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Mineralogy and Chemistry Characterization of the New Basaltic Intrusion at Maasser El Chouf/Lebanon

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Abstract

The importance of this study is to identify the newly reordered and recognized basaltic intrusion for the first time in Maasser El Chouf in Lebanon. The recorded basaltic intrusion cut the Jurassic-Lower Cretaceous rock in this area. Necessary field inspection, geology, mineralogy and chemical tests were carried out on 8 basalt samples to determine their mineralogy, petrography and chemical composition. Representative samples have been tested with polarizing microscope, X-ray diffraction (XRD) and X-ray fluorescence (XRF). Petrographic and mineralogical studies show that the basalt is characterized by presence mainly of calcic-plagioclase feldspar, pyroxene-augite and olivine minerals. Secondary minerals of iron oxides also present (ilmenite and magnetite). The most appeared property is the alteration of olivine mineral to iddingsite that indicated highly weathered process. The composition of the basaltic samples reflects ultrabasic-basic type (Basanite-Tholeiitic basalt). The existence of volcanic activity occurred mostly with Pliocene age (< 2 Ma) as indicated by previous studies for similar basalt in Lebanon. Possibly, these boulders have been carried up from some deeper intrusive magmatic body under very active tension zones. Volcanism of Lebanon basalts belong to the alkaline olivine basalt, suite generally associated with tension, rifting and block faulting movements of the continental crust. Most of the volcanisms in Lebanon and in Harrat Ash Shaam Basalt from Syria and Palestine through Jordan to Saudi Arabia are related and connected to the opening of the Red Sea Rift System, making the area with tremendous volcanic tectonic activities.

Keywords

Lebanon, Basalt, Intrusion, Basanite, Alteration, Alkaline Olivine Basalt

1. Introduction

The geological characteristics of Lebanon have been extensively studied by researchers such as Dubertret (1933, 1953, 1955, 1963, 1966), Kuttayneh (1967), Shaban (2010), Beydoun (1976, 1977, 1988), and Edgell (1997). Camp & Roobol (1992) mentioned that the eastern Mediterranean Basin acts as an extension to the Red Sea Rift System, resulting in significant tectonic activities. Lebanon's exposed rocks primarily consist of sedimentary formations, with sporadic occurrences of basaltic igneous rocks. The structural geology of Lebanon is challenging to comprehend due to its involvement in the Red Sea Rift System and its status as part of the unstable shelf in the Middle East (Guba & Mustafa, 1988).

Tectonic forces have played a crucial role in shaping Lebanon's geological processes, contributing to a complex geological setting characterized by prevalent rock deformations (Shaban, 2010). Based on work of Kuttayneh (1967), a subsequent study indicated similarities between Tertiary basalts in North and South Lebanon and Mesozoic basalt groups. These findings align with Lebanon's tectonic history since the late Jurassic period, emphasizing its relationship with the major African Rift System. It is tentatively proposed that olivine basalts result from local mantle melting under zones of tension, differing from tholeiitic origin. They ascend through thinned and weakened crust areas, potentially influenced by assimilation into underlying molten mantle materials.

Lebanese territory encompasses two major physico-geomorphological provinces as Mount Lebanon and Anti-Lebanon. This province is characterized by a regional folding system intersected by sets of strike-slip faults, due to major fracture zones. Mount Lebanon represents a regional monocline dominated by folds and flexures, while Anti-Lebanon constitutes an elongated fold, with dominant plunging anticline structures (Beydoun, 1976). The occurrence of basalt exposures in Lebanon's geographic distribution is primarily attributed to volcanic eruptions along lava veins, dikes, and faults, as well as local fracture systems. The thickness and spatial extent of these basalts at different locations and levels indicate volcanic activity during the Pliocene age (< 2 Ma ago). The basalt distribution was influenced by active tectonic deformation. For instance, the Mechki Basalt (2.0 - 3.8 Ma) erupted onto a tectonically influenced landscape, filling some valleys and sealing the Hasbaya Fault as recognized by Beydoun (1988). In contrast, the Golan Basalt is offset by the transform system in southern part of Lebanon and northern part of Palestine.

