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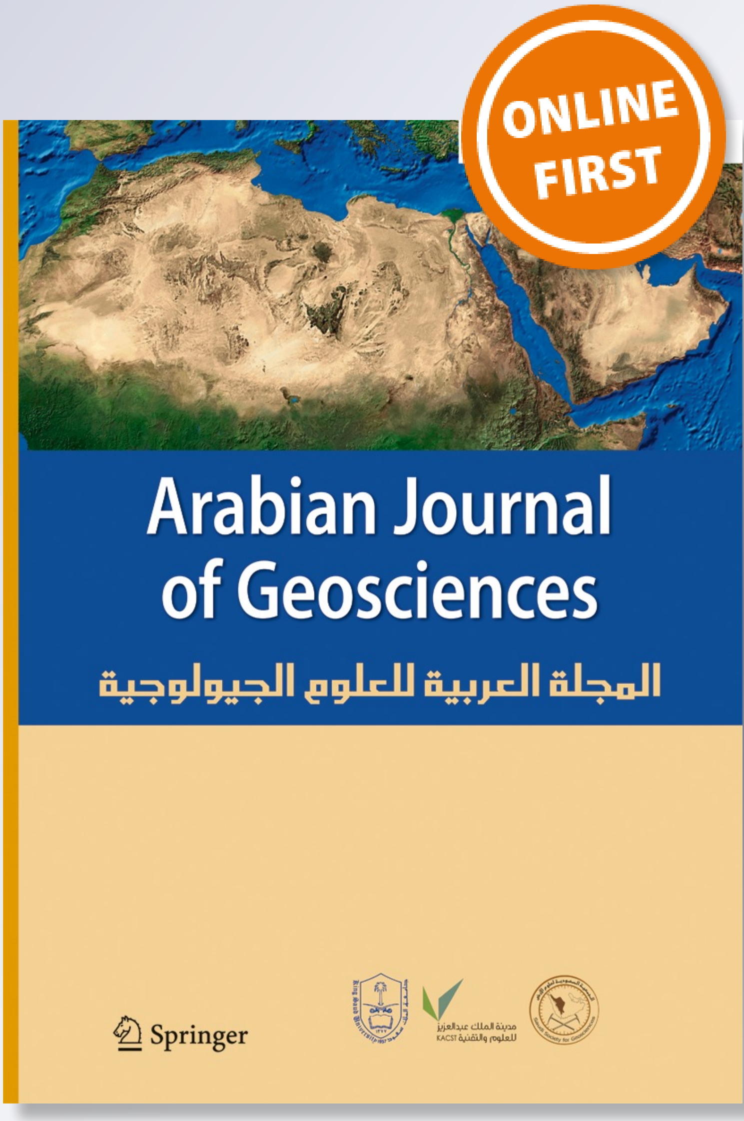

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ORIGINAL PAPER

An investigation on the Eocene Pushtasar basaltic lava in relation to Moghan Aulacogene

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Abstract
The present paper represents a petrological and geochemistrical study of Pushtasar basaltic lava in the Moghan region. This basaltic unit with interbeds of Tuff and Breccia tuff divides Upper Eocene sediments into two parts as an east-west band, the thickness of which thins from 1,300 m in the east to a few meters in the west. Therefore, petrography studies and geochemical studies were conducted on the gained samples along different parts of the rim. According to this study, the basic unit which distributes the Upper Eocene sediments into two parts is a transitional magma series with internal plate basalt geodynamic origin. Based on the previous studies, which are mainly focused on providing geological maps and oil prospecting, it seems that there was a descent in tension condition at the end of Eocene and first part of Oligocene after the compression phase in the Upper Cretacea. Probably, this tension condition made a suitable environment for the subsidence of sediments, making hydrocarbon reserves, as the processes have been done in the continental rift or Aulacogene.

Keywords Pushtasar basaltic · Aulacogene · Moghan region · Upper Eocene sediments · Tuff and Breccia tuff · Ojagh Geshlagh and Ziveh Formations

Introduction

The Moghan region can be divided morphologically to (a) the southern mountainous region which extends from the Northern Sabalan Mountain to the Koroslou Dagh ridge and (b) the northern plain. The topography of the region mainly shows east-west trends due to the geological structure of this region. Rivers generally flow from south to north originating from the Sabalan Mountain. Moghan is an agricultural site. The climate of the mountainous region is nearly cold with a heavy snow fall in winter, making spring or autumn the most suitable time for field study (Rahimzadeh 1987).

