

Mineralogy, Geochemistry and Petrogenesis of Pleistocene Volcanism from Dear Al-kahef Basaltic Field (Harrat Al-Shaam), Northeast Jordan

Hassan Al-Fugha^{1*} and Ahmad Al-Malabeh²

¹Jordan University, Department of Applied Geology, Amman Jordan

²The Hashemite University, Department of Earth and Environmental Sciences, Zarqa Jordan

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Abstract

The northeast Jordan is part of the large intra-continental volcanic province of Harrat Al-Shaam (also written: Harrat Ash-Sham), which covers an area of about 50.000 km². In Jordan, the volcanic province covers an area of about 12.000 km². They are represented by basalt flows and tephra cones. Twenty-four basaltic rock samples were collected and covered about 25 km² area 7 km northeast of the village Dear Al-Kahef were studied. The petrographical data show that the samples are olivine-, plagioclase- and pyroxene-phyric basalt type. The geochemical investigation of the rocks shows that they are under-saturated regarding the silica content, which ranges between 46.00 and 49.86 wt.%. They are mainly alkali basalts and belong to the alkaline to sub-alkaline rocks series containing 2.26 to 4.55 wt. % alkali oxides. The geochemical parameters of these by the silica content (< 50 wt%) the high MgO content (>7 wt%), the Mg-number (0.60-0.65), and the high Ni contents lies between 100 to 170 ppm, and the high Cr content in the studied rocks range from 125 to 260 ppm. This magma shows low variable abundances of compatible and incompatible trace elements reflecting a homogenous source. Their Geochemical trend hints that the parental magma ascended rapidly, and underwent only limited fractional crystallization without crustal contamination. The primitive nature of the magma is reflected the distinct chemical similarity of the studied rocks suggests that they were derived from a single enriched and homogeneous mantle source, and initiated by a low degree of partial melting (4-13 %) of garnet peridotite at a depth >100 km.

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1. Introduction and Geologic setting

In general, alkali basalts are widespread on continental plates and are usually associated with continental rifting (Wilson, 1989; Al-Malabeh, et al., 2017). This is also the environment of the extended young volcanic fields near the western margin of the Arabian plate, which is separated from the African plate by the Red Sea Rift. Such volcanic fields occur in Yemen, close to the triple junction with the East African Rift and the Aden Ridge, and northwards in Saudi Arabia, Jordan, Syria, and Turkey. The occurrence in northeast Jordan is part of the large intra-continental volcanic province of Harrat Al-Shaam (also written: Harrat Ash-Sham), which covers an area of about 50.000 km² and extends continuously in NW-SE direction from the southern rim of the Damascus basin in Syria across Jordan into northwestern Saudi Arabia (Figure 1a). In Jordan, the volcanic province is known as the Jordanian Harrat and covers an area of about 12.000 km² (Figure 1b).

The extensive volcanism of the Jordanian Harrat occurred during faulting episodes and predominantly consisted of alkali basalts, basanites, and hawaiites (Barberi et al., 1979; Shaw, 2003; Al-Malabeh and Hamed, 2020). The volcanism of the Jordanian Harrat occurred over a relatively long time from the Early Miocene to the Holocene (Barberi et al., 1979; Kempe, and Al-Malabeh, 2013) with an age range from

0.2 to 18.5 Ma as determined by K-Ar dating (Siedner and Horowitz, 1974; Barberi et al., 1979; Moffat, 1988; Tarawneh et al., 2001). During late Cenozoic times, basaltic lavas erupted probably from vertical fissures and local vents along the Jordan rift, a mountain ridge in central and northeastern Jordan (Krienitz et al., 2006; Al-Malabeh and Kempe, 2009; Al-Malabeh, and Kempe, 2012; and Al-Fugha et al., 2012).

These magmas transported upper mantle xenoliths with a composition of spinel lherzolite to the surface. These xenoliths contain olivine, orthopyroxene, clinopyroxene, and spinel as typical for the upper mantle below continental plates, analogous to worldwide occurrences (Frey et al., 1978; Thompson et al., 1980; White and McKenzie, 1989; McGuire and Bohannon, 1989; Wilson, 1989).

Jordan is part of the Arabian plate, which is drifting to the NE towards the Tauros-Zagros compressional zone due to the aforementioned opening of the Red Sea. This process is accompanied by the development of the Dead Sea transform fault, which trends N-S with a net slip along it of about 105 km (Garfunkel, 1989; Al-Fugha, and Al-Malabeh, 2019; Weinstein et al., 2006; Abu-Mahfouz, et al., 2016), and the formation of the NW-SE striking Azraq-Sirhan Graben structure. volcanic rocks are situated on the east side of this major fault. In Northeastern Jordan basalts extend along the east side of the Al-Azraq-Wadi- Sirhan basin.

* Corresponding author e-mail: h.fugha@ju.edu.jo

Bender (1968) distinguished seven different phases of major volcanic activities in northeastern Jordan based on both field observation and bore-hole data. The total thickness of these flows reached about 350 m where the upper three phases are exposed at the surface between oil pump stations H5 (Al-Safawi) and H4 (Ruweished), in the central part of the Jordanian Harrat. K-Ar dating from Harrat Al-Shaam ranges from 0.05 to 40 Ma. A historical eruption in the 17th century was also recorded (Al-Malabeh, 2010; Tarawneh et al., 2000).