The argument can be made that Lebanon's basalt is part of the major trend of volcanic eruption in the Harrat Ashaam Basalt, which spans over 45,000 km^2 as a lava plateau, stretching about 1000 km in a NW-SE direction, distributed in

Lebanon, Palestine, Syria, Jordan, and Saudi Arabia (Tarawneh et al., 2000, 2002, 2022, 2023; Tarawneh, 2020; Ilani et al., 2001; Ibrahim et al., 2003). It is presumed that the volcanism of Harrat Ash Shaam Basalt, including Lebanon's territories, underwent three main episodes of volcanic activity: Oligocene to Early Miocene (26 to 22 Ma), Middle to Late Miocene (12 to 8 Ma), and Late Miocene to Quaternary (6 to less than 0.5 Ma) (Tarawneh et al., 2000). This volcanic province is one of the largest volcanic plateaus in the Middle East and serves as a crucial source for sustainable basalt rocks, pyroclastic materials, as well as industrial minerals like zeolites and semi-precious stones (Tarawneh et al., 2023).

Regarding the chronological age of basalt in Lebanon, there is no precise information, and this study focuses on the Miocene and Pliocene ages based on work of Kuttayneh (1967). Most of the basalt distribution in Lebanon with tuffaceous materials of the Pliocene age is attributed to four major areas at Akkar, Hinayder, Kaoukaba, and El-Ghajar.

This study marks the initial documentation of a previously unrecognized basaltic intrusion in Maasser El Chouf, as it had not been mentioned before this investigation. The basalt in Maasser El Chouf differs from other known basalts in Lebanon, as indicated by existing geological maps. Recognizing the significance of this anomaly, the research focuses on thoroughly examining and characterizing the geology, petrography, mineralogy, and chemical composition of this basalt intrusion to contribute valuable insights to the geological understanding of this crucial area in Lebanon.

2. Methods and Materials

To determine the geological, petrographic, mineralogical and chemical composition of the basalt, eight samples of basaltic rocks were collected from the study area. Field studies have been carried out including detailed field inspection of the basalt. Modified geological mapping have been carried out through using GIS spectrum. The conducted tests on the basalt samples include petrographic, mineralogical, chemical analysis of X-ray fluorescence (XRF) and X-ray diffraction (XRD) have been carried out.

All samples underwent a detailed examination using thin sections that were studied by Trinocular polarizing microscope type BS-5062T with different magnifications from 40^x to 400^x with objectives 4^x, 10^x, 20^x, 40^x to discern their petrography, mineral associations, and textures. Mineral identification within the basalt was accomplished through X-ray diffraction (XRD) using Cu Kα radiation with an optic Monochromator at 60 kV/60 mA. XRF type Zetium was employed to determine the elemental analysis from sub-ppm to percentage of major and minor oxides, as well as rare earth elements (REE). Prior to analysis, samples were meticulously prepared through a digestion to produce an aqueous solution in acidified matrix (2% HNO_3/0.5% HCL), and subsequently analysed by using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). These comprehensive tests on the basalt samples were conducted at the laboratories of Al Hussein Bin

Talal University and at the Ministry of Energy and Mineral Resources in Jordan.

3. Results and Discussion

3.1. Geology of the Study Area

The village of Maasser El Chouf presents a breath-taking panoramic view encompassing the Anti-Lebanon mountain, Mount Hermon, the irrigated plains of West Beqaa, and Lake Qaraoun. Acknowledged by UNESCO as a "zero pollution" village, Maasser El Chouf is an integral part of the El-Chouf Cedar Nature Reserve (**Figure 1**), further designated as a UNESCO biosphere reserve in 2005. As outlined by Shaban (2010), the lithostratigraphic characteristics of the Jurassic period rock formation constitute the core of Lebanon's exposed rock masses. The geographic distribution is primarily structurally influenced by folding structures and sets of fault systems. Predominantly found in the Middle part of Lebanon (specifically the Keserwan Region) and the southeast part on Hermoun Mountain, with a significant presence in the north. The Jurassic rock formations in Lebanon are characterized by a monotonous sequence of dolomitic limestone

