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The Geochemistry of Pliocene Volcanism in the Shahba region, South of Syria

جيو كيمياء البركنة البليوسينية العائدة لمنطقة شهبا، جنوب سوريا

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Abstract

Pliocene volcanic rocks are considered as dominant rocks and form an important part of igneous succession in this region. The architecture type of Pliocene basalt is various as it consists of several diverse lithological formations, which vary from continuous basalts flow to scoria materials. The Pliocene basaltic rocks consist of several lava flows, which are divided into three primary petrographic groups: alkali basalt, augite alkali basalt and the basanite. The three petro-types can be classified geochemically from alkaline to sub-alkaline and termed as alkali olivine basalt. They have similar compositional ranges of major and trace elements. The geochemical composition shows that the basaltic Pliocene rocks consist of both partial melting and crystal fractions signatures. So the geochemical changing components can be considered as a result of crystal fractions that developed after partial melting process.

Keywords: Shahba, Pliocene, basalt, crystal fractions.

ملخّص

تتكشف تشكيلات البليوسين النارية على مساحات واسعة من جنوب سوريا، وهي تشكل جزء هام من التتابع الناري في المنطقة.تتكون التوضعات البركانية البليوسينية في منطقة شهبا من تشكيلات ليتولوجية مختلفة، تتراوح بين صبات بازلتية دفقية مستمرة الى توضعات خبثية متماسكة سميكة أحياناً تتضمن توضعات بيروكلاستية متنوعة. يُبنى التتابع البليوسيني الناري في منطقة شهبا من عدد متغير من الصبات البازلتية، المكونة بتروغرافيا من ثلاث مجموعات رئيسية هي: البازلت القلوي والبازلت الاوجيتي القلوي والبازانيت. يُظهر التركيب الجيوكيميائي للصخور البليوسينية، أن الصخور البازلتية المدروسة تبدي تغيرات على المحتوى التركيبي، يمكن اعتبارها أنها ناتجة عن عملية تجزؤ بلوري كان قد تطور عن عملية انصهار جزئي.

الكلمات المفتاحية: شهباء، بليوسين، بازلت، تجزؤ بلوري.

Introduction

Although the Shahba city is built on the Pleistocene basaltic formations, the studied basalts belong to Pliocene time. These basalts are covering the land which extend to the east and east western of this city (Fig 1a).

Shahba igneous formations belong to the Al Arab mountain in southern Syria, which is located at the northern part of Harrat Ash sham (Fig 1b) , one of about 20 Cenozoic volcanic field in the western Arabian peninsula.

The basalts of southern Syria are represented by three separate volcanic complexes: Miocene, Pliocene and Quaternary (Ponicarov, & *et al.* 1966). The volcanic activity during the Pliocene time in the Shahba and other areas in southern Syria started by a wide spread fissures volcanism (Sharkov, & *et al.* 1994) exposure from N-S extensional faults (Bilal & sheleh, 2004). In this stage a large basaltic plate had formed and expanded on a several hundred kilometers square. The flows –including Shaba area- extend to the Alhara desert in the west and to Yarmouk valley in the south. Later the Pliocene volcanism developed and turned to a central volcanism (Dubertret, 1933, Ponicarov, & *et al.* 1966) by emerging a series of volcanic chains tacked the same direction of the old extensional faults.

Alkali basalt and basanite form a full part of the global basaltic inventory in the south Syrian volcanic field (Ponicarov, & *et al.* 1966, Lustrino & Wilson 2007) and because they associated with recent active rift environment and the rich assemblage of mantle xenoliths (Turkmani, & *et al.* 1996; Bilal & Touret 2001), the Pliocene basalt provides direct evidence about the nature and mechanism of forming those rocks.

