



Afghan International Journal of Science (AIJS)

Publisher: Afghan International Islamic University

Website: <https://aijs.aiiu.edu.af>

e-ISSN: 3134-5859

Petrographic and Geochemical Investigation of Dasht-e-Nawur Volcanic Rocks, Ghazni Province, Afghanistan

Shah Hussain Shafayi^{1*}, Sayed Aziz Sadat² and Mohammad Naeem Sarwary³

¹ Ghazni Technical University, Department of Geological Engineering and Exploration of Mines, Ghazni, AF

^{2&3} Kabul Polytechnic University, Department of Geological Engineering and Exploration of Mines, Kabul, AF

Abstract

The Dasht-e-Nawur volcanic basin is one of the largest and best-known volcanic provinces in Afghanistan. This study investigates the petrographic characteristics, geochemical composition, and geotectonic setting of the volcanic rocks to clarify their magmatic evolution and tectonomagmatic origin. We systematically collected about ten representative rock samples. We performed petrographic analyses on thin sections using a polarizing microscope and determined major and trace geochemistry by X-ray. Petrographic observations indicate that the volcanic suite mainly comprises andesite, quartz andesite, trachy-andesite, and andesitic dacite, with predominantly porphyritic textures and massive structures. The main mineral assemblages include plagioclase, hornblende, biotite, and quartz. Geochemically, the rocks display intermediate to acidic compositions ($\text{SiO}_2 = 63\text{--}79$ wt.%) and belong to the calc-alkaline to alkaline magmatic series. Primitive mantle-normalized spider diagrams reveal enrichment in large-ion lithophile elements (LILE) together with marked negative Nb, Sr, P, and Ti anomalies, indicating a subduction-modified mantle source and extensive fractional crystallization of plagioclase, apatite, and Fe-Ti oxides. The volcanism of Dasht-e-Nawur is interpreted to be related to the Indian-Eurasian continental post-collision. Advanced fractional crystallization, accompanied by crustal assimilation and lithospheric thickening, primarily controlled magmatic evolution. Future research should therefore focus on high-resolution isotopic studies and accurate geochronological dating to enhance understanding of crust-mantle interactions and clarify the post-collisional magmatic and tectonic evolution of the south-central volcanic rocks.

Keywords: Dasht-e-Nawur, Geochemistry, Petrography, Tectonic setting, X-ray Fluorescence, Volcanic basin

Article History

Published: September 30, 2026

Accepted: August 05, 2026

Revised: July 12, 2026

Received: May 16, 2026

Cite as: Shafayi, S. H., Sadat, S. A., & Sarwary, M. N. (2026). Petrographic and Geochemical Investigation of Dasht-e-Nawur Volcanic Rocks, Ghazni Province, Afghanistan. *Afghan International Journal of Science*, 2(3), 364-381. DOI: <https://doi.org/10.66546/aijs.v2i3.85>

Introduction

The Dasht-e-Nawur basin, located at approximately 33°50'N and 67°50'E in the south-central Afghan Highlands, is one of the most significant and unique geological and ecological features in Ghazni Province (Hayes, 2018; Ostrowski et al., 2010). This elliptical, endorheic basin lies at an elevation of roughly 3,150 to 3,158 meters above sea level within the Koh-e Baba range, an offshoot of the Hindu Kush. Beyond its striking landscape, Dasht-e-Nawur is of exceptional

*Email: shafae26@gmail.com (corresponding author)

Link to this article: <https://aijs.aiiu.edu.af/index.php/aijs/article/view/85>

international importance as a wetland habitat, serving as a critical stopover site for migrating waterbirds and the world's highest breeding haunt for the Greater Flamingo (*Phoenicopterus roseus*) (Hayes, 2018; Ostrowski et al., 2010; Ostrowski et al., 2008). Additionally, the region holds archaeological significance as the site of a documented prehistoric obsidian tool-making industry, centered around the only confirmed geological deposit of obsidian in Afghanistan (Boulanger et al., 2012; Hayes, 2018).

From a geoscience and resource perspective, the basin has become a primary target for mineral exploration due to its potential for evaporative deposits, specifically lithium (Li) brines and boron (B) (Mack, 2020; Stillings et al., 2015). Geochemical indicators, including mineralized springs and dry lake sediments, suggest that the basin's geological environment is analogous to the high-altitude lithium-rich salars of the Andes in Bolivia and Chile (Hayes, 2018; Stillings et al., 2015). Recent hyperspectral investigations have further confirmed lithium-bearing minerals such as hectorite and lepidolite, alongside borax and gypsum, across the dry lake surface (Azizi, 2023).

The geological evolution of the Dasht-e-Nawur basin is closely tied to a major Pliocene-Quaternary volcanic complex covering approximately 4,000 km² (Abdullah et al., 2008; Vikhter et al., 1978). The basin itself is interpreted as a volcanic-tectonic depression or caldera formed by collapse following massive eruptions of tuffs and lavas during the Pleistocene (Abdullah et al., 2008; Hayes, 2018; Stillings et al., 2015). This volcanic activity, spanning approximately 2.8 Ma to 0.6 Ma, produced an estimated 100 km³ of igneous material, dominated by a sequentially differentiated dacite-andesite series. Major volcanic edifices, such as the Zarkadak and Mamikala stratovolcanoes, exceed 10 km in base diameter and define the southern margin of the structure (Abdullah et al., 2008; Vikhter et al., 1978).

Petrochemically, these volcanic products belong to a normal calc-alkaline series, characterized by distinctly porphyritic textures (10–60% phenocrysts) and regular variations in rock-forming oxides (Vikhter et al., 1978). The presence of chloride-sulfate thermal springs and alteration minerals such as montmorillonite, hydrous silica, and alunite, consistent with solfatara and fumarolic activity, indicates a persistent hydrothermal system (Hayes, 2018; King et al., 2014; Smith, 1975; Vikhter et al., 1978).

Dasht-e-Nawur lies within the Helmand-Arghandab median massif, a major tectonic block that has experienced significant activation during the ongoing collision between the Indian and Eurasian plates (Vikhter et al., 1978). This region is the most structurally complex part of Afghanistan, characterized by a dominant northeast-to-southwest-striking fabric of folds and faults (Hayes, 2018; Stillings et al., 2015). Older metamorphic (Middle Proterozoic) rocks occur at fault contact with younger sedimentary units to the east and southeast of the plateau, known as the Nowabad Series (Abdullah et al., 2008; Stillings et al., 2015). The surrounding mountains consist primarily of Paleozoic to Mesozoic clastic sedimentary rocks, including siltstone, sandstone, limestone, and dolomite (Hayes, 2018; Stillings et al., 2015). The thickest section of the Middle and Upper Devonian sequence from the northern part of the Dasht-e-Nawur (Dasht-e-Nawur series) consists of limestone, slates, quartzose sandstones, and shales. At the northern end, Upper Devonian sandstone and limestone are in contact with younger volcanic products (Figure 1) (Abdullah et al., 2008; King et al., 2014).

An undifferentiated Carboniferous – Lower Permian sequence is recognized in the Dasht-e-Nawur. In this region, it is divided into three units, Wakak, Bokan, and Dony-Yakhshy, consisting of variegated and grey, predominantly quartzose, sandstones, shales, and siltstones with a bed of organogenic limestone in the lower part (Abdullah et al., 2008). The Upper Permian sequence, which consists of limestone, dolomite, sandstone, and conglomerate, is widely spread across the Dasht-e-Nawur. Additionally, the Triassic and Jurassic sequences consist of limestone, dolomite, clay, sandstone, and conglomerate, and are located in the northwest region of Dasht-e-Nawur (Abdullah et al., 2008). The depression is filled with thick layers of Quaternary alluvium, lacustrine silts, and sticky clays (Hayes, 2018; Stillings et al., 2015).