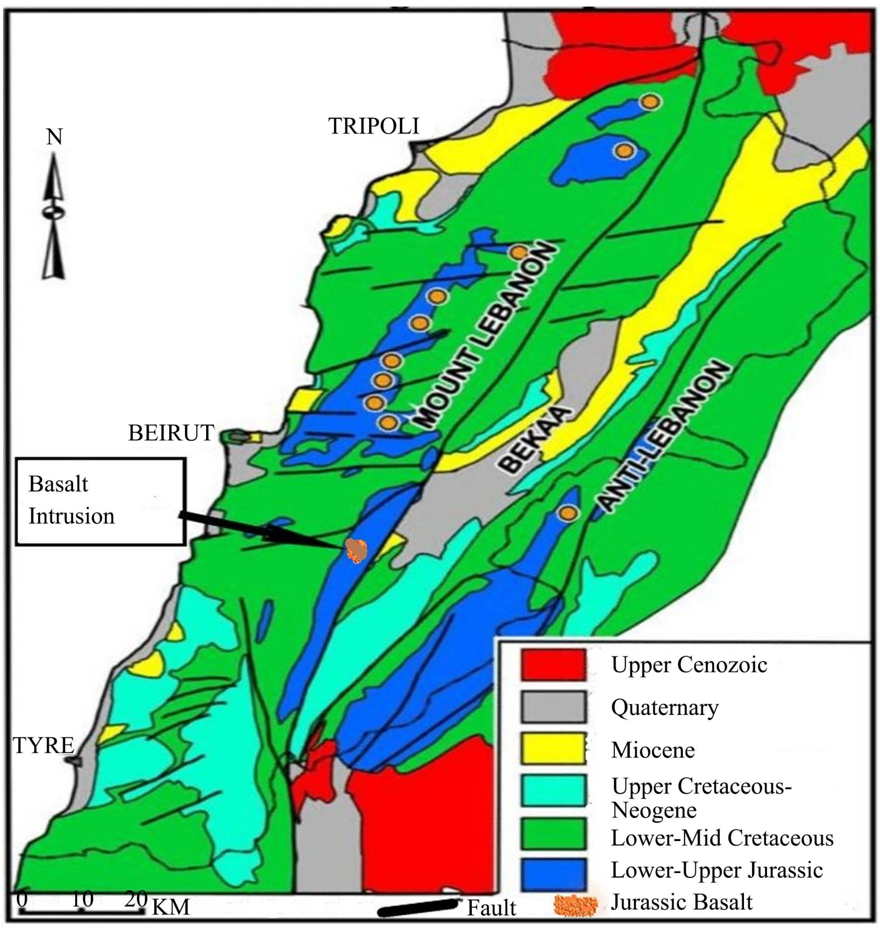

Figure 1. Geological map: the square shows the location of the basaltic intrusion, whereas the arrow shows the location of the study area.

of relatively shallow water facies. In central and north Lebanon, a volcanic horizon in the Kimmeridgian described by Dubertret (1955), interrupts this sequence as shown in **Figure 1**. The volcanic complex, reaching a thickness of nearly 200 m in north-central Lebanon that was measured by Renouard (1951), alternates with calcareous tuff, brown marl, and limestone rocks.

The geographic distribution of basalts in Lebanon was identified primarily from the available geologic maps or reports that have been published by Dubertret (1955); Beydoun (1977 & 1988) & Shaban (2010), which was carried out on different localities around the basaltic exposures. Thus, basalts with tuffaceous materials of the Pliocene age were attributed to four major domains where they are widely spread. The geographic distribution of basalt exposures can be attributed mainly to the volcanic eruptions along lava veins, dikes and faults, in addition to local fracture systems. Shaban (2010) suggested that the thickness and spatial extent of the volcanic activities in the Pliocene age (<2 Ma) at different localities in Lebanon indicates the existence of the volcanic eruption.

The basalt intrusion with circular shape at Masser El Chouf, which is located at coordinates (35˚41'12.887"E 33˚38'47.371"N) (called Radar Station) and at 2000 m ASL as shown in **Figure 1**, with an area around one km^2, cut the Lower Cretaceous-Jurassic rocks and affected by major fault system with east-west trend. The area characterized also by tectonic deformation and cut by a major faults trending E-W and SE-NW.

3.2. Petrography and Mineralogy

Megascopic field inspection indicated that the basalt present as scattered black and basaltic bombs (up to 20 cm in dimension) with greyish to black color, dens. Basalt with rounded boulders up to 5 m in dimension are present (**Figures 2(A)-(C)**), sometimes the basalt is vesicular, while the vesicles ranging upwards from 1 mm up to 10 mm in diameter. The vesicles are filled sometimes with carbonate (calcite) amygdules (**Figure 2(D)**). The texture is mostly with fine grained texture (aphanitic) (**Figure 2(E)**). The basalt is highly weathered and most of the olivine mineral phenocrysts and microphenocrysts are altered to iddingsite (**Figure 2(F)**). This is due to the highly weathered processes that have changed the colour of olivine mineral to the rusty colour due to oxidation of mafic minerals.