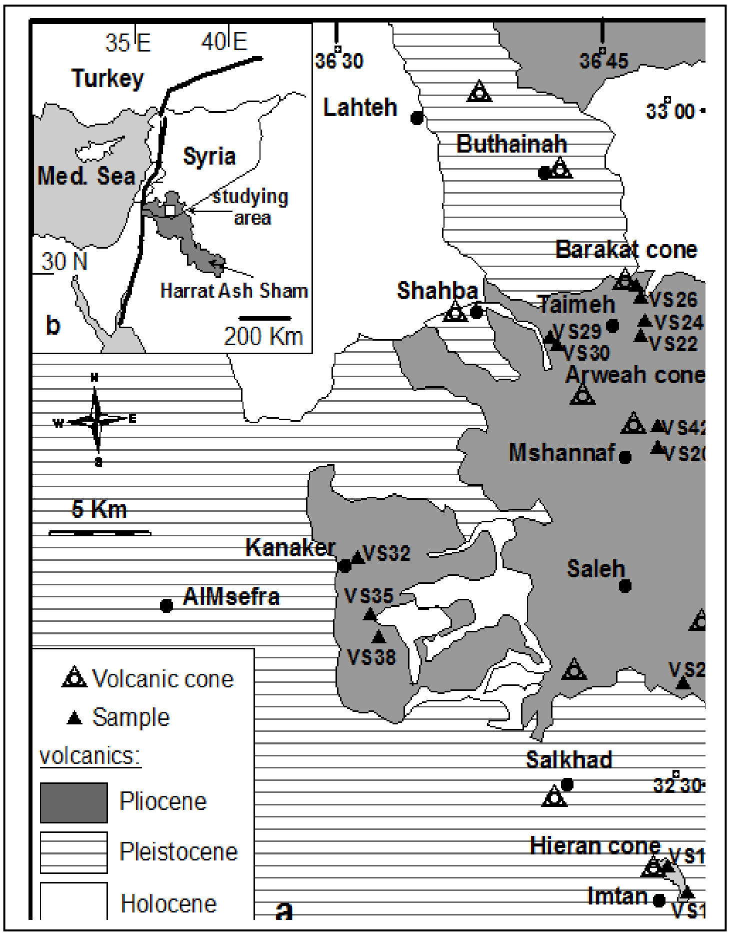

Figure (1) a: Location of the area under study in the Harrat Ash sham volcanic field. **b:** Geological map of basaltic rocks in the Shahba area. Numbers show locations of the analyzed samples.

The aims of this paper

In spite of the volcanic activity in south of Syria is extended from the middle Mesozoic to recent time, the Pliocene volcanism may the most important stage because the volcanic activity in this period accompanied with the development and uplift of the Dead Sea fault zone (Chorowicz, & *et al.* 2005) in a complex geodynamics setting (Lustrino & sharkov, 2006). On the other hand, the geochemical characteristics of Pliocene basalt flows are various and imply many indications about the origin of these rocks. Therefore this study focuses on the basalt that erupted during the Pliocene age in Shahba area southern of Syria.

Analytical methods

Fourteen fresh basaltic samples of Shahba Pliocene basalt rocks were chosen for preliminary petrographical and geochemical analysis since 2011. Locations of these samples are shown in Figure1b.

Thin sections were prepared for petrographic study done in the Department of Earth and Environmental Sciences, Kuwait University. Representative powdered sample were used for geochemical analysis. Major oxide elements were determined on fused glass disks prepared according to the method of Eastell and Willis (1990) and trace elements were tested on pressed pellets of rocky powders. The analyses were provided through the General Research Facilities (GRF) Project SG-03/01in the College of Science in Kuwait University. Results of the major oxides and minor element contents are listed in Tables 2 and 3.

Regional geology

The Harrat Ash Sham volcanic field is the largest on the Arabian plate. It extends from the southern edge of Damascus basin in Syria to the east of Wadi Sirhan Depression in Saudi Arabia. The Syrian part of The Harrat Ash Sham volcanic field contains several hundred volcanic centers which imply pyroclastic cones, shield volcanoes, and composite volcanoes that settle down along northwest-trending faults that bound asymmetric grabens associated with numerous tuff rings.