Late Mesozoic to early Cenozoic intrusive igneous rocks, such as granodiorites and granites, are mapped south and northeast of the basin (Abdullah et al., 2008; Stillings et al., 2015). Volcanism in Dasht-e-Nawur occurred from the late Pliocene to the middle Pleistocene (approximately 2.8 Ma to 0.6 Ma). The rocks belong to a sequentially differentiated calc-alkaline dacite-andesite series displaying an antidromous nature. More than ten major stratovolcanoes have been identified, with the largest (Zarkadak and Mamikala) exceeding 10 km in base diameter (Abdullah et al., 2008; Vikhter et al., 1978). Passive seismic surveys indicate that these sediments reach a maximum thickness of at least 150 m in the north and 247 m in the south (Azizi, 2023; Mack, 2020). Dasht-e-Nawur contains the only documented obsidian deposit in Afghanistan, located on the northern face of the Zardqadah volcanic cone (Boulanger et al., 2012). The geological environment of Dasht-e-Nawur is considered analogous to the high-altitude, lithium-rich Andes (Hayes, 2018; Stillings et al., 2015). The 361.6 km² dry lake surface (playa) is a primary target for lithium (Li) brines and boron (B) exploration (Azizi, 2023; Mack, 2020). Despite the basin's ecological and economic significance, a detailed characterization of its volcanic products is essential to understanding the regional petrogenesis.

Petrographic and geochemical analyses have been extensively utilized to characterize the evolution, fractional crystallization, and tectonic settings of igneous and volcanic systems. (Kaygusuz, 2022) In the Eastern Pontides of Turkey, Vural et al. (2021) investigated Late Cretaceous volcanic rocks using whole-rock major, trace, and rare earth element analyses. Their geochemical findings revealed a calc-alkaline character enriched in large-ion lithophile elements (LILEs) and depleted in high-field-strength elements (HFSEs), indicating a subduction-related metasomatized mantle source. Similarly, Kaygusuz et al. (2021) explored Carboniferous gabbroic rocks in the same region, using petrographic observations and major/trace element patterns to demonstrate metaluminous, calc-alkaline characteristics driven by fractional crystallization of plagioclase, hornblende, and pyroxene. In Southeast Asia, researchers have applied X-ray fluorescence (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) to delineate magma differentiation (Rohiman et al., 2019). For instance, studies on the Semporna volcanic rocks in Borneo utilized these techniques to classify the rocks within the subalkaline/tholeiitic to high-K calc-alkaline series, successfully linking negative Europium (Eu) anomalies and enriched light rare earth elements (LREEs) to fractional crystallization in an island arc setting (James et al., 2021). Comparable geochemical methodologies applied to Mount Masurai in Sumatra revealed LILE enrichment and HFSE

reduction, patterns that strongly correspond to metasomatism by fluids in a subduction zone (Rohiman et al., 2019). Furthermore, Berhanu characterized volcanic rocks in the southern Main Ethiopian Rift by combining detailed thin-section petrography with ICP-MS analysis, confirming that the units derived from an asthenospheric source with minimal crustal contamination. Advanced analytical techniques have also been integrated into these workflows; for example, researchers investigating the Tekkedağ volcanics combined standard geochemical modeling with Confocal Raman Spectroscopy (CRS) to precisely identify mineral phases, providing robust constraints on the fractional crystallization sequence of the calc-alkaline magma (Koralay, 2010).

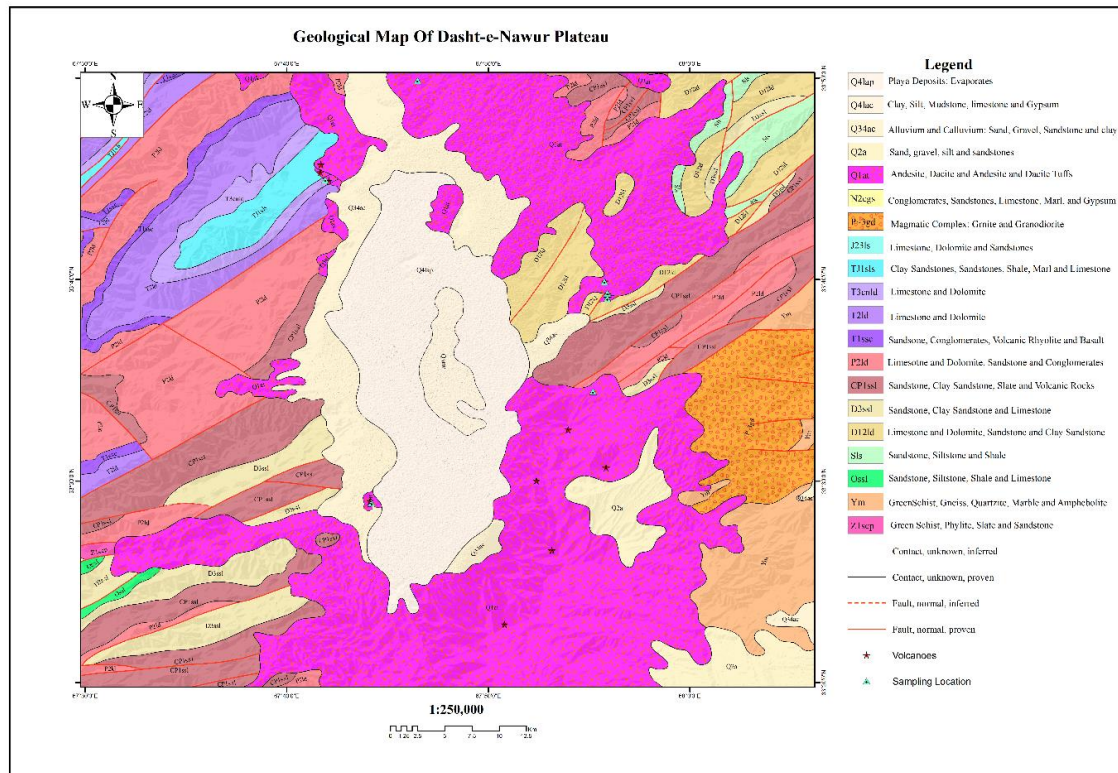


Figure 1. *Geology of the Dasht-e-Nawur, modified from Doebrich and others (Doebrich et al., 2006).*

Although the Dasht-e-Nawur volcanic field is recognized for its geological significance, previous scientific studies have primarily focused on petrography and mineral exploration. Important questions about the magma source characteristics, magmatic affinity and series, magma evolution and emplacement processes, and the region's precise geodynamic regime and geotectonic setting remain inadequately addressed. This study aims to fill this critical scientific gap by presenting the first comprehensive, integrated petrographic and geochemical investigation of the volcanic rocks in Dasht-e-Nawur. This research is novel in its use of geochemical data to identify the magma source, magmatic series, and geotectonic setting of the area, offering new insights into the petrogenesis and tectonomagmatic evolution of the Dasht-e-Nawur volcanic complex.

To address the existing knowledge gap, this study aims to answer the following research question:

1. What are the petrographic characteristics and mineralogical compositions, magmatic series, and geotectonic setting that were responsible for the generation and evolution of the Dasht-e-Nawur volcanic complex?

Materials and Methods

Field Sampling

Petrographic and geochemical studies of rocks fundamentally rely on the integrated use of field investigations and laboratory analyses. Field investigations constitute a critical component of geological research and mineral exploration, playing a decisive role in identifying, interpreting, and evaluating potential mineral resources. Through multidisciplinary approaches, these studies provide a robust framework for understanding lithological, structural, and mineralization characteristics.