Petrographic studies indicated that the basalt of Maasser El Chouf is very fine-grained rock with crypto-crystalline texture. The basaltic rock is characterized by a presence mainly of calcic-plagioclase feldspar with trachytic texture with very thinly crystals of plagioclase, with olivine and pyroxene-augite crystals. The most common micro texture is aphanitic. Olivine is present in all samples mainly as subhedral or euhedral crystals. Phenocrysts or microphynocrysts with poikilitic texture up to 5 mm in diameter and tabular development of faces are more common for olivine mineral. Sometimes it can be seen zoned and fracture olivine crystals altered to iddingsite. Pyroxene (Augite) occurs in the groundmass as anhedral grains and short prisms. Iron oxides present as magnetite and

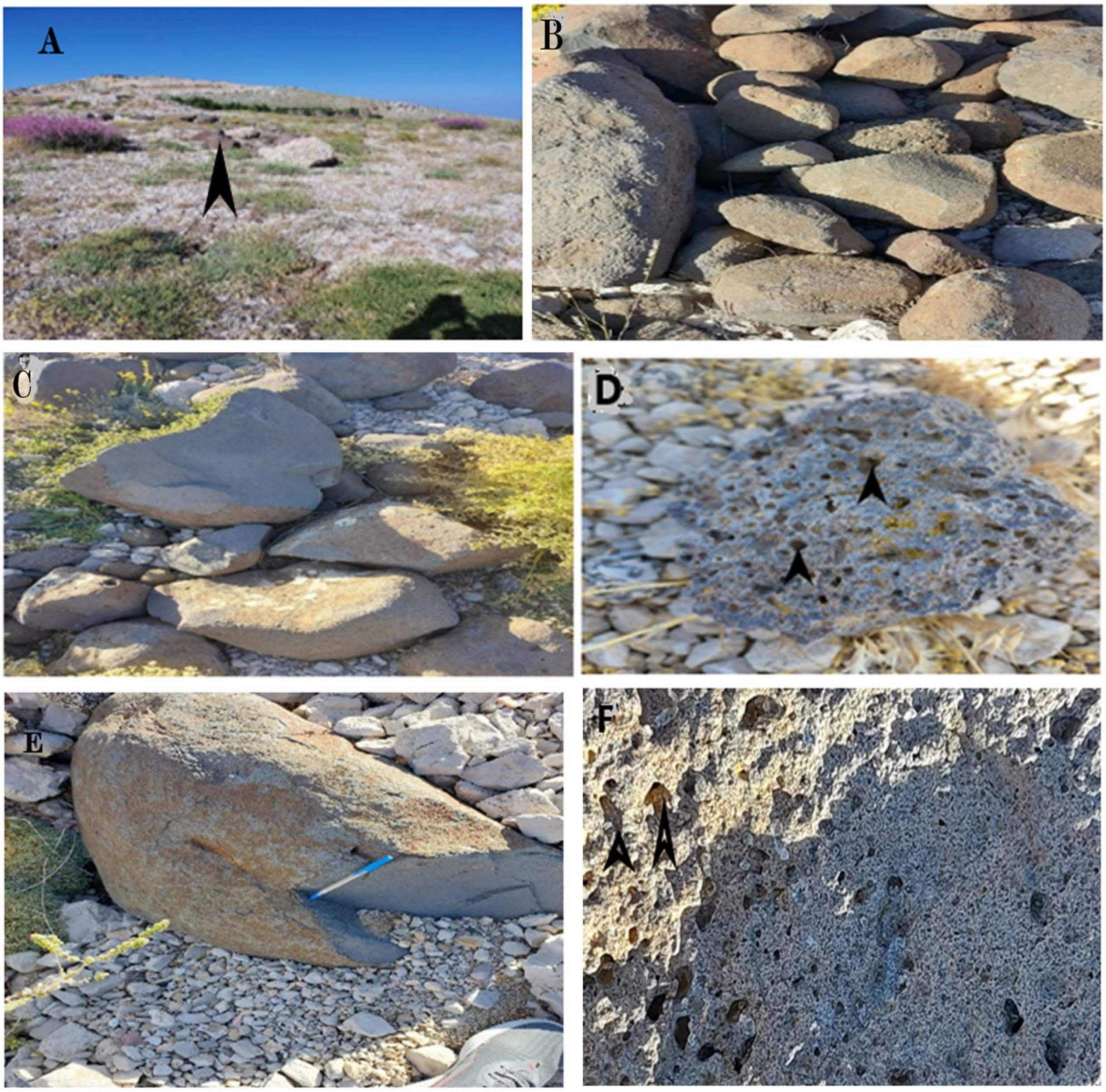

Figure 2. Photomicrograph of Maasser El Chouf basalt (A: General view of the location, the arrow shows the site of basaltic intrusion; B: rounded to subrounded dense black to greyish fine grained basalt; C: greyish subrounded dense fine grained basalt, D: vesicular fine grained basalt, arrows show small vesicles in basalt; E: Dense basalt with very fine grained texture with up to 5 m in dimension; F: Fine to medium grained basalt with very clear olivine mineral, arrows show (iddingsite).

