Al-Mukhtar Journal of Basic Sciences 00 (0): 01-09, 2026
Doi: https://doi.org/10.54172/zvtpy966

Research Article **Open Access**

Magmatic Differentiation and Silica Saturation Trend in the Alkaline Volcanic Suite of Jabal Al Hasawna, West Central Libya

Malik Othman[1*]

***Corresponding author:** malikotman76@gmail.com
Department of Geology, Misurata University, Libya

Received:
13 December 2025

Accepted:
05 May 2026

Abstract

Magmatic differentiation is one of the important factors which lead to the diversity seen in igneous rocks. This work aims to understand the processes that occurred to the alkaline magma that produced these volcanic rocks in the Jabal Al Hasawna region. The study was conducted as a follow-up to a preliminary report done by the Libyan Industrial Research Centre in 1978 on the volcanic rocks in the study area. The study concentrated on the major elements of the rocks being examined. The research paper is based on twenty-four samples, classified as one quartz-trachyte, five trachyte, nine phonolite and eight nepheline-phonolite samples. The work indicates magmatic differentiation processes of undersaturated alkaline melt differentiated into oversaturated alkaline magma formed a volcanic lava flow, perhaps at multiple batches. The study concluded that differential processes occurred for the remaining magma, rather than primitive processes, claiming that the mantle signature may not have been present, although relying on major elements alone may not be sufficient to track this matter. Therefore, the study needs more data relating to rare elements, and this is one of the limitations of this work.

Keywords: Magmatic Differentiation; Silica Saturation; Major Elements; Volcanic; Hasawna; Phonolites.

INTRODUCTION

Jabal Al Hasawna is considered one of the volcanic provinces in Libya, like Jabal al-Sawda and Jabal Al Haruj al-Aswad in central Libya. These are believed to have formed in intra-continent setting as an extension of the African tectonic plate that affected and formed the Sirte Basin (Elshaafi & Gudmundsson, 2016).

Jabal Al Hasawna is predominantly composed of alkaline basaltic and phonolite volcanic rocks that came to surface as lava flow during the Tertiary period (Jurak, 1978a). Like other volcanic regions in Libya, Jabal Al Hasawna has not received deep investigation. Although Jabal Al Hasawna is adjacent to Jabal al-Sawda, a difference in volcanic rocks can be observed, namely the presence of phonolite in Jabal Al Hasawna, while it is absent in Jabal al-Sawda (Jurak, 1978a).

The volcanic rocks in the Jabal Al Hasawna area were classified into four groups, namely quartz-bearing alkaline trachyte, which was found only in one location, and this rock represents the oversaturated volcanic rocks of the Tertiary period (Jurak, 1978a). The second type is alkaline trachyte, which does not contain nepheline. The third type is phonolite, which contains about 10% nepheline. The fourth type is nepheline-rich phonolite, where the nepheline content exceeds 20% and sometimes reaches 50% (Jurak, 1978a). Trachytes and phonolites are found not only in Jabal Al Hasawna, but they have also been documented, but in minor quantities, among the extrusive igneous rocks of Jabal Gharyan (Lustrino, et al., 2012).

It is worth noting that phonolite contains the mineral eudialyte, and this mineral is often found in alkali pegmatite and syenite, and is rarely found in phonolite (Bordet, Freulon, & Le Franc, 1955). The eudialyte mineral in the phonolite rock in the Hasawna region was formed at a late stage of the forming of the rock and it has a volatile nature and contains small proportions of rare earth elements (REE) (Busrewil & Oun, 1991).

LOCATION OF STUDY AREA:

Jabal Al Hasawna is located approximately 300 km south of Misurata city. It is a desert area covered with Tertiary volcanic rocks, located in west-central Libya. The study location lies between latitudes 28° 00’ N and 28° 40’ N and longitudes 13° 45’ E and 14° 25’ E (Figure 1).