Field methods in geology and mineral exploration comprise systematic activities conducted in the natural environment, aimed at directly observing geological phenomena, accurately recording field data, conducting targeted sampling, and preparing geological maps. This approach facilitates analysis of spatial relationships among rock units, geological structures, and alteration zones, thereby improving understanding of the governing geological processes.

Field studies play a central role in advancing geological investigations and provide valuable insights into the geological history, tectonic and magmatic processes, and mineralization potential of a given area. In this study, we collected 10 rock samples from different parts of the Dasht-e-Nawur volcanic rocks and submitted them to the Afghanistan Geological Survey (AGS) laboratories for detailed petrographic and geochemical analyses. The locations of the collected samples of Dasht-e-Nawur volcanic rocks are shown on the geological map (Figure 1) and in Table 1.

Table 1: Sampling locations of volcanic rocks of Dasht-e-Nawur

Number	Samples	Longitude	Latitude	Region (villages)
1	NW-01	67°55' 54.8"	33°39' 5.4"	Khaja Ghariban
2	NW-02	67°55' 55.057"	33°39' 9.9"	Khaja Ghariban
3	NW-03	67°55' 54.53"	33°39' 16.8"	Khaja Ghariban
4	NW-05	67°44' 28.5"	33°48' 56"	Emran
5	NW-07	67°46' 16.753"	33°48' 39.132"	Sarab
6	BH-1	67°41' 37"	33°45' 19.841"	Bahaey
7	BH-2	67°42' 5.356"	33°44' 52"	Bahaey
8	BH-3	67°44' 5.55"	33°45' 12.851"	Bahaey
9	NW1	67°44' 19"	33°28' 54.69"	Quriah
10	NW2	67°56' 38.5"	33°35' 51.2"	Shamsudeen pass

To determine the chemical composition, textural and structural characteristics, classification, geology, and geotectonic setting of the Dasht-e-Nawur volcanic rocks, we conducted

comprehensive petrographic and geochemical studies in the Afghanistan Geological Survey (AGS) and Kabul Polytechnic University (KPU) laboratories.

Petrographic investigation is a key analytical tool for systematically characterizing lithological units, emphasizing the identification of mineralogical paragenesis, textural relationships, and microstructural evolution. (Columbu et al., 2018; Kaygusuz et al., 2021; Koralay, 2010). Petrographic studies involve preparing and examining rock thin sections, typically ground to a transparent thickness of 30 microns, under a polarizing optical microscope. This analysis aims to identify the essential, accessory, and secondary mineral phases present in the sample (Berhanu, 2019; Columbu et al., 2018). This specialized examination helps determine key information about rock structures, textures, and arrangements. These details provide critical insights into the cooling history, rates, and crystallization sequences of igneous bodies (Kaygusuz, 2022; Koralay, 2010; Vural et al., 2021). To modify the chemical composition, structure, and texture characteristics of the Dasht-e-Nawur volcanic rocks, thin sections were prepared from the collected samples, and a polarizing optical microscope was used for detailed microscopic analysis.

Geochemical characterization is an essential discipline in modern petrology, providing critical quantitative constraints on the source characteristics, magmatic evolution, and tectonic provenance of igneous complexes (Berhanu, 2019; Boraiaha et al., 2020; Zaw, 1990). We conducted geochemical investigations to determine major and trace elements in the volcanic rocks of Dasht-e-Nawur using X-ray fluorescence (XRF) analysis. To classify the geochemical properties and determine the tectonic setting of the Dasht-e-Nawur volcanic rocks, we used the Geochemical Data Toolkit (GCDkit) software.

Findings

Petrographic Results

The volcanic rocks of Dasht-e-Nawur are widely distributed throughout the entire Dasht-e-Nawur. The most common geological features in the area are products of central eruptions. The volcanoes in this region are either dome-shaped or cone-shaped, with heights reaching up to 4,500 meters and rising 1,000 to 1,500 meters above the floor of the Dasht-e-Nawur (Figure 2). The largest volcanic structures are Zarkadah and Mamiqala, both stratovolcanoes with basal diameters of approximately 15 km (Abdullah et al., 2008). The primary volcanic rocks include andesite, quartz andesite, trachyte-andesite, and trachyte.

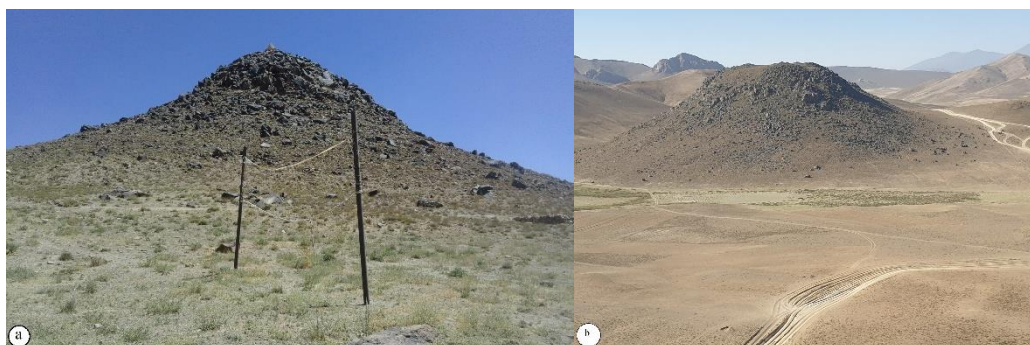




Figure 2. *Dasht-e-Nawur volcanoes: (a & b) Khaja Ghariban, (c) Bahayi, and (d) Siah-Top*

Andesite

Microscopic investigations of thin sections reveal that this rock belongs to the intermediate igneous rock group. It consists of phenocrysts of plagioclase, hornblende, and volcanic glass, along with a matrix containing biotite, pyroxene, hematite, and opaque minerals. The rocks display a porphyritic texture and a massive structure (see Figure 3a-f).