ilmenite, in addition to the presence of iron-titanium oxides and spinel. Chlorite can be seen in the groundmass of the basalt (Figure 3 and Figure 4). Amygdaloidal and trachytic textures of the plagioclase minerals, and rarely glassy texture also are present (Figure 3(A)). In some cases, the basalt occurs with phaneritic texture, where the large olivine phenocrysts, and partly pseudomorphs of iddingsite can easily be seen with naked eye (Figure 4).

Petrographic study indicated that the essential mineral assemblage of Maasser El Chouf show that the most common mineral is plagioclase (35% - 38%), followed by pyroxene (augite) (24% - 29%), Olivine (22% - 26%), iron oxides (magnetite and ilmenite) (5% - 8%), accessory and secondary minerals (1% - 3%), respectively (**Table 1**). These results are relatively similar to the results indicated and reported by Kuttayneh (1967) for the Pliocene basalt of Lebanon. The XRD results supported the petrographic study and also indicated the presence of the plagioclase (anorthite), pyroxene (augite) and olivine minerals (**Figure 5**).

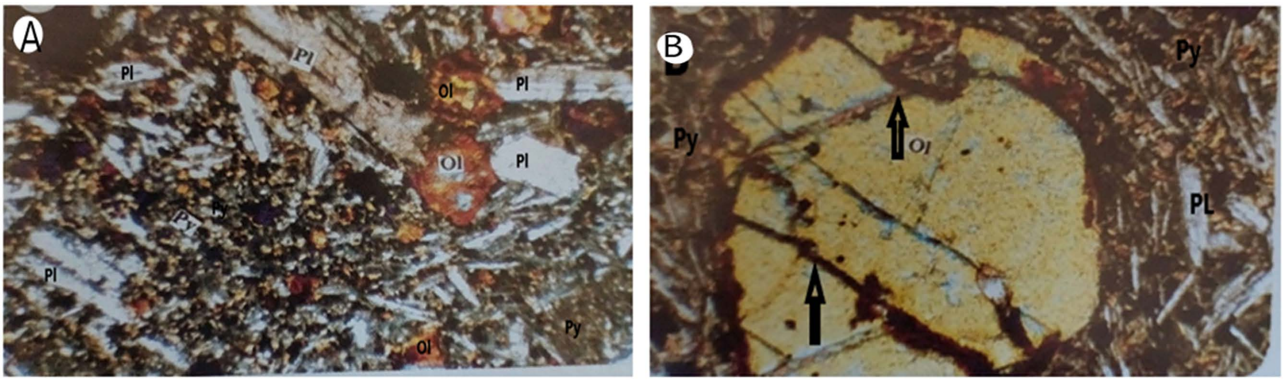

Figure 3. (A): Photomicrograph showing phenocrysts of olivine, pyroxene and plagioclase laths with microtexture of subophitic to trachytic, and sometimes with vesicular texture (XPL, X4). (B): Photomicrograph showing phenocrysts of olivine, arrows show the fractures in olivine, partly iddingsite, surrounded with micro lathes of plagioclase (trachytic texture) and euhedral to subdedral crystals of pyroxene (augite) and iron oxide minerals (PPL, X4).

