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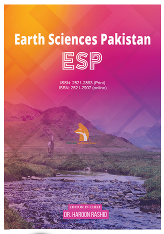

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RESEARCH ARTICLE

PETROLOGY OF THE CRUSTAL PLUTONIC ROCKS OF NAWEOBA BLOCK, ZHOB OPHIOLITE, BALOCHISTAN, PAKISTAN

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ABSTRACT

Zhob Ophiolite complex is composed of three detached blocks named Omzha, Ali Khanzai and Naweoba blocks. The crustal plutonic section of the Naweoba block is mapped and divided into gabbro and granite. Based on petrographical studies, the gabbros fell in the domain of gabbro, gabbronorite, and hornblende gabbro while granitic rocks fell in the vicinity of quartz-rich granitic rocks, granodiorite, plagiogranite and tonalite. Gabbroic rocks cover the maximum area of the crustal plutonic section and are usually medium-grained while at many places the grain size is quite large to be seen with naked eyes. Minerlogically gabbroic rocks consist of orthopyroxene, clinopyroxene, amphibole and plagioclase. These rocks maybe the fragments of main crustal plutonic section of the Zhob ophiolite. The granitic rocks having mafic minerals domINTED in the eastern portion, while the felsic minerals domINTED ones are in the west. The eastern side of the granitic body is compact and massive compared to western portion which is quite altered and shattered. Granitic rocks are composed of plagioclase, alkali feldspar and quartz where rutile and Cr-spinel exist in trace amounts. The gabbros of Naweoba block may have formed in a magma chamber as a result of fractional crystallization. While the granites maybe a late magmatic differentiate from the same magma chamber. The close correlation of gabbroic and granitic rocks of Naweoba block with Muslim Bagh, Khanozai and Bela ophiolites suggests their formation in supra subduction zone setting.

KEYWORDS

Ophiolite, crustal section, plutonic rocks, gabbro, granite.

1. INTRODUCTION

The ophiolitic study is probably, a topic in geological literature that brought different groups of world geoscientists to the conclusion of its different theories. These studies played a vital role in solving the problems risen by regular questions. Alexandre Brongniart, a French mineralogist (1740-1847) introduced the name “Ophiolite” in the geological literature for the first time in 1813, in source to serpentines in mélanges. Later the definition was changed and well-defined in the Penrose Conference (Geotimes, 1972). Ophiolites are suites of ultramafic, mafic, and felsic rocks that are interpreted to be remnants of ancient oceanic crust and/or island arcs with upper mantle (Dilek and Furnes, 2014).

Generally, well-developed ophiolite sequences of ultramafic rocks (usually serpentinized) are at the base is overlain by layered gabbros, dolerites, pillow basalt (lavas) and pelagic sediments. In fully developed ophiolite complexes radiolarian cherts are usually found as deep-sea sediments that are capping pillow lavas. Owing to high tectonic disturbance the above-mentioned sequence (ideal/ fully developed ophiolite sequence) is rarely found. The Semail Ophiolite, Oman, Macquarie Island Ophiolite, and Troodos Ophiolite (Ref), Cyprus have got much attention in recent years for geologists (Pallister and Hopson, 1981; Cocker et al., 1982; Dilek and Eddy, 1992).

In Pakistan, ophiolitic complexes are exposed in various areas and named according to their existence in the area such as Bela, Zhob, Muslim Bagh, and Waziristan. These ophiolitic complexes are thought to be exposed at the western edges of the Indian plate and mark the boundary with the Eurasian plate (Mahmood et al., 1995; Gnos et al., 1997). A well-known Muslim Bagh ophiolite complex is one of the fully-exposed ophiolites in Pakistan which is thought to be part of the Zhob Valley and along with Waziristan, Khanozai and Bela Ophiolites mark the western suture of the Indian plate with the Eurasian plate (Sengor, 1987). These fragments of Ophiolites (mentioned above) were part of the Neo-Tethyan Ocean.