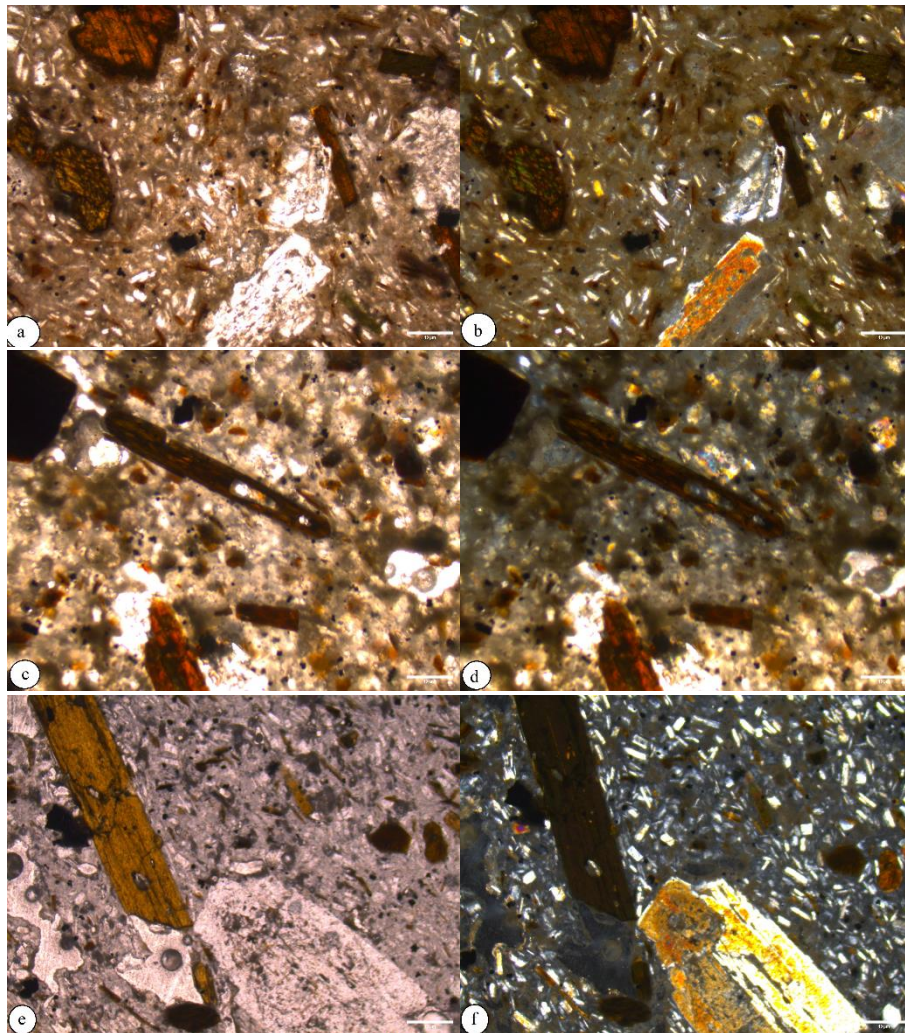


Figure 3: *Microphotographs of volcanic rock from the Khwaja Ghariban area, situated in the eastern part of Dasht-e Nawur, are presented here. In these microscopic images, plagioclase and hornblende phenocrysts are observed under (a, c, and e) plane-polarized light and (b, d, and f) crossed-polarized light.*

Thin sections from the northern region of the plateau show zonal plagioclase and hornblende phenocrysts, with a groundmass of biotite, pyroxene, quartz, hematite, and opaque minerals. These samples also exhibit a porphyritic texture and a massive structure (see Figure 4a-d).

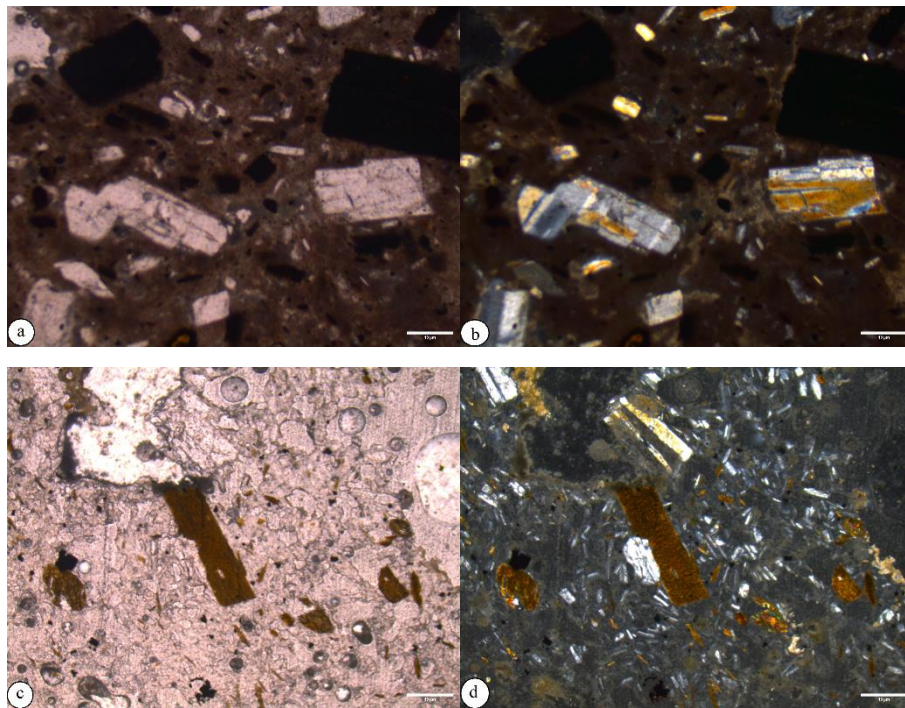


Figure 4. Polarized microscopic view of the Dasht-e Nawur volcanic rocks shows phenocrysts of zonal plagioclase and hornblende observed under: (a and c) plane-polarized light and (b and d) crossed-polarized light

The andesite rock collected from the Quriya area in the southern part of the Nawur has been analyzed using petrographic observations. These observations reveal that its primary mineral composition consists of plagioclase, quartz, and amphibole. Accessory minerals include alkali feldspar, biotite, iron oxides, and opaque phases. The rock exhibits a porphyritic texture and a massive structure, indicating a volcanic origin, formed by the rapid cooling of magma at or near the Earth's surface (See Figure 5a- b).

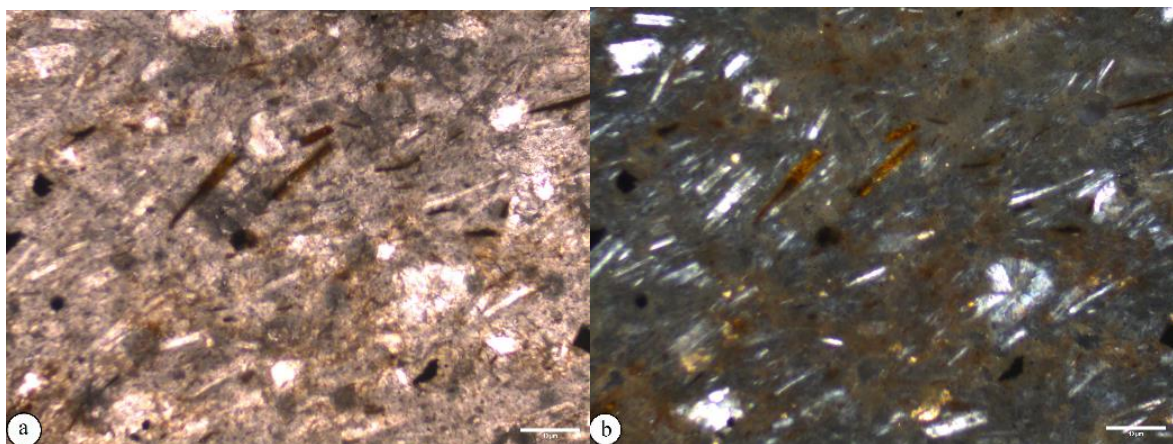


Figure 5. Phenocrysts of plagioclase, quartz, and amphibole under: (a) plane-polarized light and (b) cross-polarized light observations.

Quartz Andesite

Additionally, the thin section from Bahayi, located northwest of Dasht-e-Nawur, shows a similar porphyritic texture and massive structure. It features a distribution of phenocrysts including plagioclase, amphibole, biotite, and quartz, along with a matrix of pyroxene, iron oxides, and opaque minerals (see Figure 6a-b).

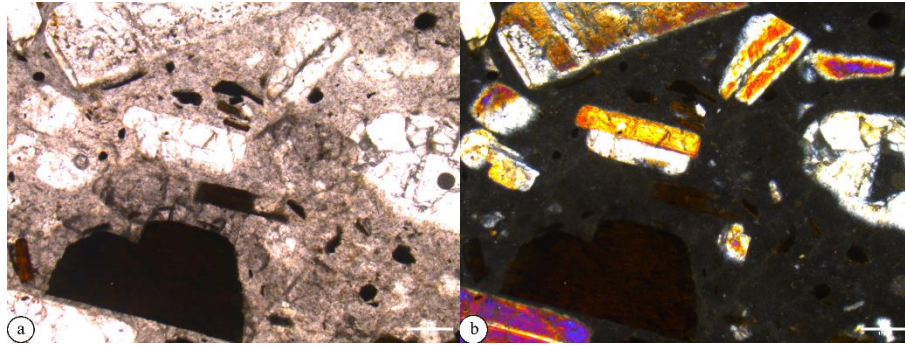


Figure 6. Microscopic view of plagioclase, amphibole, biotite, and quartz phenocrysts under: (a) plane-polarized and (b) cross-polarized observation.