3. Study Area

The study area is located within the intraplate volcanic field of the Jordanian Harrat in Northeast Jordan; within the Mafraq government about 80 km northeast of Al-Mafraq city. It is located in Dear Al-Kahef village at 32° 15' 570" to 32° 15' 580" N and 36° 45' 485" to 36° 45' 495" E (Figure 1c). The basaltic flow is accessible through several asphaltic roads that already connect several towns.

The outcrop basaltic rock covered by 50 km² of basalt flows, was developed due to intermittent eruption from deep-seated faults form of 4 successive basaltic pahoehoe and aa (or a'a) flows with a total thickness of 40 m.

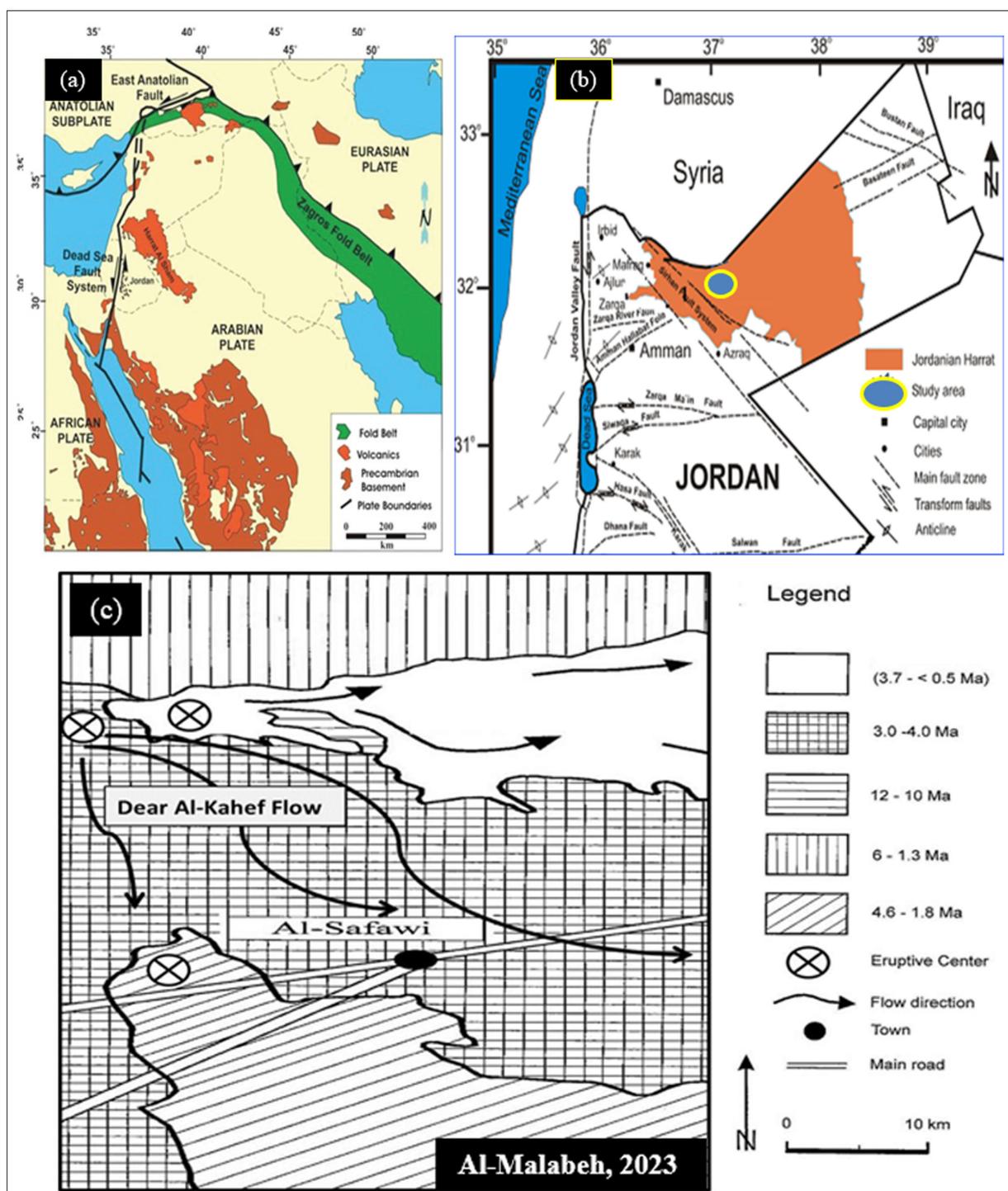


Figure 1. a. Location map of volcanic fields along the western Arabian plate (after Garfunkel, 1989; Camp Roobol, 1989 and Al-Malabeh, 1994). b. Tectonic setting of Jordanian Harrat and location of the study area (Modified after Al-Malabeh, 2009) c). Geological map of Dear Al-Kahef basaltic field (Al-Malabeh this study).

