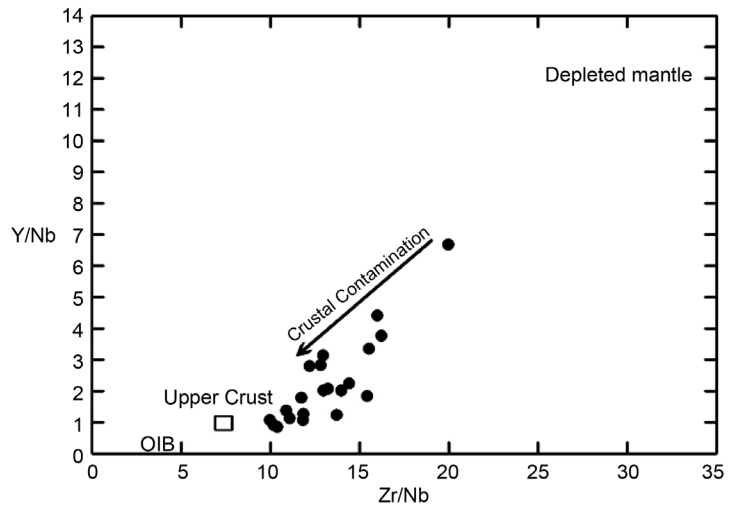


Figure 14. Position of the volcanic samples of the area in the binary plot of Y/Nb vs. Zr/Nb.

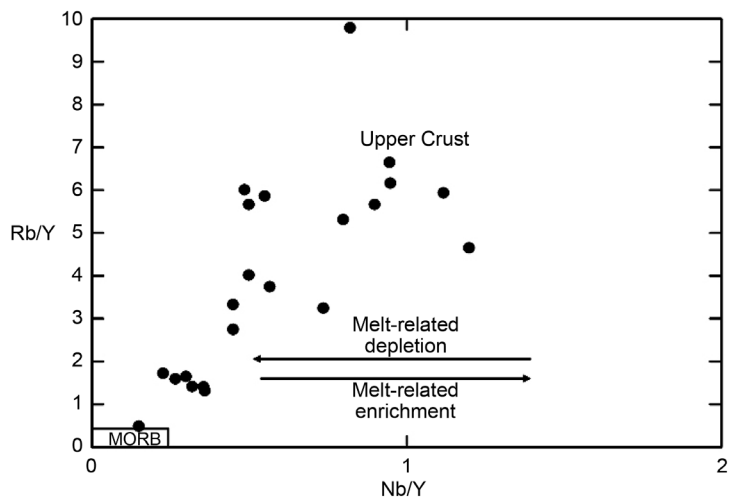


Figure 15. Position of the volcanic samples of the area binary plot of Rb/Y vs. Nb/Y [17].

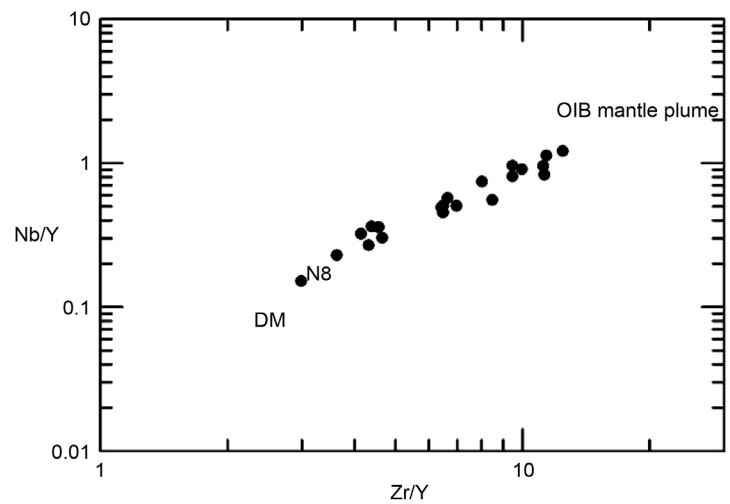


Figure 16. Position of the volcanic samples in the in the logarithmic plot of Nb/Y vs. Zr/Y [18].

source. Whereas samples gradually and linearly diverted towards the OIB mantle and exactly follow the continental crust trend. This purposes both MORB asthenospheric mantle source and continental crust involvement in the petrogenesis of volcanic rocks in the region.