The studied region is in the Ardabil province in the northwest of Iran. It is in the border of the Depression Kura-Arax with the uplift of Ahar-Meshkinshahr. The strata units of this region are some detrital sediments with some marl and calcic cross layers. The drilling studies illustrated that the Eocene and Cretacea rocks have the role of the high dip basement in the Moghan region; probably a high dip basement due to its fractures. This basic unit is a rim from the east to the west which distributes the Upper Eocene sediments into two parts (Farzin 1999).

During the 1950s, the Iranian Oil Company investigated in this area. Afterwards, and during the 1960s, in a common project, the French I.F.P and the National Iranian Oil Company performed a geophysical investigation (49 geophysical reports); based on this survey,

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Fig. 1 A view of the Pushtasar basalt along the Ardabil-Germi Road

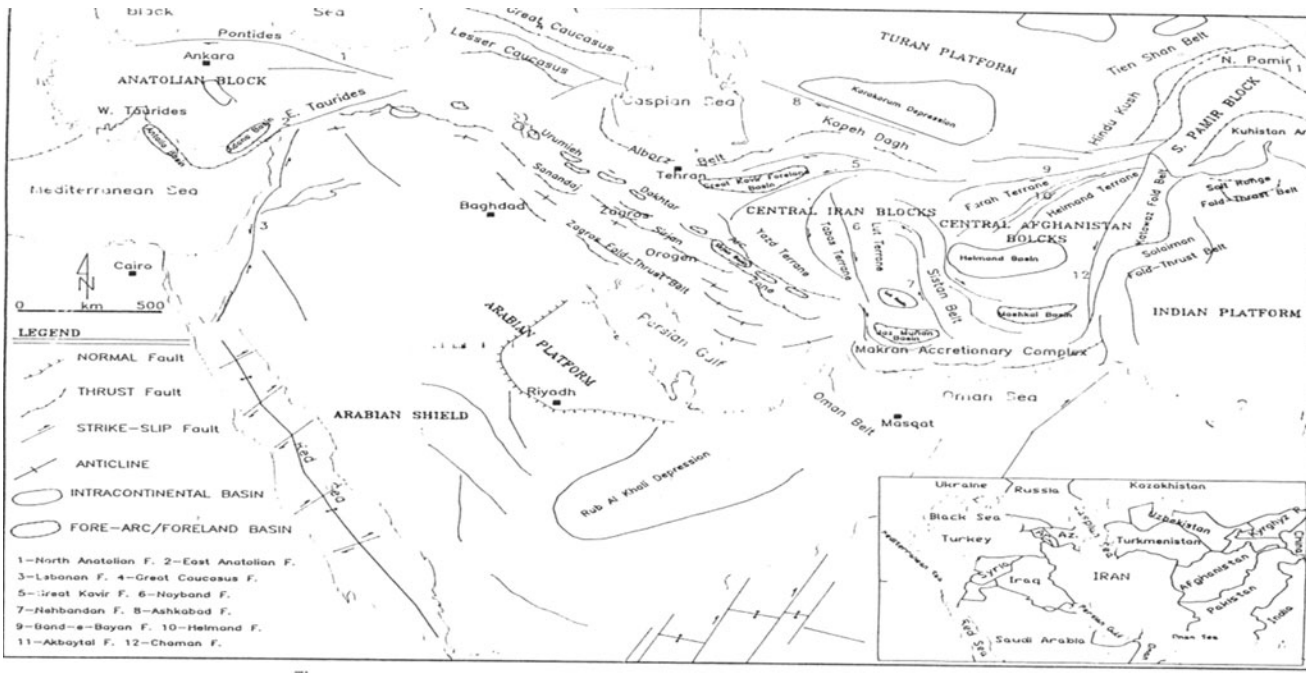

Fig. 2 The tectonic elements of Middle East

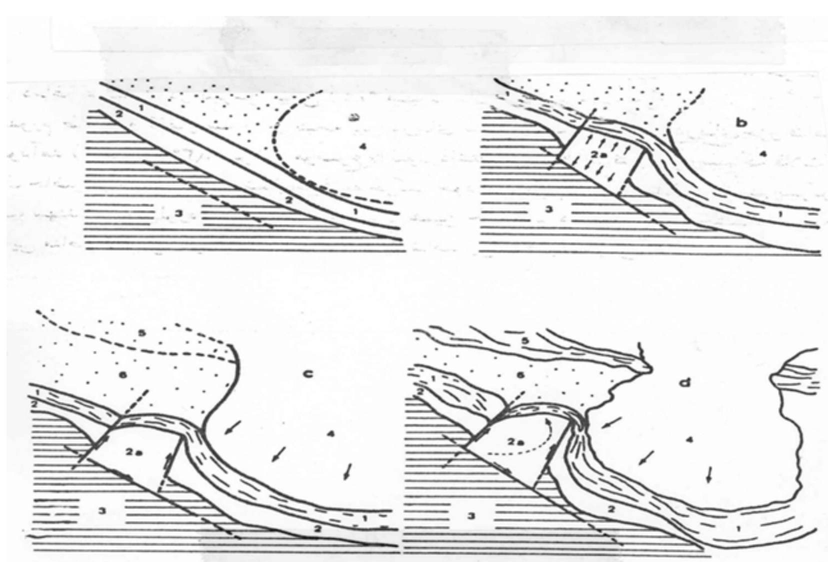

Fig. 3 A presumption of evolution Azerbaijan plateau in relation to other geological neighbor

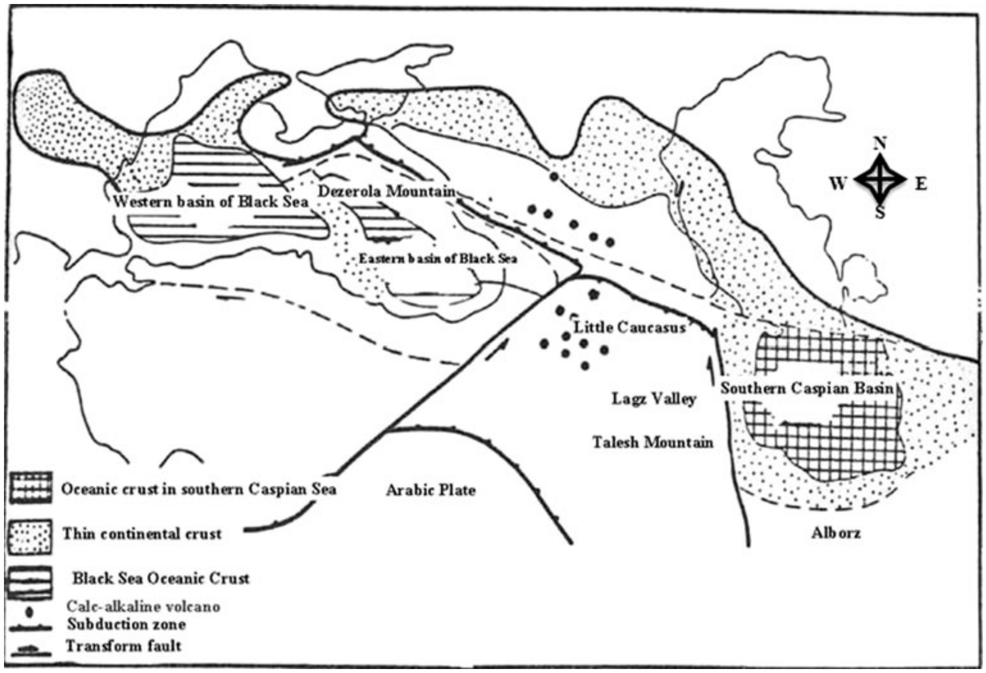

Fig. 4 A view of Para Tethys, Azerbaijan geological condition at 3.5 Ma ago (Middle Pliocene)