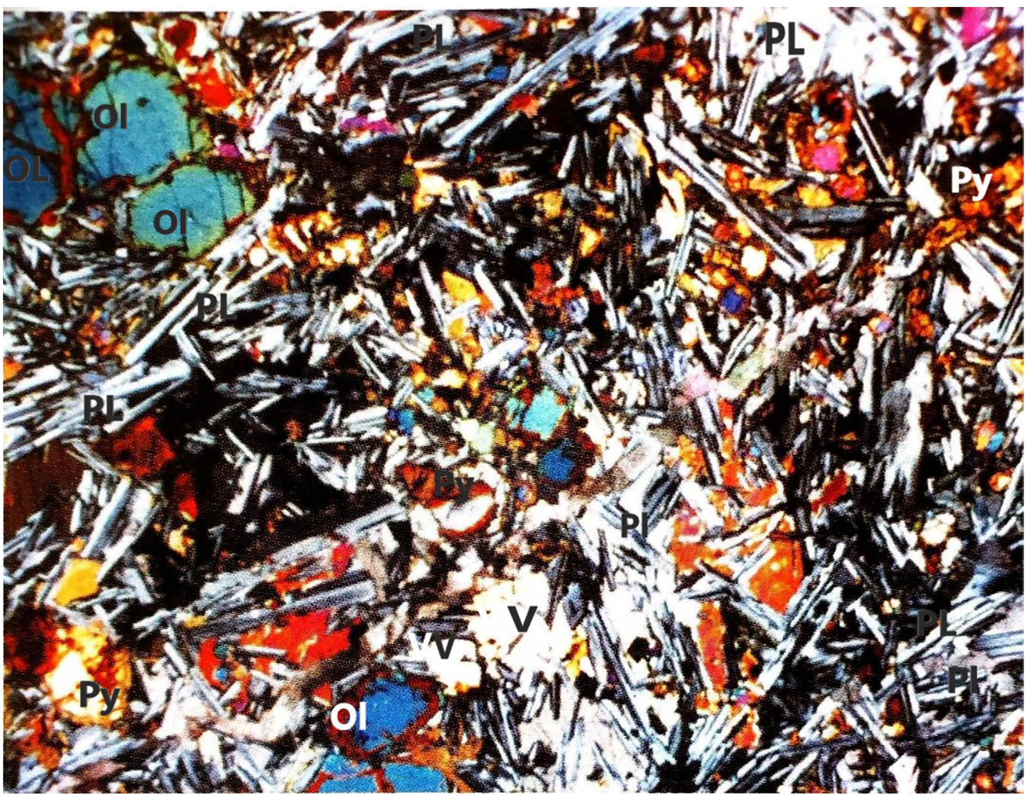

Figure 4. Photomicrograph showing phenocrysts of fractured olivine (Ol), partly altered to iddingsite, with augite-pyroxene (Py) crystals and trachytic texture of plagioclase laths and small vesicles (V), sometimes are filled with calcite (XPL, X4).

Table 1. Essential Minerals Assemblage of Maasser El Chouf Basalt in %.

Mineral	Volume percent of 8 samples	Standard deviation
Plagioclase	37	4
Pyroxene (augite)	29	3
Olivine	24	5
Magnetite and Ilmenite	7	2
Accessory minerals	3	-

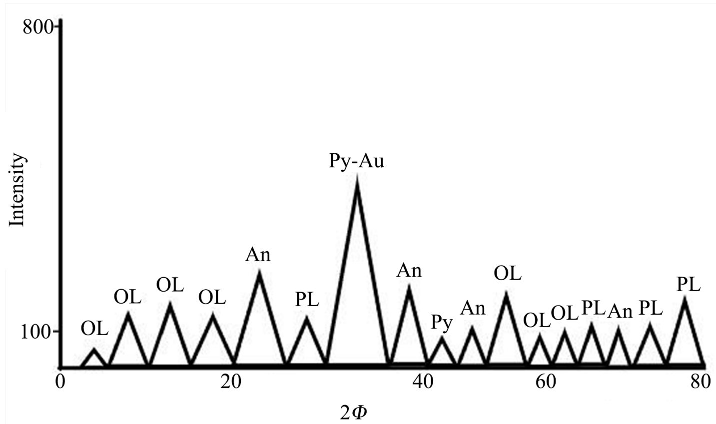

Figure 5. X-ray diffraction of selected basalt sample from the study area (Ol = olivine, Au = Augite, Py-Au = Pyroxene-augite, An = anorthite, Pl = plagioclase.