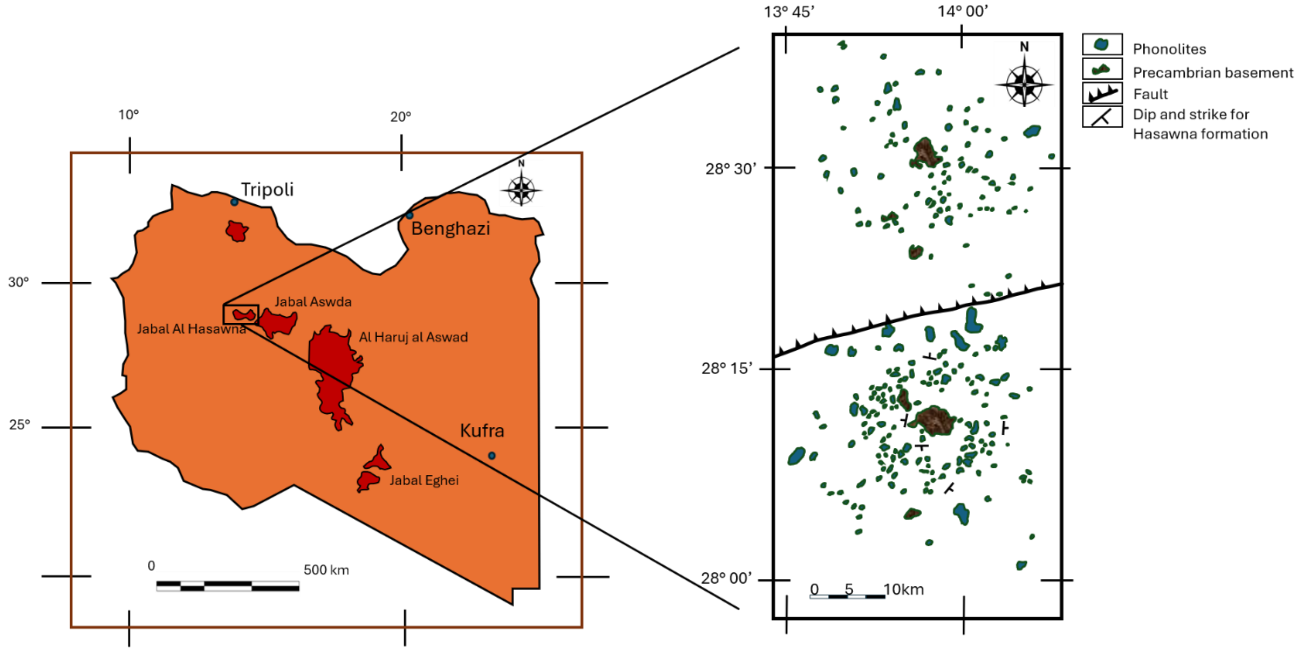

Figure: (1). Map of Libya showing the location of Jabal Al Hasawna within the Cenozoic volcanic flows (Modified after (Capitanio, Faccenna, Funiciello, & Salvini, 2011)) and distribution of phonolites in the Jabal Al Hasawna region (Jurak, 1978a).

METHODOLOGY

The methodology in this research relies on geochemical analysis of rock samples, which includes determining the percentage of major oxides in 24 rock samples. These analyses were taken from the explanatory booklet prepared by the Industrial Research Center for the Al-Hassuna region. The rock analysis, performed using laboratory methods, involves grinding the rock samples and then using X-ray spectroscopy to obtain the percentages of the major oxides that constitute the igneous rock under study.

However, it should be noted that no sample analyses were conducted in this study; rather, the data were derived from previously published analyses, which were clearly cited. The current study builds upon previous research, providing explanations not addressed in earlier studies. This is characteristic of scientific research that builds upon and starts where previous research left off. While the analysis in the previous study included the percentages of the major elements, it did not explain them within the context of magmatic differentiation. Therefore, this study aims to complement that work and add scientific explanations based on the principles of magmatic differentiation and silica saturation trend.