This rock is characterized by a mineral composition that includes plagioclase, biotite, pyroxene, and quartz as the main components. It also contains amphibole, olivine, alkali feldspar, iron oxides, and opaque minerals within its matrix. This volcanic rock features a medium-grained texture and a massive structure. The predominance of plagioclase, along with biotite and pyroxene, suggests it formed under slow-cooling conditions deep within the Earth's crust (Figure 7a-b).

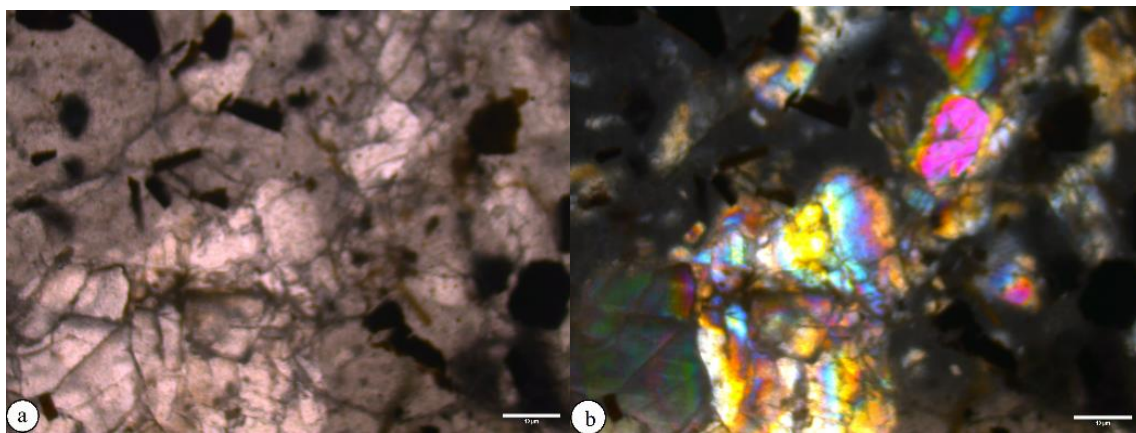


Figure 7. The microscopic features of the Bahayi quartz andesite rock from the northwest of the Nawur include: (a) plane-polarized and (b) cross-polarized observations.

Trachy-Andesite

The essential minerals found in the studied rock include plagioclase, quartz, biotite, amphibole, and quartz phenocrysts. The rock also contains accessory phases such as alkali feldspars, iron oxides, and opaque minerals. It displays a porphyritic texture and a massive structure. The optical characteristics of this thin section are shown in Figure 8a-b.

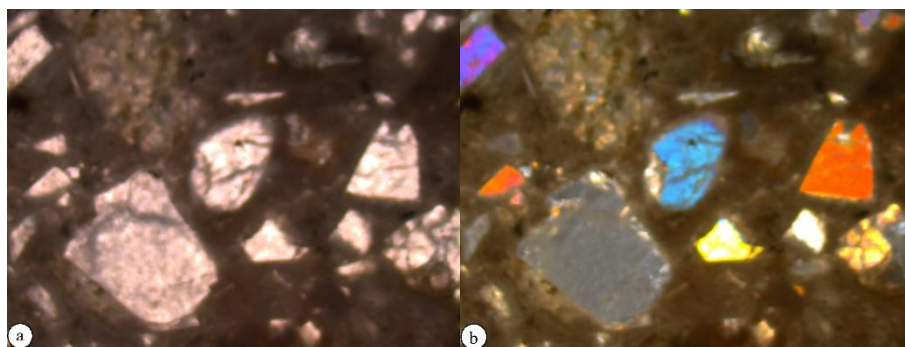


Figure 8. Plagioclase, quartz, biotite, and amphibole appear as phenocrysts under polarized microscopic observation: (a) plane-polarized light and (b) cross-polarized light.

Andesitic Dacite

The rock sample was collected at Shamsudin Pass, located east of the Dasht-e-Nawur. This rock is characterized by a phenocryst assemblage of plagioclase, quartz, and amphibole, along with accessory minerals such as pyroxene, biotite, iron oxides, and opaque phases. It exhibits a porphyritic texture and a massive structure. Based on its mineralogical composition and textural and structural characteristics, the rock is classified as an andesitic dacite (Figure 9a-b).

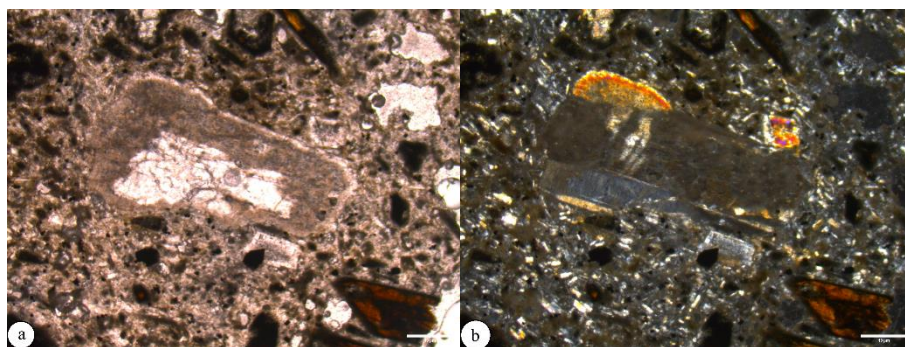


Figure 9. The microscopic view of andesitic dacite from Dasht-e Nawur is shown under (a) plain polarized light and (b) cross-polarized light observations.

Geochemical Results

Integrating geochemical studies and petrographic analysis provides a comprehensive framework for understanding petrogenetic history, classifying lithology, and interpreting geotectonic settings. These evaluations are essential for conducting high-precision geological investigations. To characterize the geochemical properties of the volcanic rocks at Dasht-e-Nawur, laboratory analyses used X-ray Fluorescence (XRF) to determine concentrations of major, trace, and rare-earth elements (Table 2).

Table 2. Geochemical characteristics of Dasht-e-Nawur volcanic rocks. Major and trace oxides in %, major and trace elements in ppm.

No	Oxides & Elements	Dasht-e-Nawur Volcanic Samples							
		BH-1	BH-2	BH-3	NW-1	NW-2	NW-01	NW-02	NW-03
1	ZnO	0.0083	0.0074	0.0037	0.0101	0.0128	0.0084	0.0089	0.0085
2	CuO	0.0006	0.0025	0.0020	0.0032	0.0038	0.0025	0.0025	0.0041
3	NiO	0.0083	0.0054	0.0047	0.0065	0.0038	0.0077	0.0082	0.0075