7. Conclusion

Tertiary volcanic rocks of the study area in northern Iran, located at Alborz Mountains, represent compositional diversity between olivine basalt to andesite; based on geochemical evidence these rocks have been contaminated with the lower and upper continental crust. The presence of different xenoliths and xenocrysts in these rocks confirms this contamination. Investigations of the ratios of incompatible trace elements suggest that the basic samples of the region are close to MORB asthenospheric mantle source and the trends between primary and evolved samples indicate a linear arrangement between the MORB source mantle and the continental crust, representing an interaction of the MORB mantle-derived magmas with continental crust. In the $(\text{Tb}/\text{Yb})_N$ vs. $(\text{La}/\text{Sm})_N$ diagram, all samples fall in spinel mantle in horizontal trend with an almost constant ratio of 1.28 (Figure 17). The contents of $(\text{Tb}/\text{Yb}) < 1.8$ are characteristics of the mantle source with spinel facies [20]. In this diagram, the most basic sample (N8) is close to the MORB source and as shown in Figure 13, the ratio of La/Sm is strongly influenced by crustal contamination and the observed linear trend resulted from crustal contamination. In the La/Sm vs. Sm/Yb diagram (Figure 18), the contents of partial melting of a MORB source are shown [21]. As it would be considered, samples of the area indicate constant ratios of Sm/Yb so that the most basic sample has the least amount of La/Sm and is closer to the MORB source. Since basic samples of the area have also been contaminated with the lower crust, the primary samples before contamination possibly have lower ratios of La/Sm, and the vertical linear trend of samples shows about 15% melting of a MORB source. All geochemical evidence indicates that the volcanic rocks in the area were originated from the 15% melting of a MORB asthe-

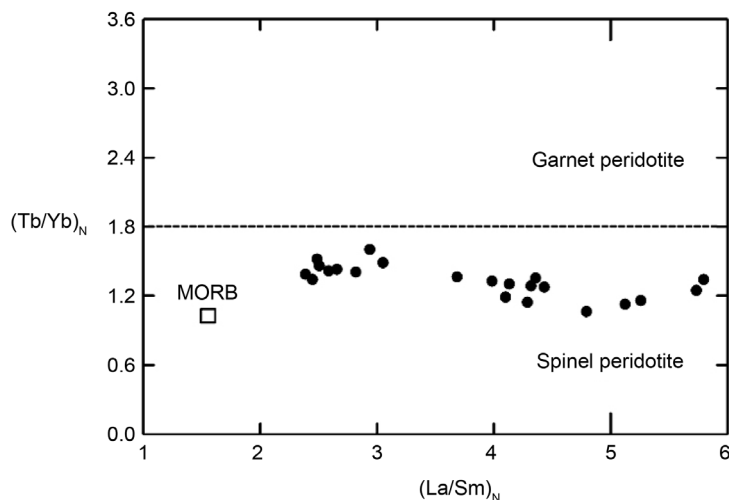


Figure 17. Position of the area's volcanic samples the diagram $(\text{Tb}/\text{Yb})_N$ vs. $(\text{La}/\text{Sm})_N$.

nosphere mantle source with spinel facies, which was contaminated with the continental crust rocks to some degree. The role of MORB asthenospheric mantle is hypothesized in petrogenesis of both the mid-oceanic-ridge basalts and intra-continental rift basalts and continental flood basalts [2]. In the logarithmic plot of K_2O/Yb vs. Ta/Yb from [22], the within-array mantle samples show a trend from the mantle MORB source to the mantle enriched within-plate (Figure 19). On the Ba/La vs. La/Sm diagram of [23], location of volcanic samples in the area is shown (Figure 20). According to [23], the ratio of Ba/La strongly depends on released fluids from the subducted slab while the La/Sm ratio is affected by the crustal contamination. As observed in the diagram, the