The methodology relies on the use of the GCDkit application, which establishes binary relationships between major elements, particularly between silica and other elements such as iron, magnesium, potassium and others, and classifies the extrusive igneous rocks that are the subject of this study.

From these relationships, magmatic evolution in the region might be explained and understood, and from this, also may be able to understand the tectonic conditions of the area and perhaps link them to the region as a whole, or at least contribute to enriching scientific research in the study area, especially since igneous rocks in Libya have not received the same level of attention as sedimentary rocks. Although the study was based on valuable data which is the major elements in the rock samples, the study did not address the quality of that data, and this is also considered one of the limitations of the study.

Geological Setting

Jabal Al Hasawna is one of five volcanic provinces in Libya, running in a southeast-northwest direction and covering an area of 66,000 square kilometers (Goudarzi, 1980), (Lustrino, et al., 2012). These regions, from south to north, are Jabal Eghei, Al Haruj Al-Sawda, Jabal Al Hasawna, Jabal Al-Sawda, and Jabal Gharyan in the northwestern of Libya. Geologically, Jabal al-Hasawna is located within the Qarqaf arc, which is the southern boundary of the Ghadames basin and the northern boundary of the Murzuq basin. The Igneous rocks of Jabal Al Hasawna consist of a group of volcanic (extrusive) rocks that are often alkaline in composition. They are consisting of alkaline basalt, phonolite, and alkaline trachyte (Jurak, 1978a), which formed in the Cenozoic Era (Klitzsch, 1968).

These rocks resulted from the magma erupting to the surface, not at plate boundaries, especially since Libya lies within the African Craton, but rather these volcanic bodies resulted from a weakening of the continental crust caused by the reactivation of pre-existing structures due to tectonic movements such as those that formed the Sirte Basin (Abdelmoniem & Mohamed, 2014).

The volcanic flows in Jabal Al Hasawna are due to passive rifting that occur from the interaction of the African and European plates which begins at the late of the Mesozoic era. This allowed magma to rise to the surface through the pre-existing faults that has been formed as a result of this passive rifting (Abdelmoniem & Mohamed, 2014), (Finlay , Abdelmoniem, & Darren, 2014), (Elshaafi & Gudmundsson, 2016). Although the melt that formed these rocks is an evolved one which has gone through several stages and is not a primitive magma, a study in southern Libya, specifically in the Wadi Eghei, proves melt with mantle signature, represented by mantle xenoliths (Radivojevi´c, Eri´c, Turki, Tolji´c, & Cvetk, 2014).

Classification of Volcanic Rocks in Study Area

All the rocks which investigated in this work are intermediate (52 – 64 % of silica) volcanic igneous rocks, and they are also alkaline in composition (10 – 16 % of alkaline) (Figure 2). They are generally divided into phonolite and trachyte. Phonolite is further divided into two types: nepheline-phonolite, which is a rock undersaturated with silica, and phonolite. Trachyte is divided into trachyte and quartz bearing trachyte, as the latter contains quartz crystals.