the first exploration well was dragged at Ortadagh anticline in 1966. Along a subsequent study conducted in 1972 and Farzaneh Farzin's MSc. thesis (1999), it has been clarified that Ojagh Geshlagh Formation with the age of Upper Eocene and Ziveh sand stone both show properties of source rock, and Pushtasar basaltic unit probably has the role of basement. The Moghan region was studied more to provide geological maps and oil prospects. So, this magmatic unit which is located in the southern mountainous part of the Moghan region was subject to the first studies. Figure 1 presents a view to the basic unit of this study.

Most likely, there was a descent in tension condition at the end of Eocene and in the beginning of the Oligocene following the compression phase in Upper Cretacea (Chakdel 1979). Probably, this tension condition made a suitable environment for the subsidence of sediments, making hydrocarbon reserves, as the processes have been done in the continental rift or Aulacogene.

Geological and tectonic conditions

This region is in the northwest of Iran. It is located within the Ardabil province with the latitude of 38°50′–39°40′ and longitude of 47°10′–48°10′. It is located in the border of the Depression Kura-Arax with the uplift of Ahar-Meshkinshahr. Also, it is located between the eastern boundary of little Caucasus and Talesh Mountains with east-west structure trends (Rouhbakhsh 2002), so it is different from little Caucasus and Talesh Mountain with NW-SE structure trends (Fig. 2).