3. Sampling and Analytical Techniques

Twenty-four representative rock samples were collected from the basalt flows. The samples were crushed and powdered using geochemical techniques. Major oxides and trace elements were analyzed on fused glass disks by using multi-channel XRF Spectrometry at the Department of Geology, University of Stuttgart, Germany. The powdered samples were dried at 110 °C. A total of 2 gm of the powder samples were mixed with 8 g of lithium tetra borate and fused in platinum crucibles over gas burners (1000°C) for 1 h. Melts were poured into a mold creating 32 mm diameter glass disks. The loss on ignition (LOI) was determined by weight lost after melting at 1000 °C.

Thin sections of the basaltic rock samples were studied in transmitted light to determine the petrography.

4. Results

4.1 Mineralogy

The studied basaltic flows of northeast Jordan, which are mainly composed of basaltic flows, are black to grey in color and fine-grained. The melanocratic rocks typically show porphyritic to glomeroporphyritic texture and are characterized by olivine, clinopyroxene, and plagioclase phenocrysts embedded in a fine-grained groundmass that mainly consists of plagioclase, olivine, clinopyroxene, opaque minerals, and glass. The average modal composition of the basaltic rock samples studied is 54 vol.% plagioclase, 25 vol.% olivine, 17 vol.% clinopyroxene, and 4 vol.% accessory minerals. Plagioclase occurs as up to 5 mm long hypidiomorphic laths and fine crystals in the groundmass. The subhedral plagioclase laths are phenocrysts with extinction angles ranging from 26 to 30 degrees indicating a labradorite composition An 50 - An 60 by using the method described by Michel Levy color chart (Keer, 1977).

The olivines phenocrysts are unihedral to subhedral, fractured, mostly unaltered, and reach lengths of 4 mm. They are colorless to pale yellow. A few exceptions exhibit resorbed margins which can be partly or completely replaced by iddingsite. The olivine phenocrysts are typically Magnesian in the basalt with a forsterite component between 75 to 82 mol%.

The clinopyroxene phenocrysts are augite which is colorless or pale brown to pale green. The phenocrysts are 1 to 4 mm in length. The groundmass augite < 0.5 mm in size, shows prismatic crystals. Small amounts of this augite are affected by chloritization where green chlorite is present along fractures and crystal rims. The accessory minerals include apatite as minute needles and opaque phases which were identified as magnetite and ilmenite

4.2 Geochemical

4.2.1. Major Oxides

Twenty-four samples of Pleistocene alkali basalts from northeastern Jordan have been analyzed for major, minor, and trace elements. The representative results are given in Table 1. The SiO₂ values range between 46.00 and 49.86 wt.% and average 47.63 wt%. They were plotted against alkalis in the (Irvine and Baragar, 1971 and Hamed et al., 2021) diagram of Figure 2. This diagram shows that all rock samples can be assigned to the alkaline to sub-alkaline suite.

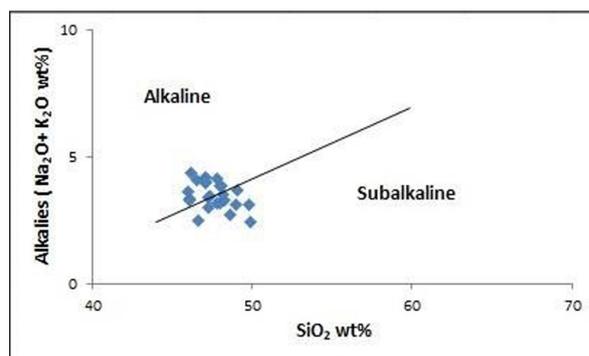


Figure 2. Alkalies Vs. SiO₂ for the studied samples (Divider is after Irvine and Baragar, 1971).

The AFM variation diagram of Figure 3 indicates that the compositions of the basaltic rocks from northeastern Jordan fall in the transition between calc-alkaline and tholeiitic fields (Irvine and Baragar 1971).

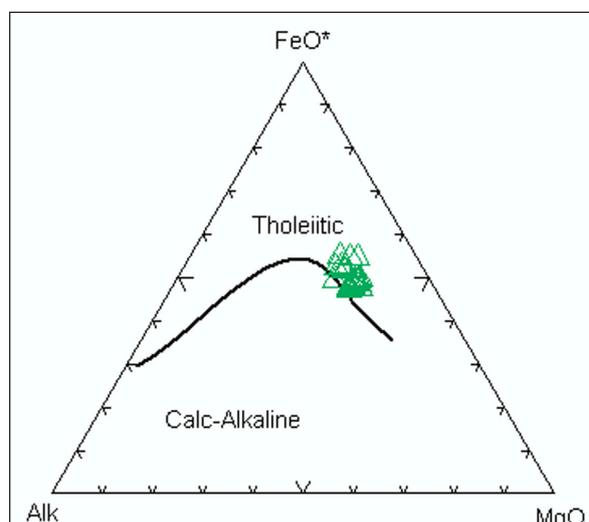


Figure 3. Discrimination (AFM) diagram plot alkalis-FeO-MgO for the studied samples (After Irvine and Baragar, 1971).