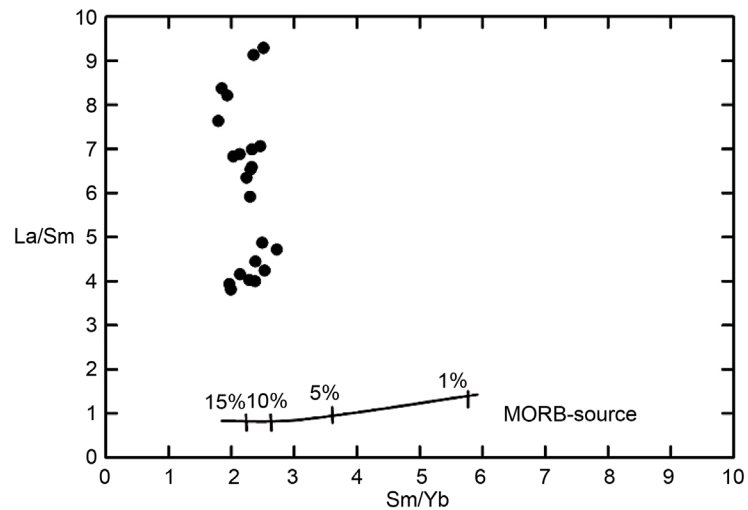


Figure 18. Position of the area’s volcanic samples on the diagram La/Sm vs. Sm/Yb [21].

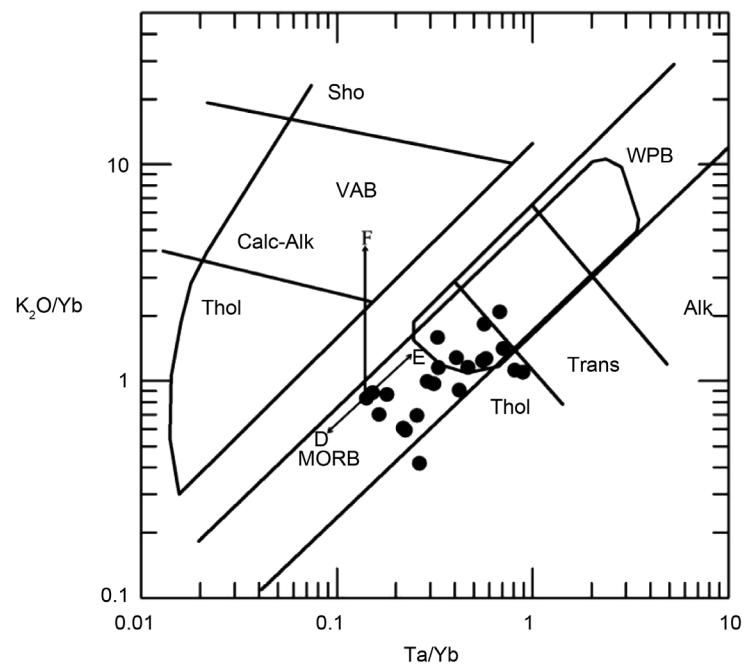


Figure 19. Position of area’s rocks in the logarithmic plot of K_2O/Yb vs. Ta/Yb [22].

samples of Nash region have the low and almost constant ratios of Ba/La, and show horizontal trend from the MORB source in the direction of crustal contamination vector. On the logarithmic diagram Th/Hf vs. Ta/Hf of [24], all the samples have fallen in the range of IV, namely the continental within-plate basalts and IV₃ district, namely the continental extensional belts or initial rift (Figure 21). Based on the evidence of magma contamination with the continental crust, which was described in previous discussions, the association of the rocks in area with the MORB-type basalts is negative and they are possibly related to the continental within-plate environment. According to [2], the as-