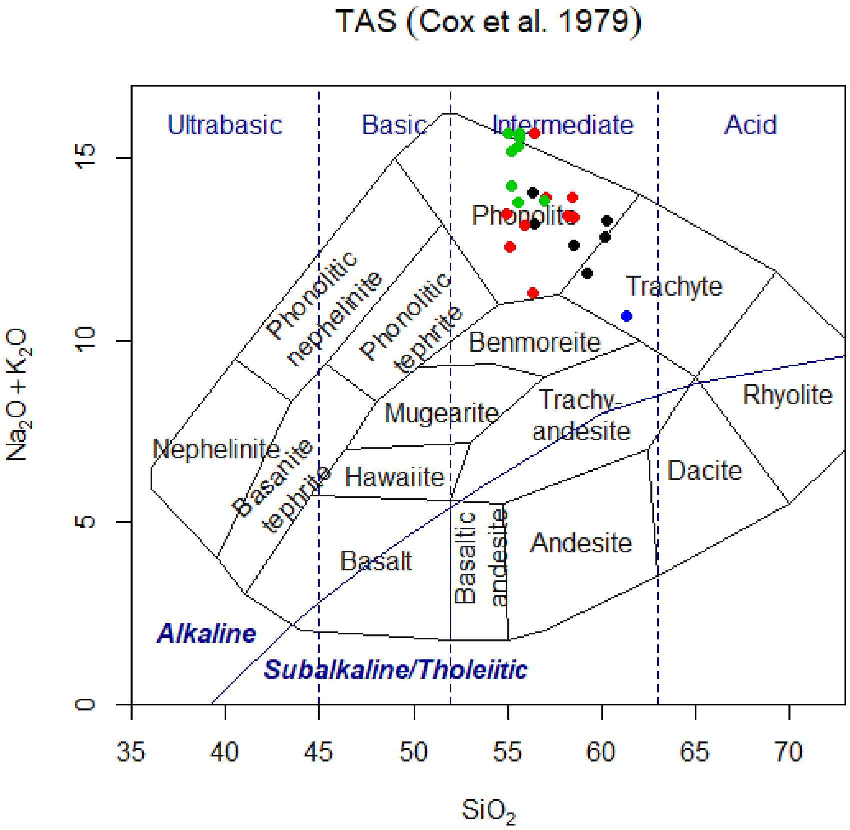

Figure: (2). Location of extrusive rocks of Jabel Al Hasawna showing distribution of samples of phonolites and trachyte (Cox, Bell, & Pankhurst, 1979)

Geochemistry and Magma Evolution

It is well established that the primitive magma has a lower silica content because it comes from the mantle. In addition, whenever a magmatic differentiation process occurs, the amount of silica increases relatively. This is due to differential crystallization. In these study samples, the work attempts to understand the rock-forming magma through the relationships between silica and other elements. In order to understand the evolution of the magma that formed these rocks, a relationship based on major elements must be established.

The main elements in oxides form obtained through the analysis of extrusive igneous rock samples from the study area (Table 1). These relationships involve silica on the x-axis and another oxide on the y-axis (Harker Plots). From these relationships, the study attempts to understand the origin and formation of the magma. A detailed presentation (Figure 3), analysis, and interpretation of these relationships follow.

1. Silica verses Alumina (SiO_2 vs Al_2O_3)

Quartz-bearing alkali trachyte has the highest SiO_2 (~61%) and the lowest Al_2O_3 (~16.8%), Alkali trachyte has SiO_2 content (~59–60 %) and Al_2O_3 is about (~17.5–18.5 %) which lower than phonolites. On the other hand, phonolite has SiO_2 contents of about (~55–58%) and relatively high Al_2O_3 (~18–20%). Nepheline phonolite, which crystalized from undersaturated magma, has the lowest silica contents SiO_2 (~54–56%) but highest Al_2O_3 (~20–21.5%). There is inverse relationship between silica and alumina in the studied samples (Figure 3a). This inverse relationship is consistent with the differential magma process. This is attributed to the relatively high silica content compared to other elements, resulting from the consumption of these elements in the formation of mafic minerals during the early stages of magma crystallization.

2. Silica verses Magnesium (SiO_2 vs MgO)

Fractional crystallization of magnesium rich phase played important role of evolving of the magma. Conversely, a lower magnesium content indicates magma evolution following the removal of magnesium-rich minerals through fractional crystallization. The variation of magnesium content in the phonolite samples may indicate multiple batches of magma of might be phenocrysts accumulation of magnesium rich crystals. It is observed from the plot (Figure 3b) that the less evolved magma forms nepheline-phonolite, while quartz bearing trachyte, crystalize from a more evolved magma, which resulted in it being less mafic.

Table (1): Major elements analyses of the studied samples of lava flow of Jabal Al Hasawna (Jurak, 1978a).