The data for Al₂O₃, P₂O₅, FeO+Fe₂O₃, and CaO scatter between 13.5 to 16.15 wt.%, average 14.69 wt% 0.01 to 0.50 wt.%, average 0.19 wt%; 10.16 to 14.02 wt.%, average 11.98 wt%; and 6.98 to 12.26 wt.%, average 9.78wt% respectively. A correlation with the determined SiO₂ content is only discernable for Al₂O₃. Figure 4 shows an increase of Al₂O₃ with decreasing SiO₂. The Mg number (Mg #; Mg/Mg²⁺+Fe²⁺) given in Table 1 ranges between 0.42 and 0.50. The determined major and minor element concentrations were also used to calculate the CIPW norm (Table 1).

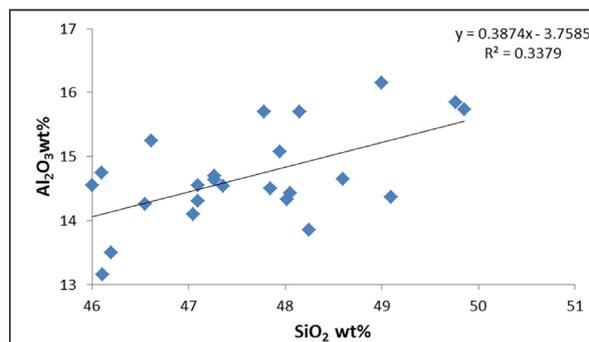


Figure 4. SiO₂ -Al₂O₃ correlation.

Normative anorthite (An) and albite (Ab) contents are high. According to the Ab-An-Or diagram of Figure 5, the majority of samples reflect the sodic affinity of the rocks. Normative apatite and nepheline contents are zero to 0.83% with an average of 0.29% and 4.2 to 0.07%, with an average of 1.14%, respectively Table 1. The latter content is, however, often zero.

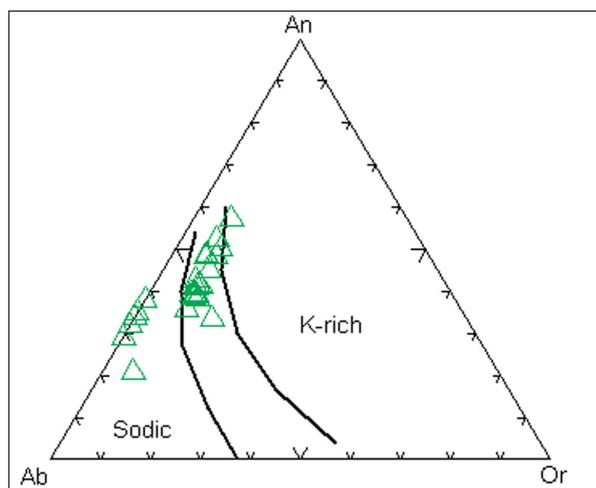


Figure 5. A triangular discrimination diagram plots Normative feldspar (Ab-An-Or) for the studied samples (after Irvine and Baragar 1971).

4.2.2. Trace Elements

The trace element data show relatively minor variation. Contents of Sr, Ba, Ni, and Cr range from 255 to 595 ppm, 360.63 ppm; 5 to 100 ppm; 100 to 170 ppm, and 125 to 260 ppm, respectively (Table 1). The concentrations of Rb, Nb, Y, and Sc are low scattering around between 2 to 12 ppm; 7 to 37 ppm; 18 to 29 ppm; and 11 to 26 ppm, respectively Table 1. A correlation of these trace-element contents with that of SiO_2 is not discernable.

5. Discussion

5.1 Bulk-rock compositions

The studied basalts are alkaline to sub-alkaline and often SiO_2 -undersaturated. Very similar rock compositions were reported by (Al-Malabeh, 1994) from NE Jordan. Shaw (2003) already emphasized that the silica undersaturated magmas from NE Jordan with high MgO and $\text{FeO}+\text{Fe}_2\text{O}_3$ contents >7 wt% and >12 wt%, respectively, give evidence for the primary nature of these magmas. However, the Mg# ranging from 0.60 to 0.65 (Table 1), could point to little fractional crystallization and removal of olivine and pyroxene. Nickel and Cr varies between 100 to 170 ppm and 125 to 260 ppm, respectively. These concentrations also suggest some degree of olivine fractionation which tends to increase the incompatible trace element concentration in the studied basalts. The determined concentrations of Sr and Ba might, thus, represent a moderate enrichment in the melt phase. Despite the indication of little olivine fractionation, the magmas studied here and by other researchers (Steinitz, and Bartov 1992; Shaw, 2003 Al Fugha, 2006; Al-Malabeh, 2009; and Krienitz et al. 2006) from the Harrat Al-Shaam volcanic field in northeastern Jordan are relatively homogeneous over a wide area. This is in contrast to the rocks from this field in Syria. Krienitz et al. (2006) proposed the considerable crustal contamination of the continental intraplate lavas there because they show a wide

variety of bulk-rock compositions and can be significantly enriched in SiO_2 . Furthermore, the Harrat Al-Shaam contains crustal nodules (Al-Malabeh, 2009). These lithics represent the lower crust and were brought from depths of 25 to 30 km (Al-Malabeh, 2003) by ascending alkali olivine basaltic and basaltic melts (Lustrino and Sharkov, 2006).