During the Late Cretaceous period, they were obducted onto the Indian plate. Zhob Ophiolite is thrusted on Early Jurassic to Paleocene Calcareous sediments of Indian passive margin and has capped by the Flysch sediments of Eocene age. The ophiolite complex of the Zhob area is a piece of “Zhob valley Ophiolites, which” likewise incorporate Muslim Bagh, Khanozai and Zhob Ophiolite. Zhob Ophiolite is differentiated into Naweoba, Ali Khanzai, and Omzha blocks (Khan, 2014). Has carried out a

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reconnaissance geological work of Naweoba block. Based on geology and petrology, this paper discusses the nature and composition of the crustal plutonic rocks of the Naweoba block of Zhob Ophiolite.

2. Regional Geology

Alexandre Brongniart, a French mineralogist (1740-1847) introduced the name "Ophiolite" in the geological literature for the first time in 1813, in source to serpentines in mélanges. Later he modified his definition of Ophiolites by including a suit of magmatic rocks which may include diabase, gabbro, volcanic and ultramafic rocks existing in the Apennines. But it was who exalted the name ophiolite to a concept that these are structurally related rock suit formed at the axial part of geosyncline as in situ intrusion (Steinmann et al., 1927). In Pakistan, ophiolitic complexes are exposed and named as Bela, Zhob, Muslim Bagh, and Waziristan Ophiolites. These ophiolitic complexes are thought to be exposed at the western edges of the Indian plate and mark the boundary with the Eurasian plate. In the Zhob area, the passive margin of the Indian plate comprises of Triassic to Eocene sedimentary succession, deposited dominantly in marine environments. These sediments are thrusted by allochthonous blocks; Zhob Valley ophiolites. The Zhob Valley ophiolites are divided into Zhob, Muslim Bagh and Khanozai ophiolites. Zhob Ophiolite was studied, mapped, and reported for the first time (Khan, 2014). The geology of Zhob Ophiolite is comprised of different lithologic units these units include Basalt-chert unit, and hyloclastite mudstone unit, composed of thick lava and pelagic sediments. Petrology and geochemistry of lavas of the basalt-chert unit divided into tholeiitic basalt, trachybasalt, dacite and basaltic andesite and that of hyaloclastite mudstone unit into picro basalt, more alkaline foidite and teprite basanite. On the behalf of geochemical analysis alkaline rocks and formed in intraplate setting while tholeiitic rocks in suprasubduction zone. The Zhob Ophiolite is thrusted on the sediments (Alozai Group) of the Indian passive margin and is overlain unconformably by flysch sediments (Nisai Formation) of Eocene age (Naeem et al., 2021). The Zhob Ophiolite is differentiated into and Omzha, Ali Khanzai, and Naweoba, blocks.

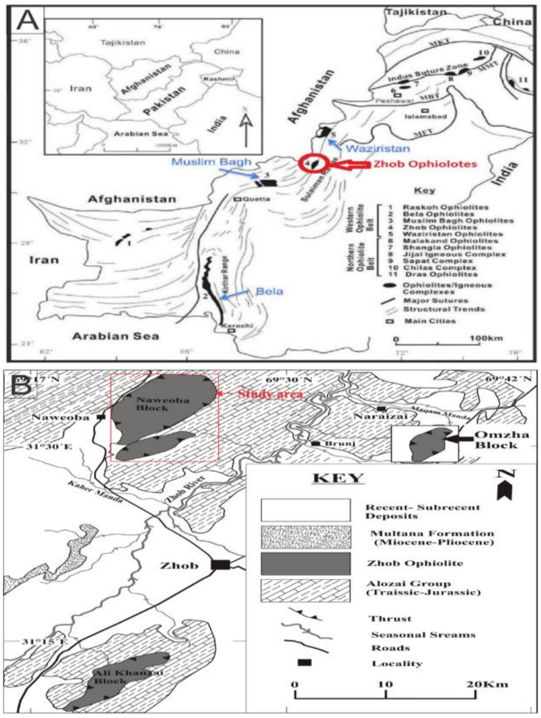

Figure 1: (A) Showing the location of Ophiolites of Pakistan (B) Geological map of Zhob area showing Zhob Ophiolite and the surrounding rock units (Jones et al., 1960). The Naweoba block is looking in the North West corner of the map (B).