Sample	1	2	3	4	5	6	7	8	9	10	11	12
SiO2	61.31	60.26	60.22	59.26	58.56	58.51	58.48	58.17	57.02	56.95	56.43	56.41
Al2O3	16.83	18.28	18.03	17.72	19.09	18.17	18.96	20.1	18.55	21.3	20.69	21.67
Fe2O3	3.89	2.6	3.22	2.64	2.27	3.51	2.22	2.44	2.88	1.94	1.96	2.15
FeO	0.69	2.2	1.6	2.6	1.63	1.28	2.35	1.3	1.02	1.51	1.28	0.81
MgO	0.26	0.08	0.19	0.6	0.07	0.38	0.05	0.17	0.43	0.24	0.03	0.34
CaO	1.51	0.92	0.97	2.17	1.36	1.39	0.99	1.39	1.61	1.59	1.02	1.15
Na2O	6.79	8	7.8	7	8.05	7.4	8.45	8.09	8.55	8.9	9.9	8.32
K2O	3.87	5.3	5.05	4.85	5.35	5.2	5.5	5.34	5.4	4.94	5.8	4.88
TiO2	0.19	0.11	0.11	0.48	0.2	0.12	0.19	0.39	0.31	0.33	0.2	0.4
P2O5	0.4	0.09	0.08	0.16	0.05	0.08	0.06	0.23	0.08	0.26	0.06	0.08
MnO	0.18	0.22	0.21	0.22	0.23	0.27	0.27	0.19	0.22	0.22	0.18	0.16
volatiles	3.77	1.27	1.88	1.6	2.57	3.04	1.84	1.85	3.28	1.35	1.93	2.92
Total	100.23	100.86	100.88	100.1	100.23	100.03	100.17	100.51	99.05	100.67	100.27	99.56

Sample	13	14	15	16	17	18	19	20	21	22	23	24
SiO2	56.35	56.34	55.94	55.68	55.66	55.53	55.52	55.24	55.2	55.15	55	54.97
Al2O3	20.43	19.4	19.38	21.25	20.91	21.12	20.29	21.13	20.5	19.96	21.63	19.49
Fe2O3	1.86	2.55	3.18	1.76	2.06	1.69	2.45	1.93	2.17	2.87	1.63	3.5
FeO	1.96	1.54	1.22	1.23	1.3	1.33	0.73	1.25	0.8	0.73	1.33	0.61
MgO	0.45	0.3	0.2	0.12	0.1	0.22	0.08	0.08	0.39	0.57	0.17	0.24
CaO	2.18	2.92	1.82	1.41	1.43	2.15	0.54	1.42	1.26	1.07	1.62	1.38
Na2O	8.53	7.07	7.25	9.5	9.55	7.85	10.85	9	8.89	8.58	9.64	8.58
K2O	5.52	4.22	5.9	6.2	6	5.95	4.5	6.2	5.37	3.99	6.05	4.89
TiO2	0.6	0.23	0.31	0.26	0.31	0.38	0.26	0.26	0.29	0.42	0.34	0.3
P2O5	0.14	0.25	0.07	0.03	0.07	0.07	0.02	0.04	0.05	0.26	0.07	0.04
MnO	0.19	0.25	0.34	0.16	0.18	0.14	0.29	0.2	0.24	0.19	0.18	0.29
volatiles	1.38	4.24	4.06	1.79	1.75	2.93	3.82	2.57	4.24	5.46	2	5.05
Total	100.25	99.53	100.39	100.37	100.27	100.1	100.8	100.5	100.36	99.06	100.33	99.68

Volatiles = CO_2, Cl, S, and H_2O

3. **Silica verses Iron (SiO_2 vs FeO)**

   The Harker SiO_2 vs FeO plot (Figure 3c) shows a direct relationship for the studied samples. Generally, the diagram illustrates the fractional crystallization of iron-bearing silicate minerals. It observed that the quartz bearing trachyte rock sample represents a more evolved magma. Quartz-bearing alkali trachyte, which is the most evolved magma in the studying samples, has a very low FeO content (~0.6%) which means that Fe-rich minerals have been fractionated out and removed from the melt. Alkali trachyte samples have FeO ranging from (0.75% – 2.5%) which represent moderate evolve magma. The wide range of iron content within this rock samples may be due to crystallization of Fe-Ti oxides such as magnetite and ilmenite, or might be due to accumulation of iron-rich phenocrysts such as clinopyroxene and amphibole.