This region was considered a part of West Alborz by Stocklin and Rotner, but Eftekhar Nezhad considered it as a part of southern Caspian depression in 1980.[1] During Upper Cretacea, the Cretacea deposits and relevant volcanic rocks folded due to water beat at Laramide phase and Qara Dagh Mountain. It seems that the Eocene or Cretacea rocks with steep dip[2] make up the basement of the region because of their low exposure on southern parts of the Moghan region and non-exposure on northern parts. The depositing Neogene layers on Cretacea rocks were confirmed by oil drilling. A tension phase was established as the Upper Cretacea pressure phase followed. It resulted in enormous volcanic movements in Eocene, probably due to a hot dome below Azerbaijan. This tension caused a continental rift with alkali volcanic rocks. However, by contrast to the Red sea rift, this rift could not survive and was closed by a pressure phase (Figs. 3 and 4).

It seems there had been a convergence between Caspian and Iran plateaus during Oligo-Miocene after a tension condition in Eocene.[3] The geological condition of the region during a—Cretacea, b—Eocene (opening and tension), c—Oligo-Miocene, and d—Plio-Quaternary is shown in Fig. 3. Moreover, in this figure,

[1] Some geologists believe Moghan basin is the southern part of Kura-Caspian.
[2] This steep dip is probably caused by breaking.
[3] It caused a rotation during Plio-Quaternary.

Table 1 The chronological condition of formations in the Moghan region

Quaternary	Recent sediments, older alluvial and fan deposits, clayey sandy conglomeratic sediments, Baku Formation (silt, clay, marl, and tuff intercalations), Apsheron Formation (thick beds of gravels with sand silt and tuff layers)
Upper Pleistocene	Aghchaghilian Formation (conglomerate, silt, sandstone and volcanic ash that lie on the sediments of Upper Miocene (Sarmatian Formation))
Tortonian and Sarmatian[a]	Detrital, calcic, and dolomitic sediments
Oligocene	Ziveh Formation (gray colloidal sediments and arkoses)
Eocene	Ojagh Geshlagh Formation[b], Pushtasar Basaltic lava flow, Salm Aghaji Formation[c], Shekarlu Formation, Gara Aghash Formation (alternation of tuffaceous sandstone and silica shale with volcanic interbred)
Paleocene	Qarasu Formation (marl with volcanic breccias)
Cretacea	Calcic and detrital sediments (a conglomerate with calcic grains is located over previous metamorphic rocks in the west of the region)
Pre-Cretacea[d]	Metamorphic rocks

[a] Alternation of clay, silt, and sandstone with interbeds of limestone can be divided into brown and red parts in below and up parts, respectively. It is difficult to distinguish them from each other, so a huge number of geologists call them as Tortonian and Sarmation formations

[b] This formation lies on the Pushtasar basic unit with a basal conglomerate and sandstone which contained volcanic fragments. It contained tuffaceous sandstone, sandy tuff, marl, and shale. This unit is growing to change from sandy in the lower part to marly in the in upper part

[c] It contained marl, clay, tuffaceous sandstone, and thin interbeds of limestone. It laid on Shekarlu Formation with a basal conglomerate and sandstone. The thickness of this sandstone unit is increasing from the west toward the east. Basic Pushtasar unit is located on it

[d] The oldest rocks of this region are mica schist, amphibolite, and gneiss—they are exposure due faulting

1—Alborz-Middel Arax Complex, 2—volcanic belt, 2a—Azerbaijan plateau, 3—the plateau of West Iran, 4—Caspian zone, 5—Cuacause, and 6—Kura have been defined.

Fig. 5 Basaltic lava and shale unit (Upper Eocene) in Mamashlu village with an eastern view

Probably, about 3.5 Ma ago (Middle Pliocene), the Great Caucasus basin closed completely due to the gradual approximation of the Arabic plate to Eurasia. Also, the Caspian-Black sea basins parted due to the movement of the Arabic plate toward North and the Caucasus Mountain formed along the contact border of the Arabic-Eurasia plates. The Talesh fault acted as a transform fault (Aghhanabati 2004).

According to studies, Moghan region was a calm region during Eocene-Miocene, and very little epirogenic movements have been observable. In fact, there are some unconformities inside the sediments of this time; for instance, the basal conglomerate of Salm Aghaji Formation which was deposited on Shekarlu Formation or the basal conglomerate of Ziveh Formation deposited on Ojagh Geshlagh Formation are some evidences to the fact. Afterwards, Attic Orogenic phase caused a hiatus from the last of Upper Miocene until Low Pliocene. The unconformity between Aghchaghilian Formation (Upper Pliocene) with older Upper Miocene

Fig. 6 A cross view from Chenagh village, the trend of basalt-megaporphyritic andesite basalt through sandy