In the region which extends from Jordan to SE Turkey, The extensional movements at the beginning of Miocene leads to separation of the Arabian plate from the African one as well as onset the Miocene volcanism (Kearey & Vine, 1995). Later the volcanic activity in the Pliocene in Shaba and all comprehensive regions associated with asymmetric uplift of the Dead Sea fault Zone (Westaway, 2003) and forming the recent topography (Novikov, & *et al.* 1993). The climax of volcanic activity took place during the last 20 My (Giannerini, *et al.* 1988). Mouty, *et al.* (1992) and others suggest a period of quiescence continuous between 8 to 16 My. On the other hand Sharkov *et al.* (1994), suggest that this volcanism is still active. Any way the resent acceptable point is that there are two basic periods of volcanic activity that separated in Miocene-Pliocene time (Lustrino & Sharkov, 2006).

Local geology

Basaltic Pliocene flows in Shahba area extend to several kilometers square. They emerge from extension faults or central cones coincide or follow the development of the Dead Sea fault zone (Ponikarov, & *et al.* 1966).

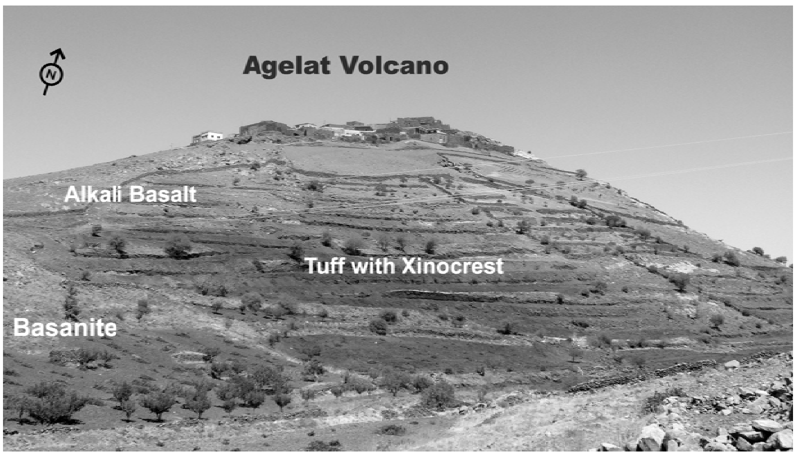

Figure (2): The Pliocene Agelat cone. Note the spreading of the volcaniclastic material as tuff bearing xinocrests.

Pliocene basalt in the studying area is represented by numerous alternations of lava sheets, often separated by horizons of red clays, which are products of weathering. The thickness of sheet ranges from 2 to 22m. In the field, these sheets have similar morphological features. The upper and lower of each of them are composing of Vesiculated texture, while the central part is composed of well crystallized massive varieties. A series of interfaces components types have been recognized where the lava flows often possess to the permanent regular joint basaltic prisms, which are massive or parted to thin layers (5 to 15cm thick and rarely up to 40cm) and their jointed pattern depend on their nature of cooling history. It overlaps scoria that has similar petrography of the previous embedded type. Flow core, that usually come in the surface of Pliocene exposure out, is covered by broken volcanic materials, which indicate prolonged period of suberial exposure (Single & Jerram, 2004) and are often associated with volcaniclastic material exposure as tuffaceous beds especially in the volcanic cones such as in the Arweah, Hieran and Agelat cones (Fig. 2). Sometimes lava flow exposure ended by flow breakout which is a thin alternation massive zone like fingers controlled by spatiality paleomorphology.

Petrography

The basaltic Pliocene rocks of the Shahba area are dominated volumetrically by three lithologies, alkali basalt, basanite and augite alkali basalt which is the less spreading type.

a. Alkali basalt

The dominant petrographic rocks type in the field. Olivine phenocrysts are euhedral to subhedral spread in the ophitic texture and forms 6 to 17% of the rock bulk with maximum diameters of about 2.5 mm. Olivine phenocrysts often surrounded by alteration rim (Iddingsitisation) (Fig 3).The clinopyroxene are subhedral phenocrysts. It often forms a glomorphical structure with olivine's phenocrysts. Opaque minerals form an important ratio of the rock bulk of about 4 to 5% accompanied with hexagonal minerals of Abatite which sets in a groundmass of microcrystalline matrix of plagioclase and olivine and pyroxene with a relatively high ratio of glass and bubbles.