3.3. Chemical Composition

The chemical analyses of 8 representative samples of basalt rocks are summarized in Table 2. Chemical analysis indicates that the basalt rock is mainly composed of SiO_2 (average 45.40%), followed by Al_2O_3 (average 13.99 %), Fe_2O_3 (average 12.77 %), MgO (average 9.48%), CaO (average 9.73%), Na_2O (average 3.19%), TiO_2 (average 2.02%), P_2O_5 (average 1.32%), K_2O (average 1.18), and MnO (average 0.19%), respectively. The studied volcanic rocks have been classified on the basis of their total alkali (Na_2O + K_2O) versus silica (SiO_2) variations. Figure 6 shows the location of the studied samples that are plot into the field of Basanite-Tholeiitic basalt, which reflects ultrabasic-basic type basalt regarding the Total Alkali Silica (TAS) diagram of Le Maitre et al. (1989). It can be argued that the differences of chemical results of all oxides in the samples have small variations that could be referred to the homogeneity of the chemical composition source of the mantel. Geochemical parameters used for constraining the extent of magmatic differentiation like Mg# shows a wide range of variation from 27 to 50 which indicates much evolved nature of the volcanic rocks. The results of trace elements of basalt (Cr, Sr, Ni, Zr, Cu, Zn and I) are shown in Table 3. The average Cr (135 ppm), Sr (117 ppm), Ni (285 ppm), Zr (280 ppm), Cu (20 ppm), Zn (201 ppm) and Ir (45 ppm), respectively. These basalts differ from Mid-Ocean Ridge Basalts in their much higher concentrations of K_2O, P_2O_5, Cr, Sr, Ni and Zr, and their relatively lower concentrations of Mn, Cu, Ir and Zn. Although some potassium enrichment is a result of alteration phenomena. It can be concluded that the high potassium abundance is a primary feature of these basalts. This conclusion results from the significantly different abundance data for trace elements which are less susceptible than potassium to make alteration effects, e.g., Ba, Sr, Zr as indicated by Cann (1969, 1970).

Table 2. Major element chemical composition of selected basalt samples in %.

Oxide	B1	B2	B3	B4	B5	B6	B7	B8
K_2O	1.26	1.19	1.13	1.23	1.16	1.19	1.15	1.18
P_2O_5	1.60	1.33	1.16	1.32	1.25	1.22	1.25	1.44
SiO_2	45.68	44.87	45.45	45.89	45.30	45.19	45.33	45.55
CaO	9.57	9.44	9.36	9.21	9.12	9.55	9.33	9.44
MgO	9.69	9.88	9.25	9.57	9.44	9.34	9.65	9.09
Fe_2O_3	13.24	11.80	12.85	13.20	13.30	12.54	13.18	13.11
Al_2O_3	13.06	14.93	14.87	14.02	13.97	14.02	13.03	14.09
TiO_2	2.08	2.02	2.05	1.95	1.98	2.05	1.98	2.08
MnO	0.16	0.19	0.10	0.21	0.21	0.20	0.18	0.19
Na_2O	2.56	3.67	3.44	2.71	3.23	3.29	3.67	2.88
LOI	1.10	0.63	0.34	0.69	0.14	1.41	0.28	0.95
Total	99.97	99.95	100.00	100.00	99.10	100.00	99.03	99.97

Table 3. Trace element composition of selected basalt in ppm.

Element	B1	B2	B3	B4	B5	B6	B7	B8
Cr	140	138	113	140	138	139	139	136
Sr	120	119	116	118	116	118	115	117
Ni	300	289	288	257	288	298	276	284
Zr	288	300	287	296	278	256	259	283
Cu	206	199	198	202	197	202	193	209
Zn	200	202	205	195	198	205	198	208
Ir	50	48	44	45	43	48	47	40