4	MgO	1.4017	1.7904	0.0000	1.9810	3.3180	2.5504	1.5874	2.9061
5	Al ₂ O ₃	13.1444	12.0952	10.7271	15.0686	16.3167	20.5903	17.3388	16.7389
6	SiO ₂	67.9812	64.9979	72.0693	68.6672	66.0431	78.0763	79.1652	76.0491
7	Fe ₂ O ₃	2.7296	2.7910	0.4753	3.4035	5.9705	4.2256	3.6972	4.0555
8	CaO	4.9803	5.0371	2.4340	5.1379	7.3145	4.9843	4.4730	4.8625
9	TiO ₂	0.3718	0.3409	0.0729	0.4213	0.7113	0.4603	0.4345	0.4956
10	K ₂ O	2.5588	2.7316	3.0909	2.8570	2.9007	3.1247	3.2211	3.2250
11	SO ₃	0.9832	4.0607	0.3614	0.4815	0.6264	0.7305	0.8310	0.7022
12	Cr ₂ O ₃	0.0000	0.0000	0.0000	0.0102	0.0156	0.0000	0.0000	0.0000
13	P ₂ O ₅	0.0000	0.0000	0.0000	0.3270	0.6552	0.4533	0.6104	0.3915
14	Mg	8443.85	10785.31		11933.59	19987.98	15363.97	9562.45	17506.44
15	Al	69547.19	63995.88	56757.39	79727.96	86331.76	108943.23	91739.46	88565.72
16	Si	317668.97	303728.63	336772.28	320874.72	308612.81	411571.34	369931.00	355369.38
17	P				1428.09	2861.14	1979.61	2665.38	1709.77
18	S	3932.82	16242.68	1445.77	1926.01	2505.79	2921.93	3324.15	2808.88
19	Cl	1753.29	2406.21	361.35	862.18	1424.11	1095.85	1117.70	1854.64
20	K	21147.01	22575.06	25544.38	23611.51	23972.51	25823.60	26620.44	26652.57
21	Ca	35573.42	35979.18	17385.96	36699.52	52246.24	35601.89	31950.92	74731.83
22	Sc				0.00	0.00	118.76	94.59	68.17
23	Ti	2226.23	2041.60	436.25	2522.69	4259.35	2756.55	261.54	2967.45
24	V	47.68	53.47		80.67	191.54	100.36	88.11	56.79
25	Cr				69.92	106.69			
26	Mn	611.64	373.21	312.80	683.81	839.89	858.57	773.55	870.31
27	Fe	19088.34	19517.66	3323.65	23800.95	41751.46	29549.55	25854.66	28360.12
28	Co		59.81				110.73		107.18
29	Ni	65.68	42.45		51.51		60.72	64.41	59.32
30	Cu		20.34		25.58	30.49	20.32	20.28	32.42
31	Zn	66.43	59.53	29.60	80.67	102.69	67.07	71.00	67.75
32	Rb	46.47	43.56	104.97	41.56	36.37	43.16	46.94	44.17
33	Sr	489.78	467.69	144.30	810.04	928.90	884.93	870.17	849.81

34	Zr	172.21	174.55	78.50	233.71	142.64	949.40	253.56	235.61
35	Nb	15.66	11.03	13.51	10.39	11.22	12.64	12.86	12.84
36	Mo	6.53		8.66		4.68	4.09	4.41	
37	Ba	976.67	825.34	347.22	1260.25	1244.58	1316.65	1280.49	1286.78
38	Pb	34.90	28.61	32.15	27.99	25.82	26.61	27.73	22.99
39	Bi	17.14	12.44	19.78	10.49	11.86	12.44	12.85	10.52
40	Th	16.68	12.16	20.78	13.24	10.12	13.63	12.70	9.82

Geochemical Classification

In this study, we plotted the TAS and Jensen's cation plots to classify volcanic rocks from Dasht-e-Nawur. The rocks indicate intermediate-to-acidic compositions and are characterized by significant enrichment in silica oxide (SiO_2). The silica content ranges from 63 to 79 wt.%, reflecting their intermediate-acidic to acidic nature. Based on the geochemical diagrams, the studied rocks are classified as andesite, dacite, and trachyandesite (Figure 10).

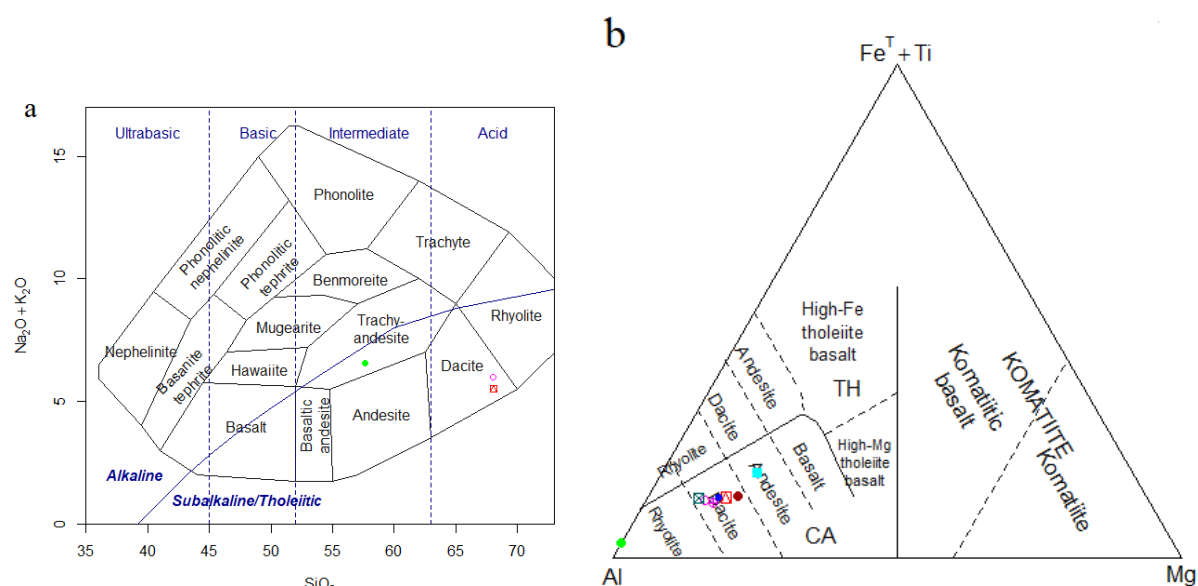


Figure 10. Geochemical classification: based on (a) TAS plot (Cox et al., 1979) and (b) Jensen's cation plot (Jensen, 1976).

The high $\text{Fe}_2\text{O}_3/\text{MgO}$ ratio, along with trace elements such as Sr, Zr, and Ba, indicates that magmatic differentiation and tectonic conditions played a significant role in forming the volcanic rocks of the Nawur platea. Geochemical studies using the magmatic series discrimination diagram developed by Miyashiro (1974) show that these rocks are part of the alkaline series (Figure 11a). These rocks formed in active tectonic settings, specifically in a subduction-zone environment, where magma was produced by partial melting of mantle and lithospheric materials. The geotectonic context of these rocks is shown in the tectonic discrimination diagram (Figure 11b), which underscores the important role of tectonic processes in the formation and evolution of these volcanic units.

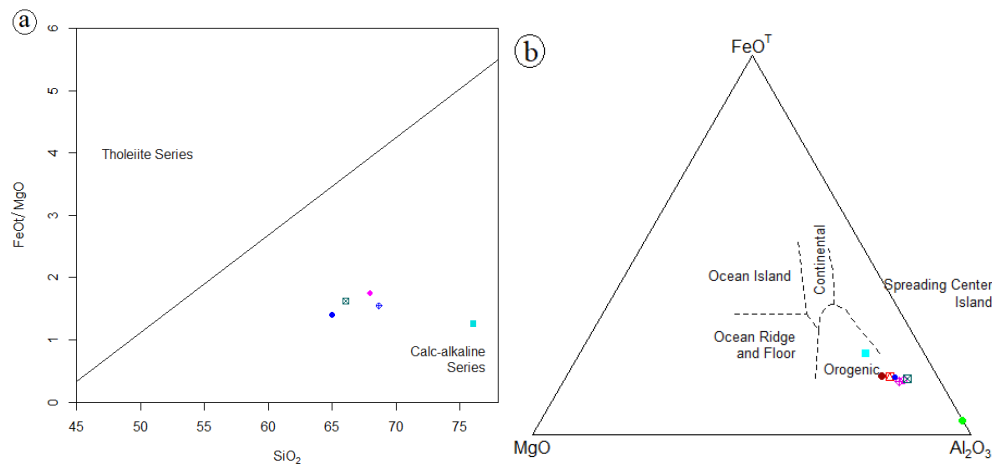


Figure 11. (a) *Calc-alkaline series* (Miyashiro, 1974) and (b) *geotectonic situation* (Pearce et al., 1977) of Dasht-e-Nawur volcanic rocks.