Omzha block is composed of different lithologic units named as mafic-felsic, ultramafic and volcanic-volcanoclastic- pelagic rocks. Mentioned rocks are highly mixed up, deformed and are bounded by thrust faults. On the basis of geochemistry and petrography these rocks are divided into diorite, gabbro, plagiogranite, trachy-andesite and pheno-tephrite basalt, trachy basalt, chert, limestone, and mudstone. Ultramafic rocks are highly serpentinised while gabbroic rocks of the block are partially developed and intensively deformed. The intrusions of gabbroic rocks are cross cut by plagiogranite, diorite and anorthosite. Dismembered and highly deformed rocks metamorphic sole rocks of Omzha block are composed of metamorphic facies which include green schist, amphibolite and quartz mica schist (Ahmed et al., 2020; Ali et al., 2020). The Ali Khanzai block is considered the second largest among these three blocks, contains, thick volcanic-volcanoclastic and pelagic rocks, surrounding the altered, deformed and highly weathered peridotite, gabbro, and metamorphic rocks (Rehman et al., 2021). Among these three blocks the Naweoba block is the largest block of Zhob ophiolite which is in the north of the Zhob town (Figure 1B). Reconnaissance geology of the Naweoba block is carried out that contains crustal plutonic as well as mantle rocks segment which is found beneath the thick lava-chert unit.

The Muslim Bagh ophiolite complex is one of the fully-exposed ophiolites in Pakistan (Vredenburg, 1901). This ophiolite (MBO) is made up of two main bodies generally termed as Saplai Tor Ghar Massif (STGM) on the eastern side and Jang Tor Ghar Massif (JTGM) (Bilgrami, 1964). The ophiolite is underlain by the sedimentary-igneous assemblage; Bagh Complex (Mengal et al., 1994). The geochemical marks of the ophiolite suggest that it is formed in a supra-subduction zone environment (Kakar et al., 2014). The Khanozai Ophiolite has well-formed crustal plutonic rocks overlying the mantle section rocks (Popal et al., 2019; Haq et al., 2019). comprises of serpentinized peridotite having chromitite segregations (Ullah and Khan, 2019). The ophiolite is underlying the slivers of metamorphic soles and thick lava with pelagic sediments in the (Gwal) mélange. Isolated outcrops along the road were clarified as harzburgite after microscopic studies and such bodies are usually blanketed by recent alluvium (Ullah and Khan, 2019).

3. Materials and Methods

An extensive and detailed geological fieldwork was conducted and carried out in the Naweoba block of Zhob Ophiolite northern Balochistan, Pakistan. The crustal plutonic section of the block was mapped on a large scale with the help of a Geological map prepared by Hunting Survey Corporation. Topographic maps, Avenza maps and geological earth images also played a pivotal role in the preparation of the Geological map. For maximum observation and marking the contact among the several lithological units, many traverses were made across the lithologic units of the block. Various features of igneous rocks were observed in the field, such as color, texture, structure and lithological units. Several samples of different types of rocks were cut with the help of a geological hammer and collected during the fieldwork. During the collection of rock samples, different field photographs were taken with specified coordinates. Numerous field tools were used such as (GPS) Global Positioning System and Avenza map software. Avenza map android application was used to capture field photographs and coordinates of different structural features. Brunton compass was used for the measurement of dip and strike of some rocks in the area. Other field types of equipment include a Geological hammer (Estving pick end), dilute HCL, a hand lens and a digital camera was used. Rock samples were collected and identified during the fieldwork, for further classification these samples were prepared in the laboratory and placed under a microscope. Thin sections of the above-mentioned samples were prepared with a size of 4×2 cm glass slide in the rock cutting lab of the Petrology and Mineralogy (PET-MIN) branch at the Geological Survey of Pakistan. During petrographic studies, many optical properties were noted and along with their photomicrographs with various photographs features. The captured photomicrographs during the geological fieldwork were labeled with the help of various softwares such as GIS and Coral Draw.