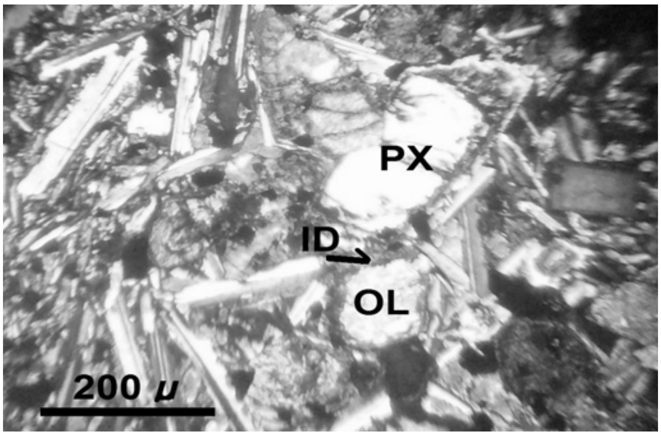

Figure (3): Olivine phenocrysts are subhedral. They are mostly surrounded by slight dark brown or reddish-brown iron alteration (iddingsitisation) (ID), and sometimes by magmatic corrode.

b. Basanite

The second major petrographic rocks type in the Shahba area. These rocks are dark colored and form massive flows that occasionally contain vesicles. Basanite flows form a continuous blocks that vary in thickness measure from 2 to 8 meters. The basanite of Shahba Pliocene exposure is fine grained, hypocrystalline and show porphyritic textures. Olivine is the most common phenocrysts, which is generally euhedral to subhedral and usually is dominanted and more common than other phenocrysts shapes and form 15 to20% of the rock bulk (Table 1). Phenocrysts are between 2 and 4 millimeters in size and constitute about 15 to 35 % of samples. Augite is mostly subhedral and pale pink to purple in plane polarized light. Fine-grained clinopyroxene measures about 0.1 millimeter and is situated between intergranular opaque minerals or set as mesostasis in a groundmass of interstitial nepheline and glass. Albite plagioclase phenocrysts and finer-grained acicular laths are partly replaced by sericite.

Table (1): Modal compositions of the main minerals in the Shahba Pliocene basalt. (volume %).

	Alkali basalt	Augite alkali basalt	Olivine alkali basalt
Olivine	6-17	8-15	15-20
Clinopyroxene	6-9	8-18	6-10
Plagioclase	9-24	8-22	7-20
Alkali feldspar	3-4	2-4	2-3
Magnetite	2-4	2-4	2-4
Ilmenite	2-3	2-4	2-3
Glass	4-8	8-23	3-6

c. Augite alkali basalt

Samples are porphyritic with holocrystaline to microlites groundmass. Plagioclases are often euhedral to subhedral or as small-microliths within the matrix. It rarely shows oscillatory zoning and sericite alteration. Olivine phenocrysts are the second dominant mineral phase. It is euhedral to subhedral in shape and form 8 to 15% of the rock bulk (Table 1).

The clinopyroxene (8-18% in bulk) are subhedral phenocrysts with two almost perpendicular cleavages and sometime exhibit zoning, as well as simple and lamellar twinning. Augite is the dominant pyroxene's mineral and secondary augiteigrene. They were observed in the microcrystalline matrix or together with olivine and plagioclase as poicklitic texture. In some samples pyroxene contains magnetite emergence put on its roof or some time implies on it. Glass constitutes about 8 to 23% of groundmass.

Geochemistry

The chemical composition of the Pliocene Shahba samples Show a weak differentiation with high alkalinity so these samples can be classified as alkali basalt and basanite on the basis of TAS classification scheme (Le Bas, & *et al.* 1986) (Fig. 4).