Tectonic Setting

Trace-element data are used to discriminate the tectonic settings of volcanic rocks in the Dasht-e-Nawur complex. The primitive mantle-normalized spider diagram based on Sun and McDonough (Sun & McDonough, 1989) shows enrichment in large-ion lithophile elements (LILE) such as Rb, Ba, Th, U, K, and Pb, indicating the influence of slab-derived fluids and crustal contamination in the magma source (Figure 12).

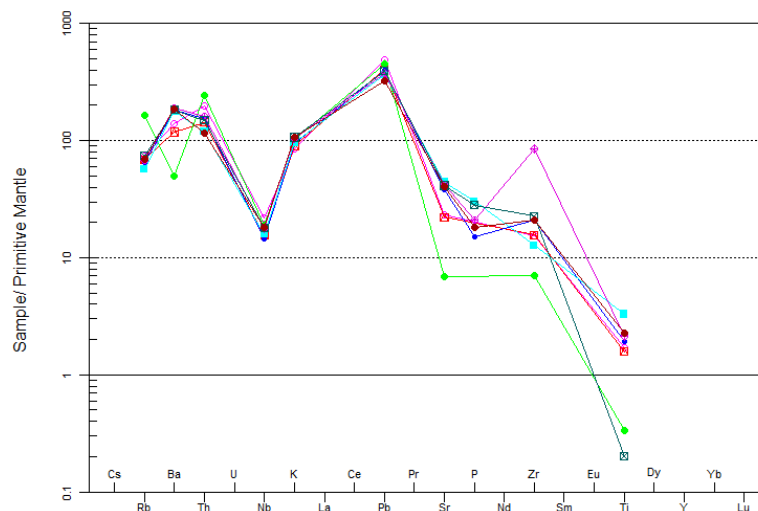


Figure 12. *Trace elements spider diagram based on the primitive mantle* (Sun & McDonough, 1989).

The pronounced negative Nb and Ti anomaly is characteristic of subduction-related volcanic rocks and suggests formation in post-collisional volcanism. Negative anomalies of Sr, P, and Ti reflect fractional crystallization of plagioclase, apatite, and Fe–Ti oxide minerals during magma evolution (Figure 12).

Discussion

The volcanic rocks of the Dasht-e-Nawur exhibit progressive differentiation from intermediate andesites to more evolved dacitic and trachytic compositions. Geochemical trends observed in TAS and Jensen diagrams demonstrate that fractional crystallization is the primary process governing magmatic evolution. Petrographic evidence, such as abundant plagioclase,

hornblende, and biotite phenocrysts, along with zoned plagioclase, indicates a dynamic magma chamber with variable cooling conditions. Trace element patterns, notably negative anomalies in Sr, P, and Ti, further substantiate fractional crystallization involving plagioclase, apatite, and Fe-Ti oxide phases.

Geochemically, the volcanic suite is enriched in large-ion lithophile elements (LILE) such as Rb, Ba, Th, and K relative to high-field-strength elements (HFSE), and exhibits pronounced negative Nb anomalies. These features indicate derivation from a subduction-modified mantle source. Elevated $\text{Fe}_2\text{O}_3/\text{MgO}$ ratios and enrichment in crustal-sensitive elements suggest variable degrees of crustal assimilation during magma ascent through the Helmand–Arghandab lithosphere.

The Pliocene–Quaternary volcanism of Dasht-e-Nawur is tectonically associated with the post-collisional setting between the Indian and Eurasian tectonic plates. This volcanic activity is classified as being part of a calc-alkaline continental arc setting. The high silica content (63–79 wt.%) and evolved compositions indicate a mature arc environment strongly influenced by lithospheric thickening. This process promotes extensive magmatic differentiation and crustal interaction.

To contextualize the volcanic evolution of Dasht-e-Nawur, we compared our results with analogous volcanic and plutonic complexes globally and regionally. The enrichment of LILEs and depletion of HFSEs observed here strongly correlate with the Late Cretaceous Avliyana volcanic rocks investigated by Vural et al. (2021) and Cenozoic calc-alkaline complexes studied by Kaygusuz (2022) in the Eastern Pontides of Turkey. Similar to the fractional crystallization pathways observed in those systems, where plagioclase, hornblende, and pyroxene control the differentiation sequence, the Dasht-e-Nawur rocks exhibit systematic decreases in MgO, Fe_2O_3 , and CaO with increasing SiO_2 , highlighting the ubiquity of crystal fractionation in shaping calc-alkaline series. However, unlike the active-arc or late-orogenic frameworks often cited in older literature, the distinct high-K, post-collisional signature of Dasht-e-Nawur underscores a transitional dynamic. It provides a key benchmark for post-collisional magmatism in the Alpine-Himalayan convergence zone.

The Dasht-e-Nawur volcanic complex, which dates from the Pliocene to the Quaternary, differs markedly from the altered Eocene–Oligocene volcanic sequences in the Koh-e Baba and Helmand–Arghandab massifs. This difference is characterized by its relatively unaltered, compositionally evolved series of dacitic to andesitic lavas and a more felsic geochemical composition. Geochemically, these volcanic rocks show a clear calc-alkaline to alkaline affinity, with higher alkali enrichment than the North Chagai volcanic suite. They also lack the tholeiitic trends or elevated magnesium oxide (MgO) contents that are typical of the Panjao and Asparan volcanic provinces. In contrast to the mantle-derived alkaline basalts of Sarlogh and the rare-earth-element-enriched phonolite–carbonatite assemblages of Khanneshin, the Dasht-e-Nawur complex is primarily characterized by large stratovolcanic edifices. Additionally, it retains significant subduction-related geochemical signatures, particularly notable negative anomalies of niobium (Nb) and titanium (Ti).

Conclusions

The petrographic and geochemical study of the Dasht-e-Nawur volcanic complex provides a detailed understanding of magmatic evolution and the tectonic framework in south-central Afghanistan. Through the integrated analysis of petrographic and geochemical data, the following conclusions are extracted:

- The Pliocene-Quaternary volcanic rocks of the Dasht-e-Nawur mainly consist of andesite, trachy-andesite, quartz andesite, and dacite. They exhibit dominant porphyritic textures, massive structures, and mineral assemblages that include plagioclase, quartz, hornblende, and biotite.
- Geochemically, the rocks are intermediate to acidic (63-79 wt.% SiO₂) and belong predominantly to the calc-alkaline to alkaline magmatic series. Enrichment in LILEs and negative Nb anomalies indicate derivation from a subduction-modified mantle source, whereas negative Sr, P, and Ti anomalies confirm fractional crystallization of plagioclase, apatite, and Fe–Ti oxides as the principal magmatic differentiation process.
- The studied volcanic rocks record the effects of both crustal assimilation and interaction with a subduction-modified subcontinental lithospheric mantle source. Negative Nb–Ta–Ti anomalies and LILE enrichment provide geochemical evidence for upper-crustal contamination and lithospheric mantle involvement during magma evolution and emplacement.
- While the current major-oxide and trace-element dataset effectively constrains the high-K calc-alkaline affinity and subduction-modified mantle source of the Dasht-e-Nawur volcanic suite, the absence of comprehensive HREE and radiogenic isotope data (Sr–Nd–Pb–Hf) limits detailed quantitative petrogenetic modeling. Furthermore, the lack of high-precision geochronological constraints restricts the accurate reconstruction of the temporal evolution of volcanism and its relationship to regional tectonic activity. Future research should therefore focus on high-resolution isotopic investigations and precise geochronological dating to better quantify crust–mantle interactions and elucidate the post-collisional magmatic and tectonic evolution of the south-central volcanic rocks.