5.2 Crustal contamination

A few magmas can erupt without the effect of contamination (Thompson et al., 1980, Al-Malabeh, et al., 2004). The concentration of elements such as Sr, Rb, and K can be used to improve the understanding of the geochemistry and petrogenesis of magma. The comparable geochemical data deduced from the similar concentration of major elements, and mimicked by trace element ratios, e.g. K/Ba, and Ba/Rb, and the primitive nature of the magma, serve as evidence for a closed-system magma chamber for the studied volcanoes, and suggest that assimilation of upper crustal materials was minimal. The depletion and enrichment of the incompatible elements in the studied basalt were explained by partial melting rather than contamination.

5.3 Differentiation and fractionation of the studied magma

The parental magmas of the studied basaltic rocks are qualified as primary; silica content never exceeded 50 wt% and ranges between 46.00 to 49.86 wt%. This matches the content below 50 wt% reported for primary magmas (Wilson, 1989 and Al-Malabeh, et al., 2004). MgO content in the investigated samples exceeds 7 wt% and ranges between 7 and 10 wt%, which is also compatible with the primary nature of the magma and argues for rapid ascent from the mantle with minimal fractionation. Consequently, the Mg#, which is considered one of the most important petrogenetic indicators for primary magmas, ranges in the studied rocks between 0.60 and 0.65. These values fit well with the values of 0.60 and 0.75 reported for primary magmas (Kesson, 1973, El-Hasan and Al-Malabeh, 2008). However, Wilson (1989) reported a value of > 0.6 for the distinction of primary magmas.

The Ni and Cr concentrations are good indicators for the fractionation of olivine and pyroxene. They also used fundamental criteria for determining the primary nature of magma. Ni content varies from 100 to 170 ppm. These values are consistent with the concentrations of Ni in primary magma (Green, 1980) The high Ni content matches well with the high MgO content of the rocks. Cr content in the studied rocks lies between 125 and 260. These values are intermediate between those reported for primary magmas of 142 ppm (Hughes, 1982). On the basis that Cr content may be considered as an index of fractionation, it would appear that the studied rocks were produced from limited fractionated magmas.

5.4 Identification of Inferred Mantle Source

A fundamental problem in understanding the magmatic process of development of the studied volcanoes centers on 1) the composition, mineralogy, and nature of the inferred source, and 2) the degree and mechanism of partial melting.

The primary melts of the Harrat Al-Shaam volcanic field were generally derived in the mantle below the crust as also evidenced by ultramafic xenoliths (Steinitz and Bartov 1992; Shaw et al 2003; Al-Fugha, 2006, Krienitz et al. 2006; and Al-Malabeh, 1994). Seismic and gravity data indicate that

the crust below this field is about 37 km thick (McBride et al., 1990; Sawaf et al., 1993). As the Arabian lithospheric mantle beneath the crust could be chemically and isotopically heterogeneous, various suggestions previously made from which part of the mantle the characterized primary melts, in principle, could be derived from transferred to the Jordanian part of the Harrat Al-Shaam volcanic field.

In general, primary alkali basaltic melts can be formed by a small degree of melting in the mantle at pressures above 13 kbar. At lower pressures, tholeiitic melts are formed (Mysen and Kushiro, 1977; Jaques, Green, 1980; Ibrahim, and Al-Malabeh, 2006). Green (1970) reported that alkali basaltic melts can be derived at depths of 90 km (30 kbar) by about 5% partial melting and also by a higher degree of partial melting in the lithospheric mantle above (60 to 90 km). However, alkali basalts could also be differentiating of more primitive picritic partial melts (Al-Malabeh et al., 2002; Ozdemir et al., 2019). Based on this experimental information (Rooney et al., 2005), for instance, suggested that the recent basalts of the Ethiopian rift were produced by a small degree of partial melting of peridotite at mantle depths corresponding to pressures of 15 to 25 kbar. Thompson et al. (1980) also suggested that the Tertiary basalts from central France, which are similar in their mineralogy to those of northeastern Jordan, formed by partial melting of garnet lherzolite at 15 to 30 kbar pressure as evidenced by spinel lherzolite nodules. For the Harrat Al-Shaam volcanic field. Shaw (2003) proposed that the volcanic rocks have their source in the lower lithosphere and suggested that the alkali rocks were probably derived from a mixed lithospheric asthenosphere source. According to Al-Fugha 2006; Al-Fugha and Bany Yaseen 2019 and Bany Yaseen, 2019, proposed that the alkali basalts of the Tel-Remah, Atarous, and Jurf El Darawish volcanoes in NE and central Jordan were formed in a primitive upper mantle that has suffered partial melting at a temperature ranging between 930 to 1075°C and pressure around 15 to 25 kbar.