Table 2 shows that the K_2O content decreases in the rock samples to less than 15%. By contrast, the Na_2O content varies from 2.35 to 3.85. The Al_2O_3 content relatively shows a high ratio (with average about 15.84%). It is distributed between plagioclase and feldspar minerals that prevalent in the studying rocks.

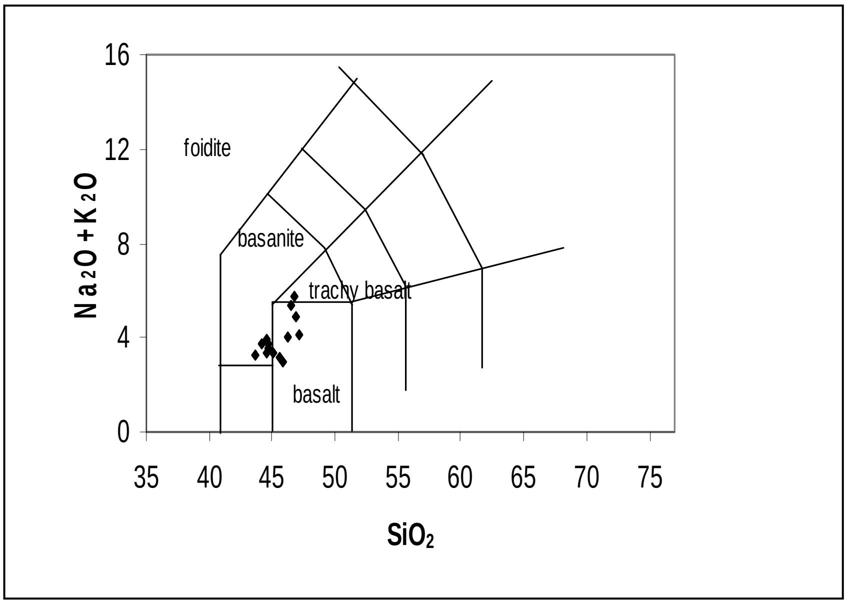

Figure (4): Total alkali versus silica (TAS) diagrams for chemical classification of the Pliocene Shahba samples. After (Le Bas, & *et al.* 1986).

Fe_2O_3+FeO show similarity in content in most samples samples that variety are about 13.6 to 18.07% with Fe_2O_3 value higher than FeO value. FeO is considered multiphase oxide which appears in the oblique minerals (magnetite and iliminite) and emerges as patches of magnetite on corroded olivine, while on the contrary Fe_2O_3 often linked to alteration process of iddingsite (Iddingsitisation).

Table (2): Content of major oxides (wt %) of the Pliocene Shahba samples from south of Syria.

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O
VS16	46.44	2.46	14.98	4.87	9.44	6.24	10.11	3.71	1.66
VS17	44.17	3.67	13.5	4.55	9.08	10.63	10.61	3.01	0.71
VS20	44.68	2.31	10.64	6.09	12.87	10.45	9.04	2.62	0.95
VS21	45.91	2.04	16.49	5.71	5.33	10.88	10.56	2.35	0.66
VS22	45.54	1.24	17.98	4.07	8.2	8.02	11.4	2.56	0.61
VS24	47.2	1.45	19.71	4.44	8.8	4.3	9.87	3.16	0.93
VS26	46.88	2.46	16.84	4.19	8.35	5.55	10.44	3.6	1.32
VS29	43.62	2.24	14.32	5.46	11.36	11.55	7.89	2.36	0.86
VS30	44.56	2.31	13.18	5.37	13.3	8.05	8.07	2.89	1.02
VS32	44.64	2.18	15.12	4.31	8.64	10.63	10.54	3.01	0.75
VS35	46.22	1.12	15.13	3.8	7.48	10.66	11.24	3.19	0.82
VS38	45.04	1.4	17.45	4.37	8.79	8.76	10.06	2.7	0.69
VS42	44.57	1.72	16.56	4.26	9.02	7.88	12.42	2.51	0.8
VS44	46.79	1.83	19.97	3.32	6.55	5.85	9.18	3.85	1.86

The six most common minor incompatible elements concentration ratios are listed in Table 3. The investigated rocks are characterized by their high concentration of compatible (ferromagnesian) elements including Co, Ni, Cr, and V. Cobalt and Nickel content hovers between 47 to 70 and 134 to 160 ppm respectively. Barium varies from 637 to 713 ppm and 643 to 949ppm for strontium.