Authors Contribution

- Shah Hussain Shafayi was responsible for sample collection and laboratory, petrographic, and geochemical analyses.
- Sayed Aziz Sadat was responsible for conducting geological studies and for revising and editing the manuscript.
- Mohammad Naeem Sarwary was responsible for geological mapping.
- The authors have written, reviewed, and approved the final version of the manuscript.

References

Abdullah, S., Chmyriov, V., & Dronov, V. (2008). *Geology and mineral resources of Afghanistan. Volume 1.*

- Azizi, T. (2023). Detecting Lithium Brine in Afghanistan Using Spaceborne Hyperspectral Data. <https://hdl.handle.net/2077/78257>
- Berhanu, G. (2019). Geology, petrology and geochemistry of volcanic rocks around Arba Minch, Southern Ethiopia. *Earth*, 8(3), 160-168. <https://doi.org/10.11648/j.earth.20190803.14>
- Boraiaha, C. K., Joshi, K. B., Kerr, A. C., Padhi, J. K., Mishra, S. S., & Chandan, R. (2020). Field, petrographic and geochemical characteristics of Sullya alkaline complex in the Cauvery Shear Zone (CSZ), southern India: Implications for petrogenesis. *Journal of Earth System Science*, 129(1), 111. <https://doi.org/10.1007/s12040-020-1369-1>
- Boulanger, M. T., Davis, R. S., & Glascock, M. D. (2012). Preliminary characterization and regional comparison of the Dasht-i-Nawur obsidian source near Ghazni, Afghanistan. *Journal of archaeological science*, 39(7), 2320-2328. <https://doi.org/10.1016/j.jas.2012.01.038>
- Columbu, S., Piras, G., Sitzia, F., Pagnotta, S., Ranieri, S., Palleschi, V., Lezzerini, M., & Giamello, M. (2018). Petrographic and mineralogical characterization of volcanic rocks and surface depositions on Romanesque monuments. <https://doi.org/DOI:10.5281/zenodo.1256051>
- Cox, K., Bell, J., & Pankhurst, R. (1979). The Interpretation of Igneous Rocks. (No Title), 450. <https://doi.org/10.1007/978-94-017-3373-1>
- Doebrich, J. L., Wahl, R. R., Ludington, S., Chirico, P., Wandrey, C., Bohannon, R., Orris, G., Bliss, J., Wasy, A., & Younusi, M. (2006). *Geologic and mineral resource map of Afghanistan* (Vol. 1038). US Department of the Interior, US Geological Survey.
- Hayes, K. A. (2018). *Geochemical Evidence for Mixing Between Basin Pore Waters and Evaporated Lake Water, Dasht-e-Nawar, Afghanistan* University of Nevada, Reno]. <https://www.proquest.com/openview/20e7274546c91c8556aca2ad8bc7e443>
- James, E., Ghani, A. A., Akinola, O. O., & Asis, J. (2021). Petrology and geochemical features of Semporna volcanic rocks, Southeast Sabah, Malaysia. *Sains Malaysiana*. <https://doi.org/DOI:10.17576/jsm-2021-5001-02>
- Jensen, L. (1976). A new cation plot for classifying subalkalic volcanic rocks. *Ontario Division of Mines Miscellaneous Paper*, 66. <https://www.scirp.org/reference/referencespapers?referenceid=2192904>
- Kaygusuz, A. (2022). Petrographic and Geochemical characteristics of Paleozoic Gabbroic rocks around Tasdelen (Ozdil/Trabzon, NE Turkiye). *Journal of Engineering Research and Applied Science*, 11(2), 2111-2122. <https://journaleras.com/index.php/jeras/article/view/298>
- Kaygusuz, A., Aydıncakir, E., Yucel, C., & Atay, H. E. (2021). Petrographic and geochemical characteristics of carboniferous plutonic rocks around Erenkaya (Gümüşhane, NE Turkey). *Journal of Engineering Research and Applied Science*, 10(2), 1774-1788. <https://www.journaleras.com/index.php/jeras/article/view/255>

- King, T., Berger, B. R., & Johnson, M. R. (2014). *Characterization of potential mineralization in Afghanistan: four permissive areas identified using imaging spectroscopy data* (2331-1258).
- Koralay, T. (2010). Petrographic and geochemical characteristics of upper Miocene Tekkedağ volcanics (Central Anatolia—Turkey). *Geochemistry*, 70(4), 335-351. <https://doi.org/10.1016/j.chemer.2010.03.002>
- Mack, T. J. (2020). Passive seismic survey of sediment thickness, Dasht-e-Nawar basin, eastern Afghanistan. In *Military Geoscience: Bridging History to Current Operations* (pp. 161-170). Springer. https://doi.org/10.1007/978-3-030-32173-4_12
- Miyashiro, A. (1974). Volcanic rock series in island arcs and active continental margins. *Amer. Jour. Sci.*, 274. <https://doi.org/10.2475/ajs.274.4.321>
- Ostrowski, S., Mostafawi, N., Noori, H., & Rajabi, A. (2010). The Greater Flamingo *Phoenicopus roseus* still breeds in Dasht-e Nawar, Afghanistan.
- Ostrowski, S., Rajabi, A. M., & Noori, H. (2008). Birds and mammals in Dasht-e Nawar, Afghanistan: occurrence and hunting pressure, 2007 surveys. *Wildlife Conservation Society, New York, New York, USA*.
- Pearce, T., Gorman, B., & Birkett, T. (1977). The relationship between major element chemistry and tectonic environment of basic and intermediate volcanic rocks. *Earth and Planetary Science Letters*, 36(1), 121-132. [https://doi.org/10.1016/0012-821X\(77\)90193-5](https://doi.org/10.1016/0012-821X(77)90193-5)
- Rohiman, A., Prijanto, D., Prabowo, A., Ratdomopurbo, A., Setiawan, R., Effendi, M., & Wahyudi, E. (2019). Geochemical characteristics of volcanic rocks from Mt. Masurai's caldera, Jambi, Indonesia. *Journal of Physics: Conference Series*,
- Smith, G. I. (1975). *Potash and other evaporite resources of Afghanistan* (2331-1258).
- Stillings, L. L., Mack, T. J., Chornack, M. P., Kalaly, S. S., Ahmadi, M. I., & Qasim, A. (2015). *A Summary of Data Collected by the US Geological Survey at Dasht-e-Nawar, Afghanistan, in Support of Lithium Exploration, June-September 2014*. US Department of the Interior, US Geological Survey. <http://dx.doi.org/10.3133/ofr20151059>.
- Sun, S.-S., & McDonough, W. F. (1989). Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. *Geological Society, London, Special Publications*, 42(1), 313-345. <https://doi.org/10.1144/GSL.SP.1989.042.01.19>
- Vikhter, B. Y., Yermenko, G., Chmyrev, V., & Abdulla, D. (1978). Pliocene-Quaternary volcanism of Afghanistan. *International Geology Review*, 20(5), 525-536. <https://doi.org/10.1080/00206817809471419>
- Vural, A., Kaygusuz, A., & Akpınar, I. (2021). Petrological characteristics of late Cretaceous volcanic rocks of Demirören (Gümüşhane, NE Turkey) region. *Journal of*

Engineering Research and Applied Science, 10(2), 1828-1842.

<https://www.journaleras.com/index.php/jeras/article/view/260>

Zaw, K. (1990). Geological, petrological and geochemical characteristics of granitoid rocks in Burma: with special reference to the associated W □ Sn mineralization and their tectonic setting. *Journal of Southeast Asian Earth Sciences*, 4(4), 293-335.

[https://doi.org/10.1016/0743-9547\(90\)90004-W](https://doi.org/10.1016/0743-9547(90)90004-W)