The Ti-richness of the studied alkali basalts could be attributed to low degrees of melting of a peridotite source (Shehata and Theodoros, 2011) and compatible with high MgO and FeO+Fe₂O₃ contents >7 wt% and >12 wt%, respectively. As the FeO+Fe₂O₃ contents show a scatter in a plot versus SiO₂ (Figure 6) this could reflect a variable degree of partial melting of a relatively homogenous source.

Traditionally, large volumes of basalts erupted in a continental environment over a longer time as in the Harrat Al-Shaam volcanic field are related to hot-spot volcanism, which is believed to be caused by an ascending mantle plume. For instance, this might be true for the Tertiary Snake River plain basalts in the northwestern United States of America. According to Shervais and Vetter (2009) the source for these basalts is the shallow mantle although some alkali basalts of this volcanic province might require pressures higher than 15 kbar for the source region. On the other hand, the mantle xenoliths in the various volcanic intraplate regions of the Arabian plate are broadly similar, including the ones studied here, suggesting that this Cenozoic volcanism with several centers might have the same base which can hardly be a single hot spot in the mantle. Shaw (2003) proposed that this volcanism may be the product of the melting of the upper mantle wedge that was fertilized already during the Pan-

African subduction. Another reason for the fertilization of the mantle below the Arabian plate could be a delamination process with crustal material involved (Massonne and Fockenberg, 2012).

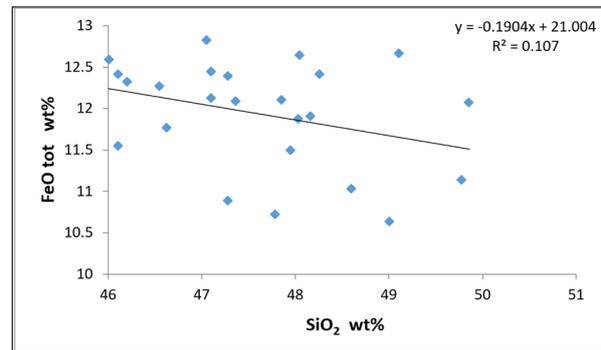


Figure 6. SiO₂-FeO tot correlation.

As the Arabian plate moved northwards colliding with Eurasia and forming the Taurus-Zagros mountain belt, significant crustal thickening occurred in the collisional zone in Tertiary or even earlier times. Such compression affected also areas south of this zone in the range of the fault-rich regions of Jordan, Syria, and Turkey. For instance, the region of the Golan Heights is a highly faulted and deformed plateau, which was subject to continuous deformation phases (Meiler, 2011). Thus, local crustal thickening could have taken place in the region of today's Harrat Al-Shaam volcanic field in the past resulting in eclogitization of the lower crust, especially when we consider a lower geothermal for this process than it is now, and its foundering into the mantle. The delaminated crust could have fertilized the mantle to cause the production of significant melt volumes in the fertilized mantle regions in late Cenozoic times to form the Harrat Al-Shaam volcanic field.

The inferred origin of the studied rocks is thought to be in the garnet peridotite zone of the mantle. This interpretation is based on the constancy of Y, which ranges from 18 to 29 ppm; the high Zr/Y ratio; and the high TiO₂/Y ratio (Frey et al., 1978). The high Ni, Cr, and Co contents in the samples support that they were generated in a mantle of peridotite composition (Wilson, 1989, Smadi et al., 2018.). Moreover, the low Zr/Nb, Y/Nb, and high Y/Zr ratios may indicate the enriched nature of the garnet peridotite mantle source (Figure 7).

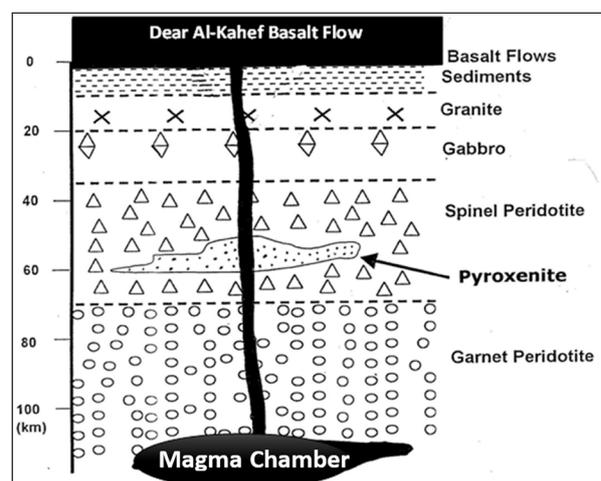


Figure 7. Schematic diagram of the studied basalt, crust, and mantle for the Jordanian Harrat and magma partial melting zone (Modified after Al-Malabeh, 2009).

6. Conclusions

The consideration of the bulk-rock chemical compositions of basalts from the Jordanian portion of the Jordanian Harrat at Dear Al-Kahaf Basaltic field supports the concept that:

The igneous rocks (basalt) can be derived from a garnet-hercynite source in the upper mantle with a low degree of melting.

The distinct chemical similarity of the studied rocks suggests that they were derived from a single enriched and homogeneous mantle source, and initiated by a low degree of

partial melting (4-13 %) of garnet peridotite at a depth >100 km.