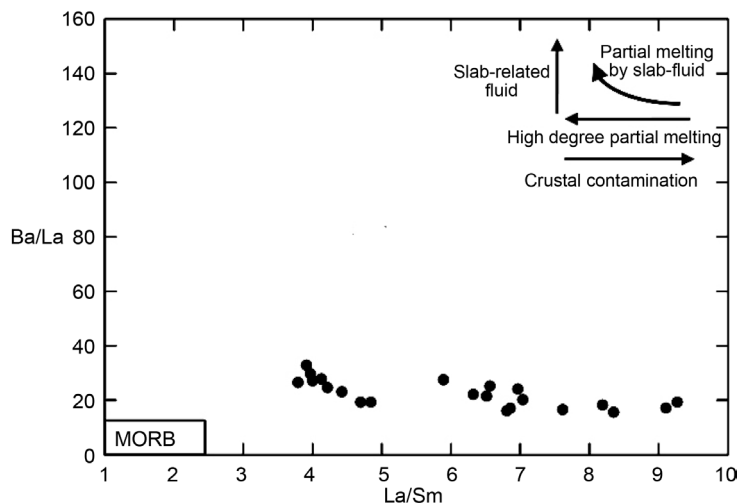


Figure 20. Position of area's rocks in the plot of Ba/La vs. La/Sm [23].

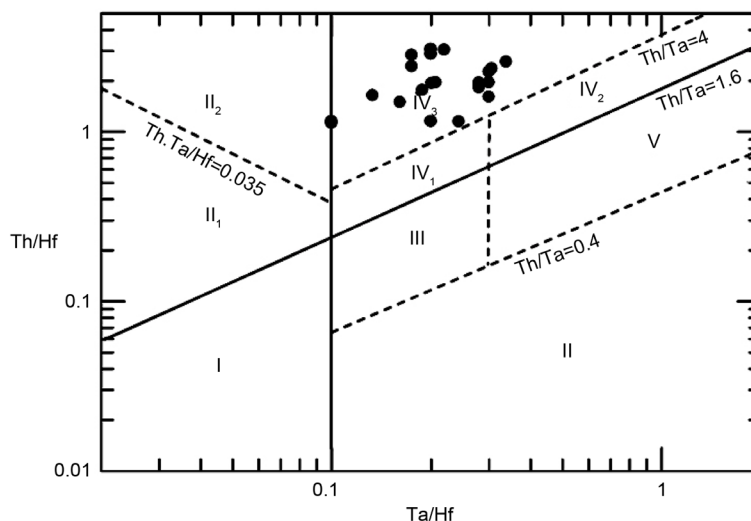


Figure 21. Logarithmic plot of Th/Hf vs. Ta/Hf adapted from [24] defined as following in the areas, I: MORB region type N in the divergent plates margin II: basalts of the convergent plates margins areas II₁: basalts of the oceanic island arc areas II₂: Basalts of the continental-margin arc volcanic regions and the continental-margin arc islands III: E-type MORB regions and basalts of the within-plate oceanic islands IV: basalts of the continental within-plate [IV₁: the intra-continental rifts and the continental margin toleites rifts IV₂: alkali basalts of the intra-continental rift regions IV₃: basalts of the continental extensional belts or initial rift] V: basalts of the mantle plumes areas.

thenospheric mantle MORB source plays an important role in the petrogenesis of intra-continental rifts, indicating the most active extension, and this could be seen in volcanic rocks of the Afar rift in Ethiopia, the Rio Grande in New Mexico, America and the Basin and Range province in the West America. We believe that volcanic rocks in the area were generated by 15% melting of an asthenospheric mantle MORB source with spinel facies within continental rift environment that was contaminated with continental crust rocks to some degree and underwent the AFC process.

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