Discussion

The SiO_2 content varies in a restricted range from 43.62 wt% to 47.2 wt%. MgO also shows a somewhat mild variation from 4.3 wt% to 10.88 wt%. The K_2O content increases in the Shahba rocks from 0.61 wt% to 1.86 wt%, while the Na_2O content varies from 2.35 wt% to 3.85 wt%.Figure 5 shows Harker variation diagrams that display the variations in the content of major oxides and most common trace elements plotted against the silica content.

The variation trends are explained by fractionation of mineral phases observed in the rocks. For example, the decrease in the FeO and Fe_2O_3 contents, against an increase of silica (Fig 5) is explained by fractionation of aegirine-augite and the opaque minerals (magnetite and limonite).

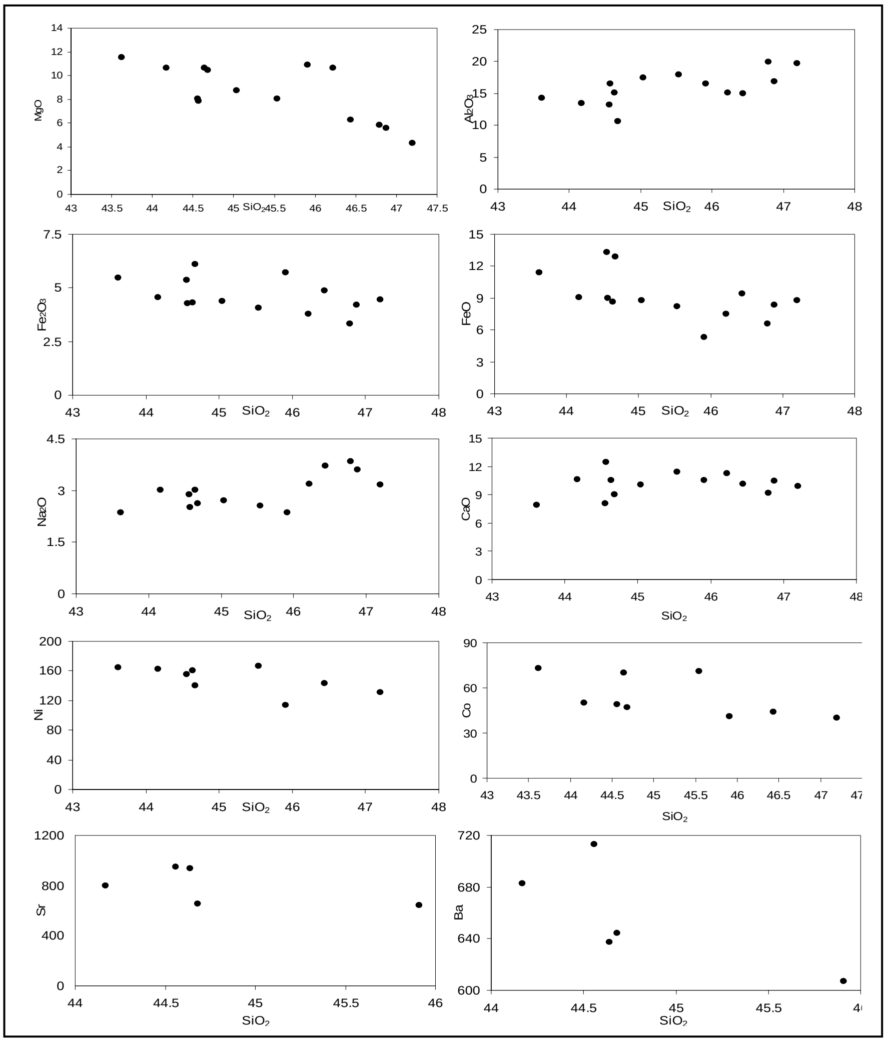

Figure (5): Harker variation diagrams for the Pliocene Shahba samples in south Syria.