The mantle region produced significant amounts of alkali basaltic melts because it was fertilized before either by Pan-African subduction or by crustal delamination in the Cenozoic as proposed here.

The melts reached the surface with very limited assimilation of crustal material.

A minor degree of olivine fractionation might have occurred for the studied rocks.

Table 1. Major, trace elements and CIPW norm data for Dear Al-Khaf basaltic rock.

Sample No.	1	2	3	4	5	6	7	8	9
SiO ₂ Wt%	48.02	46.11	46.2	47.27	47.95	49	48.6	46.62	47.78
TiO ₂	1.42	1.46	2.7	1.5	1.2	1.26	1.22	1.66	1.77
Al ₂ O ₃	14.33	13.15	13.5	14.7	15.08	16.15	14.65	15.25	15.7
Fe ₂ O ₃	2.95	2.95	4.15	3.00	2.70	2.77	2.72	3.16	3.27
FeO	8.93	8.6	8.18	7.88	8.80	7.86	8.32	8.6	7.46
MnO	0	0	0.01	0.04	0.01	-0.01	0.04	0.03	0
MgO	8.53	8.3	7.72	7.73	7.95	7.75	5.86	6.74	6.04
CaO	9.3	11.6	9.6	12.01	9.9	9.7	12.26	11.42	11.27
Na ₂ O	3.25	2.8	3.15	2.6	2.72	2.7	2.31	2.01	2.53
K ₂ O	0.6	0.53	1.2	0.42	0.45	0.44	0.42	0.48	0.66
P ₂ O ₅	0.17	0.3	0.06	0.01	0.32	0.01	0.02	0.02	0.1
H ₂ O	1	0.78	0.5	0.7	0.87	0.82	0.63	0.76	0.7
Total	99.7	98.77	99.17	100.06	100.15	100.64	99.25	98.95	99.48
Mg#	0.63	0.63	0.64	0.64	0.64	0.64	0.60	0.60	0.61
CIPW Norms									
Or	4.2	3.97	7.98	3.25	3.35	3.35	3.3	3.54	4.64
Ab	25	18.16	20.58	21.9	24.45	24.15	20.9	18.35	22.75
An	21.3	20.34	17.72	19.92	26.25	26.45	26.97	30	28.15
Ne	1.5	3.35	3.53	0.28	0	0	0	0	0
Wo	8.93	14.14	11.61	13.34	7.92	8.21	13.3	10.45	10.9
En	5.3	8.54	7.65	7.85	9.9	12.03	11.5	11.16	9.25
Fs	2.62	4.25	2.58	4.26	6.62	8.22	8.52	6.7	4.72
Fo	10.67	8.2	7.66	5.85	4.79	2.9	1.72	3.55	3.6
Fa	6.16	4.54	2.9	9.49	3.48	2.08	1.35	2.25	1.9
Mt	4.06	4.12	5.9	4.17	3.72	3.81	3.75	4.4	4.55
It	2.64	2.7	5	2.78	2.2	2.3	2.22	3.1	3.25
Ap	0.4	0.71	0.18	0.05	0.75	0	0.05	0.02	0.2
Or	4.2	3.97	7.99	3.25	3.35	3.35	3.3	3.54	4.65
Trace elements in ppm									
Cr	145	150	125	219	130	250	120	128	260
Ni	155	160	137	102	110	100	100	100	135
Zn	90	239	86	595	75	75	140	75	65
Sc	20	17	19	25	28	15	20	17	20
Sr ppm	370	430	545	330	360	340	350	365	420
Rb	3	12	7	10	8	4	14	5	6
Ba	136	119	189	305	70	75	230	135	260
Nb	16	20	18	35	15	19	22	5	9
Zr	180	152	147	147	181	145	172	185	170
Y	20	23	21	20	18	21	22	20	18
Ce	39	65	60	50	40	55	60	41	20

Table 1. continue...