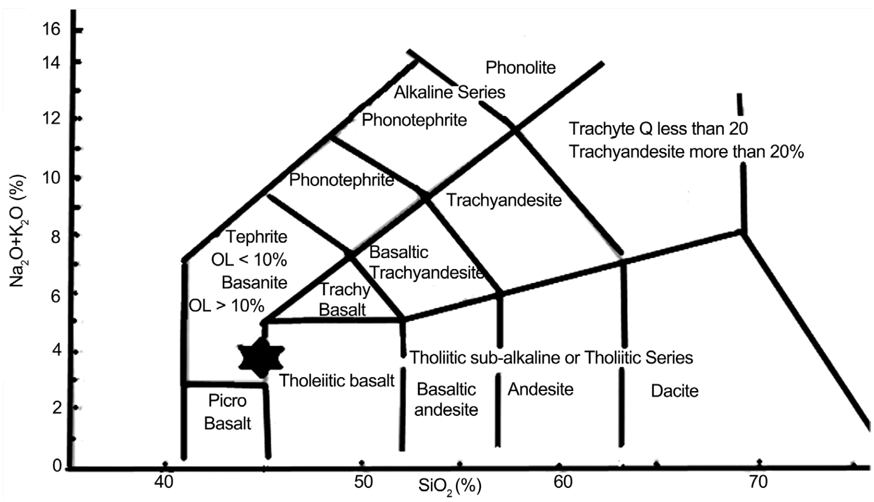

Figure 6. The star shows the location of the studied samples type (Basanite-Tholeiitic type) regarding the Total Alkali-Silica diagram (TAS).

4. Conclusions and Recommendations

New basaltic intrusion was identified for the first time in Maasser El Chouf at Lebanon. This intrusion has intersected the Lower Cretaceous-Jurassic rocks in the region. The research involved thorough field inspections, geological mapping, mineralogical examinations, and chemical testing on eight basalt samples. These collective efforts aimed to provide a comprehensive understanding of the mineralogy, petrography, and chemical composition of the newly discovered basaltic intrusion.

This study contributes to the understanding of the geological history of Lebanon, which is a part of the Red Sea Rift System, marked by significant tectonic activities through the territory of Lebanon. The basaltic intrusions in Lebanon, including Maasser El Chouf are associated with volcanic activity during the Pliocene age, possibly originating from deeper intrusive magmatic bodies. Their thickness and spatial extent at different localities and levels indicates the existence of volcanic activity in the Pliocene age (<2 Ma). This volcanic activity is related to the opening of the Red Sea Rift System, which has caused extensive tectonic movements in the region. It could be argued that the basalt of Lebanon is a part of the major trend of volcanic eruption at the Harrat Ash Shaam Basalt, which covered lava plateau stretching over about 1000 km in NW-SE direction, from Lebanon, Palestine, Syria through Jordan to Saudi Arabia. This volcanic province is one of the largest volcanic plateaus in the Middle East and it can be considered as important source for basalt rock and industrial minerals like volcanic tuff and zeolite minerals.

The results revealed that the basalt at Maasser El Chouf is characterized by the presence of calcic-plagioclase feldspar (anorthite), pyroxene-augite, olivine, and secondary minerals like iron oxides (ilmenite and magnetite). The essential mineral assemblage of Maasser El Chouf indicated that the most common mineral is plagioclase (35% - 38%), pyroxene (augite) (24% - 29%), Olivine (22% - 26%), and iron oxides (magnetite and ilmenite) (5% - 8%), accessory and secondary minerals (1% - 3%), respectively. Notably, it was observed a significant alteration of olivine to iddingsite, indicating a highly weathered and chemical process. The chemical composition of the basaltic samples regarding TAS classification suggests an ultrabasic-basic type, specifically Basanite-Tholeiitic basalt type. These basalts differ from Mid-Ocean Ridge Basalts in their much higher concentrations of K_2O, P_2O_5, Cr, Sr, Ni and Zr, and their relatively lower concentrations of Mn, Cu, Ir and Zn. The XRD results supported the petrographic and chemical studies and also indicated the presence of the plagioclase (anorthite), pyroxene (augite) and olivine minerals.

In summary, this research sheds light on the previously unrecognized basalt intrusion in Maasser El Chouf, and provides valuable insights into the geological, mineralogical, and chemical characteristics of this unique basaltic formation. These findings contribute to the broader understanding of the geology of Lebanon and its tectonic history, adding to the body of knowledge about the region's volcanic-geological evolution. On the other hand, given that the Maasser El Chouf region is considered as a natural reserve, the discovery of this basalt intrusion within topmost part of the area for the first time, we recommend that it be one of the most important points that can be included on the tourist map of the region to attract tourists and enjoy its geological features.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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