Fig. 7 A view of the basalt unit along Salm Aghaji road with a shale unit over it and lower unit which is lies on it

Fig. 8 The exposure of the pillow lava structure of Pushtasar basaltic unit along Ardebil-Germi Road

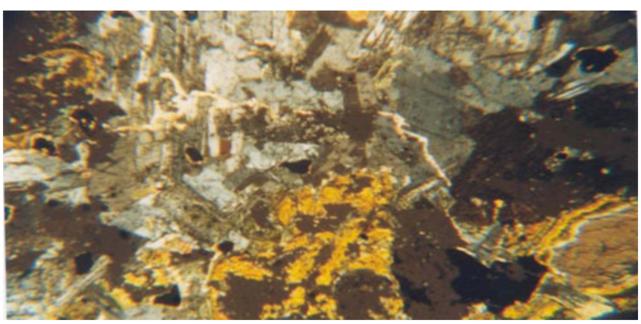

Fig. 9 Olivine gabbro 50 times enlarged

sediments was also due to this fact; therefore, the whole of strata between Eocene-Miocene folded during the Attic phase. The region was semi-calm at Upper Pliocene where the Passadenian Orogenic phase was the most significant tectonic occurrence, causing tectonic structures like Aslandoze and Ajishma anticlines or Qarasu fault. The majority of faults in this region are reverse-type faults, but Qarasu is a normal fault which caused a vertical displacement between the height of eastern and western coast of Qarasu River (Rafiei 2000; Moghadam 2000; Badialzamani 1968). In Table 1, a brief strata illustration of this region has been presented.

Fig. 10 Basalt 50 times enlarged (*purple* around pyroxenes can be interpreted as existing titanium in pyroxenes)

Fig. 11 Hylaoporphyry texture with hyaline and fine grain background 50 times larger

Fig. 12 Influencing gabbro unit through basalt-megaporphyritic andesite basalt in the Ghaffarkandy area

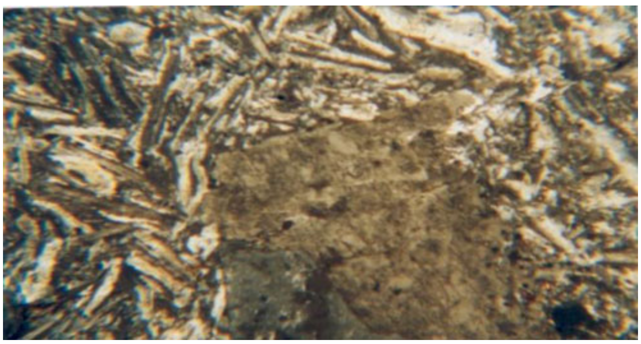

Fig. 13 Altered plagioclase in microlitique background 50 times larger

Pushtasar basaltic lava flow

The name of this basaltic unit is adopted from Pushtasar village in the Republic of Azerbaijan. This basaltic unit with interbeds of tuff and breccia tuff indicated on the geological Moghan map (1/250,000) as EB3, is a key layer to distinguish Salam Aghaji Formation from Ojagh Geshlag Formation. In fact, it divides Upper Eocene sediments into two parts as an east-west band. It is due to an enormous eruption at Upper Eocene, the thickness of which thins from 1,300 m in the east to a few meters in the west (see Figs. 5, 6, and 7).

Fig. 14 The flowing lava location in the North of Salm Aghaji village

Fig. 15 Zonation in plagioclase due to magma pollution or changing physical-chemical conditions of magma, 100 times enlarged

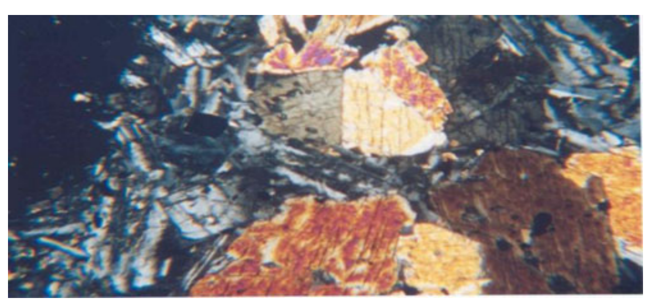

Fig. 16 The existence of amphibole around pyroxene is probably due to the increasing of potassium and oxygen fugacity from crustal pollution, 100 times enlarged