Table (3): Content of trace elements (ppm) of the Pliocene Shahba samples from south of Syria.

Sample	Co	Cr	Ni	Ba	Sr	V
VS16	44	222	143	-	-	-
VS17	50	218	162	683	801	188
VS20	47	234	140	644	653	175
VS21	41	250	114	607	643	180
VS22	71	252	167	-	-	-
VS24	40	209	131	-	-	-
VS29	73	256	164	-	-	-
VS30	49	222	155	713	949	190
VS32	70	206	160	637	935	185

The decrease in the MgO content with silica can be explained by the fractionation of olivine and aegirineaugite, the latter partly being also responsible for the unclear decrease of CaO.

Although Irvine (1965) had shown that the chromo Spinel mineral crystallize at the earless stages of the primary magma crystal fraction process, the high concentration of chrome element in the most initial magma get not to depletion by chromo Spinel only, but also by the later clinopyroxene crystallization phase (Bell, & *et al.* 1994). Thus we can attribute the relative negative correlation of chrome in addition to vanadium, which behave similar to chrome (Preston, & *et al.* 1998) to crystal fraction process.

Ba and Sr are known to readily substitute for K in K-feldspar (Wilson, 1989; Eby, & *et al.* 1998) thereby the high depletion of Ba and Sr in the studied rocks (Fig 5) can be attributed to the fractionation of alkali feldspar and plagioclase.

In spite of the previous signs, the crystal fraction processes have played a limited role in the evolution of the Shahba Pliocene basalt. Especially by presence untypical indicators in the Harker diagrams in addition to the presence of the high concentration of Cr and Ni content in the Shahba samples which indicates that the magma is slightly fractionated (for example, Ibrahim & Al-Malabeh, 2006) since Cr content is usually used as an index of fractionation.

Ni and Al_2O_3 show a negative correlation against MgO(Fig 6a). These two plots are viewed as evidence for insignificant or lack of fractionation process (Shaw, & *et al.* 2003; Krienitz, & *et al.* 2007). Also the negative correlation of Al_2O_3 versus MgO(Fig 6b) refers to the same result where the melting is developed the generated liquid is rich in magnesium (Wilson 1989). In addition to all samples have a value of SiO_2 less than 46% plotted parallel at the 5% line which refers to partial melting of upper melting (Achepkov, 1991).