Sample No.	10	11	12	13	14	15	16	17	18
SiO ₂ Wt%	48.05	48.25	47.1	47.85	46.55	47.1	47.05	48.15	46
TiO ₂	1.42	1.37	1.7	1.45	1.62	1.45	1.5	1.45	1.8
Al ₂ O ₃	14.43	13.85	14.3	14.5	14.26	14.55	14.1	15.7	14.55
Fe ₂ O ₃	2.92	2.89	3.2	2.95	3.12	2.95	2.96	2.97	3.3
FeO	9.72	9.52	8.92	9.15	9.15	9.5	9.87	8.95	9.3
MnO	0.1	0.1	0.1	0.1	0.12	0.11	0.11	0.1	0.11
MgO	9.14	8.95	8.9	8.8	8.85	9.15	9.26	8.5	9.28
CaO	9.35	8.8	10.34	9.92	10.25	9.8	8.92	8.38	9.85
Na ₂ O	3.1	2.49	3.35	3.32	3.35	3.25	3.3	2.77	2.85
K ₂ O	0.77	0.77	0.85	0.8	0.75	0.71	0.75	0.76	0.75
P ₂ O ₅	0.27	0.22	0.50	0.18	0.35	0.17	0.22	0.22	0.18
H ₂ O	0.3	0.37	0.25	0.27	0.82	0.32	0.28	0.35	0.8
Total	100.67	98.68	100.61	100.39	100.29	100.16	99.42	99.4	99.87
Mg#	0.63	0.63	0.64	0.63	0.63	0.63	0.63	0.63	0.64
CIPW Norms									
Or	4.66	4.72	5.18	4.78	4.55	4.29	4.47	4.64	4.51
Ab	25.06	26.98	20.44	22.5	19.78	21.19	24.17	23.91	20.05
An	21.85	18.9	20.24	21.2	20.5	21.91	20.59	27.17	23.67
Ne	0.26	1.06	3.8	2.7	4.2	3.01	1.76	0	1.94
Wo	8.5	9.01	10.7	10.31	10.8	9.8	8.5	4.63	9.21
En	4.89	5.17	6.52	6.03	6.43	5.71	4.9	10.08	5.54
Fs	2.62	2.81	3.02	3.14	3.13	3	2.63	3.37	2.53
Fo	11.7	11.29	10.2	10.24	10.16	11.2	12.05	7.14	11.58
Fa	7.3	7.07	5.41	6.08	5.71	6.72	7.57	4.17	6.18
Mt	3.85	3.81	4.21	3.86	4.14	3.92	3.94	3.93	4.42
It	2.35	2.3	2.85	2.4	2.72	2.44	2.5	2.44	3.09
Ap	0.37	0.27	0.83	0.15	0.56	0.14	0.28	0.27	0.15
Or	4.2	3.97	7.99	3.25	3.35	3.35	3.3	3.54	4.65
Trace elements in ppm									
Cr	147	133	132	147	201	132	152	218	132
Ni	158	159	155	157	155	152	152	155	139
Zn	99	95	95	95	100	85	85	80	80
Sc	23	21	25	12	13	17	16	17	13
Sr ppm	375	350	365	375	360	365	360	255	360
Rb	5	3	6	12	8	5	2	11	10
Ba	50	100	40	20	25	5	60	45	45
Nb	22	20	13	11	10	7	18	10	11
Zr	140	154	174	146	182	175	138	185	Rb
Y	18	21	20	22	19	20	23	19	20
Ce	27	20	30	18	45	38	41	30	20

Table 1. continue...

Sample No.	19	20	21	22	23	24
SiO ₂ Wt%	46.1	49.86	49.77	47.27	47.36	49.1
TiO ₂	2.02	1.27	1.45	1.37	1.48	1.44
Al ₂ O ₃	14.74	15.73	15.84	14.63	14.53	14.36
Fe ₂ O ₃	3.51	2.76	2.96	2.88	2.98	2.94
FeO	8.91	9.31	8.18	9.51	9.11	9.72
MnO	0.11	0.11	0.11	0.1	0.1	0.11
MgO	8.95	8.23	7.71	8.97	8.9	9.9
CaO	9.99	6.98	8.59	9.71	9.21	7.46
Na ₂ O	2.61	1.84	2.57	2.7	2.77	2.99
K ₂ O	0.68	0.57	0.57	0.68	0.66	0.71
P ₂ O ₅	0.21	0.2	0.21	0.19	0.17	0.31
H ₂ O	0.92	1.94	1.22	0.81	0.93	0.82
Total	99.85	99.9	100.28	99.92	99.4	101.1
Mg#	0.64	0.61	0.63	0.63	0.64	0.65
CIPW Norms						
Or	0	4.39	0	0	0	0
Ab	4.26	3.55	3.48	4.2	4.04	4.38
An	21.83	16.11	21.1	23.3	23.97	25.53
Ne	25.27	32.23	28.81	24.7	24.33	22.21
Wo	0.07	0	0	0	0	0
En	8.78	0	4.28	8.44	7.67	4.32
Fs	5.42	17.99	18.71	5.41	7.53	10.9
Fo	2.21	12.59	9.84	2.94	3.81	5.57
Fa	11.19	0	0	11.13	9.63	8.7
Mt	5.41	0	0	7	5.51	4.89
It	4.72	3.71	3.89	3.82	3.99	3.83
Ap	3.51	2.13	2.47	2.29	2.52	2.36
Or	0.2	0.21	0.27	0.21	0.14	0.49
Trace elements in ppm						
Cr	137	215	135	135	135	152
Ni	75	85	90	85	80	80
Zn	140	147	135	145	143	145
Sc	26	25	22	11	17	21
Sr ppm	355	595	370	345	350	310
Rb	6	10	5	5	4	6
Ba	7	15	12	20	27	37
Nb	195	185	173	182	155	146
Zr	21	22	20	21	20	24
Y	23	19	41	26	37	43
Ce	27	20	30	18	45	38

Qz: Quartz, Or: Orthoclase, Ab: Albite, An: Anorthite, Ne: Nepheline, Wo: Wollastinite, En: Ensite, Fs: Ferrosite, Fo: Forsterite, Fa: Fayllite, Mt: Magnetite, It: Ilmenite, Ap: Apatite

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