4. **Silica verses Calcium (SiO_2 vs CaO)**

   The relationship between silica and calcium is inverse (Figure 3d), which is normal during the development of alkaline magmas where the proportion of silica increases relatively with the decrease of calcium. This indicates fractional crystallization of plagioclase and clinoperoxene, and their removal from the system as the magma continues to evolve. This leads to the withdrawal of calcium in the early and middle stages of magma crystallization. Quartz trachyte, with a calcium content of approximately (1.2%), is the most evolved rock formed from calcium-poor magma. The remaining magma is very quartz-rich and highly alkaline. Alkali trachyte, with a calcium content ranging from (1.3% to 2.2%), supports the removal of plagioclase and pyroxene from the system. Phonolite has calcium ranging from (1.0 to 2.5%), which shows mid-evolved melt.

5. **Silica verses (SiO_2 vs Na_2O+K_2O)**

   The plot (Figure 3e) reveals the developing of the melt and also provides insight into its alkalinity. Nepheline phonolite has a high alkalinity content (10% - 12%). This supports the claim that it was not formed from primitive magma but from residual melt. That is because primitive magmas are low in alkalinity with low silica. Phonolites contain a lower percentage of silica (56%-58%) and a lower alkali content (9%-11%) compared to nepheline phonolite. Phonolites appear scattered in the diagram, which may give the impression of multiple magma pulses. This is consistent with interpretations obtained from previous diagrams such as calcium, iron, and magnesium verses silica plots.

6. **Silica verses Titanium (SiO_2 vs TiO_2)**

   The presence of titanium in magma is most often represented by oxide minerals such as ilmenite, or titanite. This means that the titanium content in the magma decreases as these minerals crystallize, thus depleting the magma of this element. In other words, the higher the silica content (progress of magma differentiation), the lower the titanium content, (Figure 3f). The early crystallization of pyroxene may also have contributed to the development of titanium-poor magma. However, the trachyte samples exhibit a somewhat random distribution, ranging from low to high titanium content, which could indicate accumulation of titanium- and iron-rich phases within these samples.