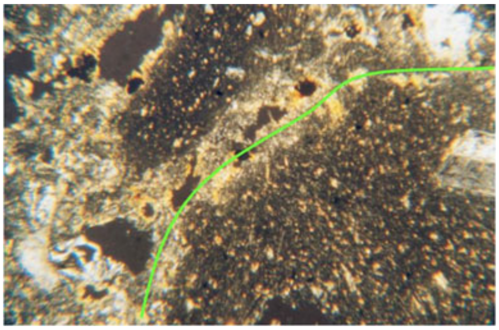

Fig. 17 Magmatic mixture in crystal lithic vitric tuff, 50 times enlarged

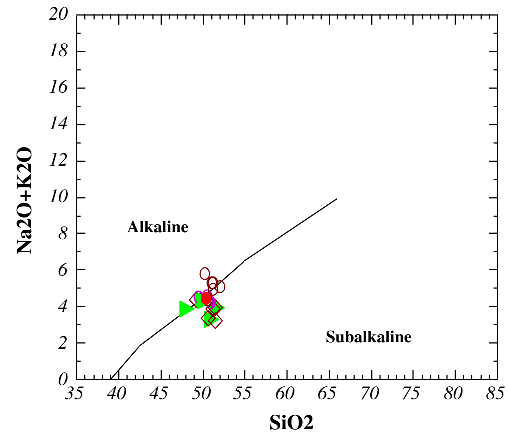

Fig. 20 Irvine and Baragar diagram (1971)

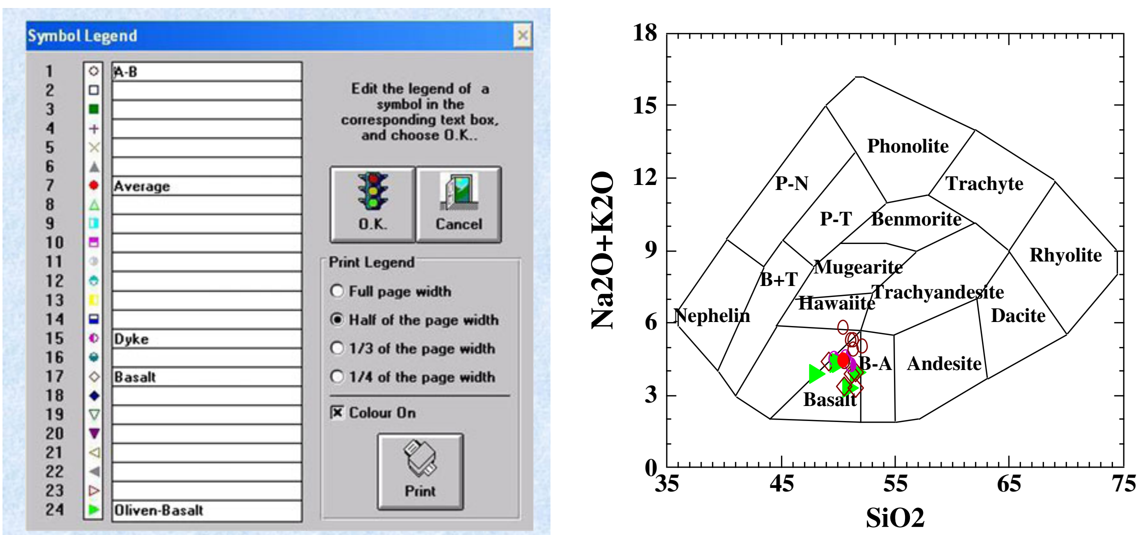

Fig. 18 The Cox et al. chart (1979)

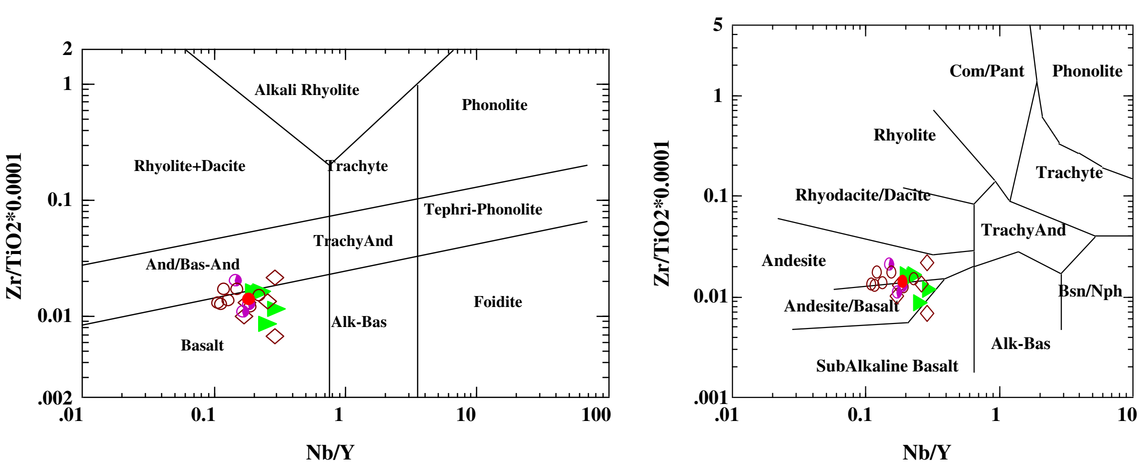

Fig. 19 The Winchester and Floyed chart (1977)