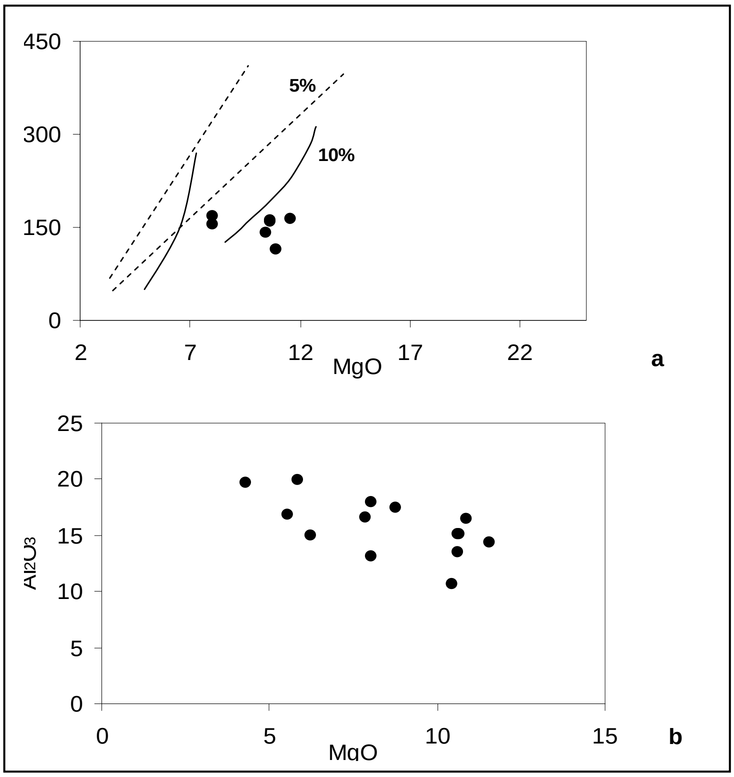

Figure (6): a Ni versus MgO diagram after (Achepkov, 1991). **b** Al_2O_3 versus MgO diagram.

This result is promoted by the positive correlation of Ni/FeO and Co/FeO versus Al_2O_3/MgO diagrams (Fig 7) that usually indicates that magma had formed by partial melting process (Francalanci, & *et al.* 2000). As a result, the magma bulk of Shahba region formed by partial malting undergone later to limited crystal fraction process.

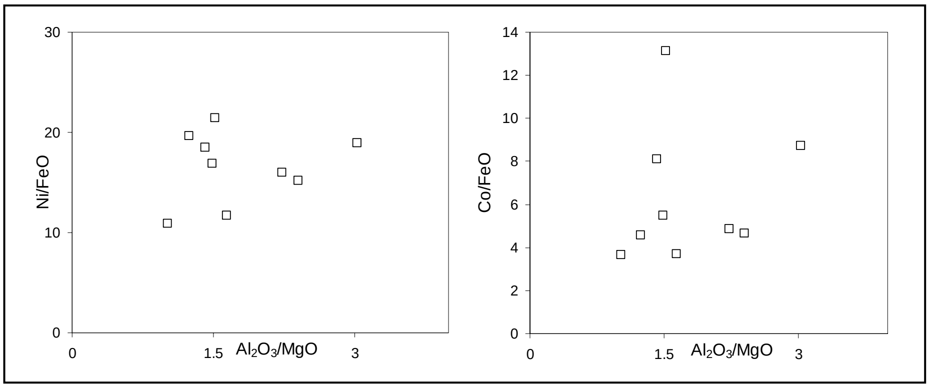

Figure (7): Al_2O_3/MgO versus Ni/FeO and Co/FeO diagrams on condition that MgO> 3 wt %. After (Francalanci, & *et al.* 2000).

Conclusions and recommendation

The Shahba area, the focus of this study, is a small volcanic area in southern Syria, represents one of the many volcanic centers in the Harrat ash sham volcanic field. These Shahba volcanic rocks constitute an important component of the mafic Pliocene magmatic activity. It products cover significant areas around Shahba city.

Field mapping documented that these basaltic rocks occur in different forms: continuous lava flows, cinder cones and tufaceous sheet deposits. A series of interfaces components types have been defined in the lava flow structure.

The studying Pliocene basalt mainly composed of olivine, plagioclase, and augite phenocrysts enclosed by fine- to medium-grained intergranular textures. Modally, three essential petro-types are recognized including: Alkali basalt, Augite alkali basalt and Basanite.

Petrochemical classification indicates that the two essential petro-types can be classified as alkali basalt and basanite. They have similar compositional range of major and trace element.

Major oxide and minor elements analyses were performed in order to characterize chemically the Shahba Pliocene basalts. Harker variation diagrams and other plots, along with some petrologic indexes, show that the melts were not modified perfectly by crystal fractionation process. The high content of some elements like Cr and Ni in addition to the some relevant plots such as the Ni and Al_2O_3 versus MgO plots indicate that the Shahba basaltic melts were generated by partial melting. So we can consider that the magma bulk of Shahba area formed by partial malting undergone later to limited crystal fraction process.

Acknowledgments

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