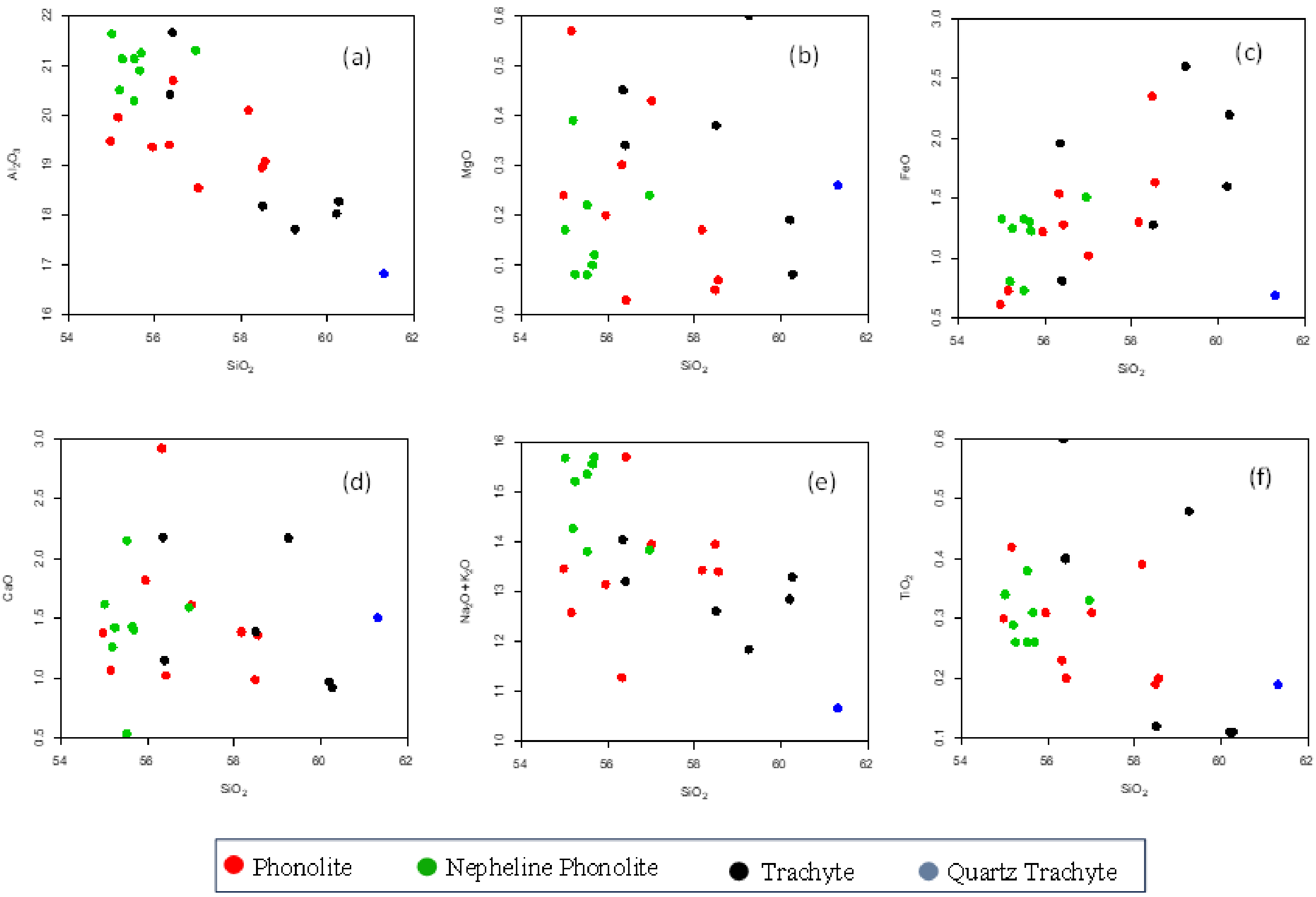

Figure: (3). Harker plot showing SiO_2 vs (Major elements) for all samples: Quartz-alkali trachyte, alkali trachyte, phonolite and nepheline phonolite.

DISCUSSION

Early Fe-Mg mineral crystallization played a significant role in the evolution of the magmatic system that under gone magmatic differentiation. Phonolite samples demonstrate enrichment of iron which in lines typical alkaline systems. Nepheline phonolites have not been formed directly from primitive magma, but rather crystallized from residual melt that underwent a magmatic evolution process. The variation of FeO contents within the samples reflects multi batches of magma, or variable phenocrysts accumulation. The alkaline continental rift environment can explain the geological setting of the region. The presence of different types of extrusive igneous rocks in the study area, ranging from nepheline phonolite resulting from silica-poor alkaline magma to quartz trachyte, is likely due to their formation in different lava batches.

CONCLUSIONS

The study, revealed through geochemical relationships between the major elements, that the volcanic rocks in the study area were formed through differential magma processes, predominantly characterized by fractional crystallization. This resulted in four types of rocks representing different stages of magmatic differentiation: nepheline phonolite, phonolite, alkali trachyte, and quartz-bearing alkali trachyte.