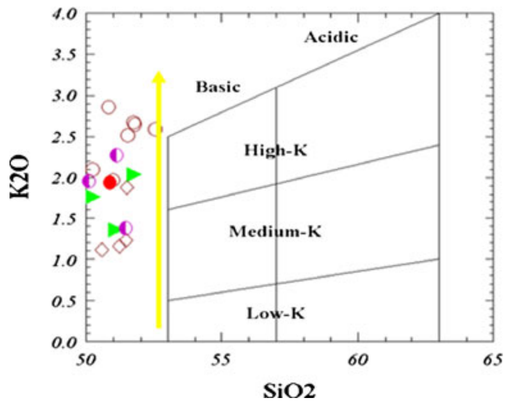

Fig. 21 Gill diagram (1981)

Probably, the center of the eruption was somewhere in the Talesh Mountains within the Republic of Azerbaijan. The main out crop of this lava in Iran is observable in Germi city.

Petrology of Pushtasar basaltic unit

The specification of igneous rocks resulted in their present chemical components. So, petrology is a suitable procedure in illustrating some of the past geological occurrences. Therefore, petrography studies are decent study procedure in geological studies (Middlemost 1987). Because some igneous rocks of this region have been fine grained or even cryptocrystallinized, besides petrography study, 20 rock samples were nominated by Winchester and Floyd in 1977 and Cox et al. (graphs) in 1979 based on the gained results through X.R.F analysis (Rollinson 1992).

According to studies, it seems that basaltic fluid initially had flowed, but it was gradually contaminated as more remained inside the crust. Therefore, the type of rocks has turned from the olivine basalt and basalt from east to basaltic andesite or even pyroclastic rocks in the west as thickness reduces. Moreover, it seems the eruption mainly occurred through the water due to existing pillow lava structures in diverse parts (see Fig. 8).

The eastern samples like those gained in the Tolone section (near the political border of Iran with the Republic of Azerbaijan, south of Germi city) are olivine gabbros with intergranular texture or basalt (see Figs. 9, 10, and 11).

Moreover, sub volcanic rocks[4] were found at this study site. For example, there is a semi-deep dike in the south of the Mazraea village which originated from a local olivine gabbro (see Figs. 12 and 13).

Additionally, while reducing thickness of this rim toward the west, the magma got more silica due to crustal pollution. So from the Ajirlou (Ali kandi) village, an andesitic basalt unit can be observed (see Figs. 14, 15, and 16).

Some pyroclastic samples are gained from the west side of the rim near the Abesh Ahmad village (see Fig. 17). Finally, besides petrography studies, 20 rock samples were nominated by Winchester and Floyd in 1977 and Cox et al. in 1979 (graphs) based on the gained results through X.R.F analysis (Rollinson 1992). Based on the chemical classification of igneous rocks, Winchester and Floyd in 1977 or Cox et al. in 1979 (graphs) (Rollinson 1992), the samples are mainly located within basalt boundary but some of them are found within basaltic andesite which may have happened due to costal pollution or partial crystallization (see Figs. 18 and 19).

Geochemistry of Pushtasar basaltic unit

Generally speaking, according to the gained geochemical studies on the 21 volcanic samples gained along the different parts of this rim, the following items resulted in:

1. A transitional magma series can be referred to these samples according to the Irvine and Baragar diagram in 1971 (Rollinson 1992) (see Fig. 20)
2. According to the Gill diagram in 1981 (Rollinson 1992), these plotted samples are not within the orogenic andesite basis constant SiO2 value (see Fig. 21), the variation of K2O value is probably due to crustal pollution.
3. According to the normalized spider diagram (N-MORB),[5] an LREE[6] enrichment can take place due to the low magmatic anatexis of source rocks, so some minerals such as garnet which contain HREE[7] elements remain in mantle (Rollinson 1992) (see Fig. 22); moreover, according to a normalized spider diagram of the upper crust, a depletion of LILE[8] elements (like K, Rb, and Ba) or some HFS[9] elements (like Nb, Ta, and Zr) are due to crustal pollution and separation minerals with Ti, Nb, and Ta compounds (see Fig. 22).
4. According to the Pearce and Norry tectonic magmatic diagram in 1979 (Rollinson 1992), these samples are mainly plotted within plate basalt area (see Fig. 23).

Conclusion

The strata units of this region are detrital sediments with some marl and calcic cross layers. This basaltic unit with interbeds

[4] These fine igneous rocks crystallized in upper crust as dike or sill structures.

[5] Middle ocean ridge basalt.
[6] Light rare earth elements.
[7] Heavy rare earth elements.
[8] Rare elements (lithophile elements).
[9] Rare elements with ionic potential upper than 2.

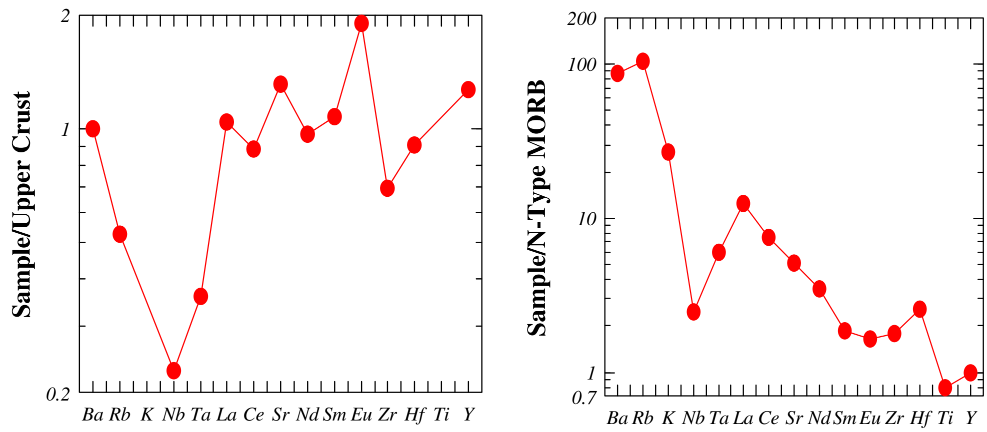

Fig. 22 The spider diagrams of samples to N-type MORB and to upper crust

of tuff and breccia tuff divides the Upper Eocene sediments into two parts as an east-west band, the thickness of which thins from 1,300 m eastward to a few meters westward, and the type of rocks turned from olivine basalt and basalt to basaltic andesite or even pyroclastic rocks as we move on westward and as the thickness reduces. Additionally, based on geochemical studies, it is a transitional magma series within plate basalt geodynamic origin. Therefore, it seems that it should be due to an enormous eruption at the Upper Eocene which mainly occurred through water, and this basaltic fluid gradually was contaminated to a level that remained inside the crust. Probably, the center of eruption was somewhere in the Talesh Mountains within the Republic of Azerbaijan. In fact, this basic study unit is a key layer to distinguish the Salam Aghaji Formation from the Ojagh Geshlag Formation. According to previous studies, which are mainly focused on providing geological maps and oil prospecting, it seems that the Ojagh Geshlagh Formation with the age of Upper Eocene and Ziveh sand stone show the property of source rock, and the Pushtasar basaltic unit probably has the role of basement. The drilling studies illustrate that the Eocene and Cretacea rocks have the role of a high dip basement in the Moghan region, and this basement is probably high dip due to fractures. Most likely, there was a descent tension condition at the end of the Eocene period and the beginning of the Oligocene after the compression phase in Upper Cretacea. Probably, this tension condition made a suitable environment for subsidence of sediments, making hydrocarbon reserves, as the processes have been taking place in the continental rift or Aulacogene.

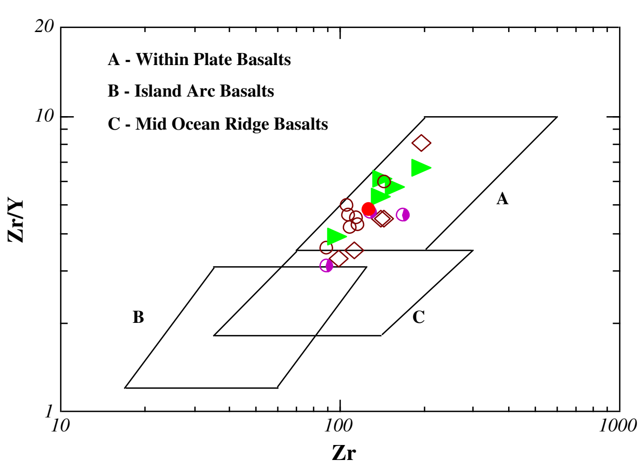

Fig. 23 Pearce and Norry tectonic magmatic diagram (1979)

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