The study also showed an increase in silica content as the magma evolved. The crystallization of mafic minerals reduces alumina while increasing silica due to the depletion of alumina from the remaining magma caused by this crystallization. This is further supported by a decrease in calcium and magnesium as the magma goes through the differentiation, also due to the crystallization of mafic minerals such as pyroxene and ca-plagioclase. Consequently, the remaining magma becomes increasingly rich in silica.

The alkalinity of the magma, may indicate that the magma evolved towards increasingly alkaline compositions, which formed nepheline phonolite. This represents a highly evolved, silica-undersaturated residual magma. However, the presence of a scattered distribution of phonolite in the silica-alkali diagram may indicate an open magma system or the possibility of multiple magma pulses.

Over all, there are possibly two paths for magma. The first path, in the differentiation stage, involved the production of highly alkaline, silica undersaturated magma, which formed phonolite and nepheline phonolite rocks. In contrast, the second path formed, by way of differentiation, of a silica-enriched, low-alkali magma, which resulted in trachyte and quartz trachyte rocks.

Duality of interest: The authors declare that they have no duality of interest associated with this manuscript.

Funding: No specific funding was received for this work.

REFERENCES

Abdelmoniem , M., & Mohamed, A. (2014). Composition and age of Cenozoic volcanism in Libya. *PhD thesis. Scottish Universities Environment Research Centre (SUERC). http://theses.gla.ac.uk/5517.*

Bordet, P., Freulon, J., & Le Franc, J. (1955). Phonolite a eudialyte du Jebel Fezzan. *Bull. Soc. Franc. Min. Crist., 78, 425–31.*

Busrewil, M., & Oun, K. (1991). Geo-chemistry of the Tertiary alkaline volcanic rocks of Jabal Al Hasawinah, Libya. *In Third Symposium on the geology of Libya.*

Capitanio, F., Faccenna, C., Funiciello, R., & Salvini, F. (2011). Recent tectonics of Tripolitania, Libya: an intraplate record of Mediterranean subduction. *In: Van Hinsbergen,D.J.J., Buiter, S.J.H., Torsvik, T.H., Gaina, C., Webb, S.J. (Eds.), Formation and Evolution of Africa: A Synopsis of 3.8 Ga of Earth History: Geological Society London, Special Publications, 357, pp. 319–328.*

Cox, K., Bell, J., & Pankhurst, R. (1979). *The interpretation of igneous rocks.* Allen and Unwin, London, p 450.

Elshaafi , A., & Gudmundsson, A. (2016). Volcano-tectonics of the Al Haruj volcanic province, central Libya. *Journal of volcanology and geothermal research 325 (2016) 189-202.*

Finlay , S., Abdelmoniem, M., & Darren, M. (2014). The origin of Cenozoic magmatism of Libya. *Geophysical Research Abstracts Vol. 16, EGU2014-15877, 2014 EGU General Assembly 2014.*

Goudarzi, G. (1980). Structure-Libya. *In: Salem, M.J., Busrewil, M.T. (Eds.), The geology of Libya, vol. III. Academic Press, London, pp. 879–892.*

Jurak, L. L. (1978a). *Geological map of Libya 1:250,000 sheet Jabal Al Hasawanh NH 33-14, Explanatory booklet.*

Klitzsch, E. (1968). Der basalt vulkanismus des Djebel Harudj, Ost-Fezzan, Libyen. *In Vol. 57 (pp. 585-601). 1968, Stuttgart*.

Lustrino, M., Cucciniello, C., Melluso, L., Tassinari, C. C., dè Gennaro, R., & Serracino, M. (2012). Petrogenesis of Cenozoic volcanic rocks in the NW sector of the Gharyan volcanic field, Libya. *Lithos 155 (2012) 218–235*.

Radivojevi´c, M., Eri´c, S., Turki, S. M., Tolji´c, M., & Cvetk, V. (2014). Textural and compositional characteristics of mantle xenoliths from southeastern Libya: Evidence of mantle refertilization processes. *Geophysical Research Abstracts. Vol. 16, EGU2014-7945, 2014. EGU General Assembly 2014*.