4. Results

4.1 Field Features of the Crustal Rocks of Naweoba block

The Naweoba is the largest block among the three blocks of Zhob Ophiolite, which is in the north of Zhob town. It consists of various units of

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sedimentary and igneous origin. Based on composition, the crustal plutonic section of the Naweoba block is mapped and divided into two different types of rocks: mafic (gabbroic rocks) and felsic (granitic rocks) (Figure 2). The gabbroic rocks cover a maximum portion of the crustal plutonic section of the block and are deformed and extremely weathered. In hand specimen, the fresh color of gabbro is typically dull green to light green, while the weathered color is dull earthy, black to light brown (Figure 4A). These plutonic rocks cover northwestern side of the block where it marks its contact with volcanic rocks.

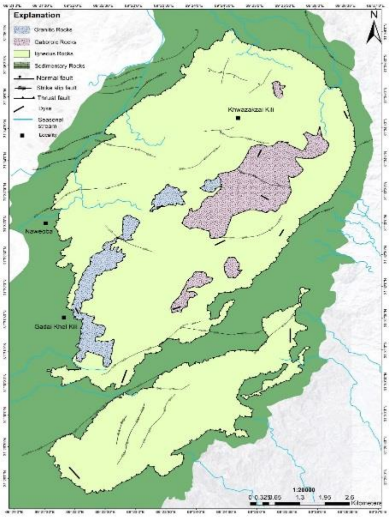

Figure 2: Geological map of the crustal plutonic rocks of Naweoba block Zhob Ophiolite.

In the studied area two types of gabbro (layered and massive gabbro) are present but most of the crustal plutonic section is covered by massive gabbro. Layered gabbros are highly weathered, tectonically fragmented and exist rarely, owing to this, their mineralogical layers are poorly developed and difficult to be identified. It is usually medium to large-grained, but patches of fine gabbro are also present. Massive gabbro covers a considerable area and marks their presence as continuous prominent hills in the assigned area. The gabbroic rock unit is found in immediate contact with granitic and ultramafic rocks. Veins of the micro-granitic composition are present in the shear zone between gabbro and basalt.

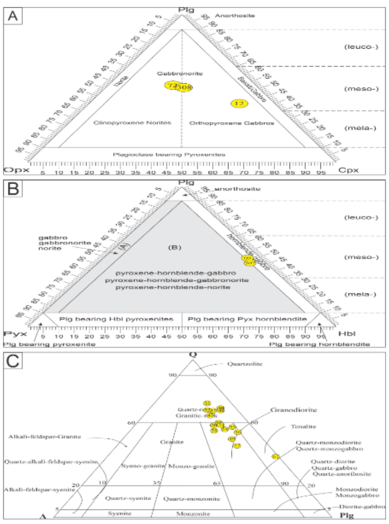

Figure 3: IUGS Diagrams show the classification of (A, B) Gabbroic rocks and (C) Granitic rocks

In the crustal part of Naweoba block, several small to large mafic veins to dykes are present intruding through gabbroic rocks trending N-S. These mafic dykes' range in width from few centimeters to hundreds of centimeters (Figure 4B-C). Patches and Xenoliths of gabbro is found in the western portion of the study area (Figure 4D). Few dykes of the ultramafic composition are also present in the studied area intruding through gabbroic rocks. At some places, few dykes of granitic rocks intruding through gabbro are quite prominent (Figure 4E). In the eastern side of the gabbroic section mafic dyke is also present. A Dyke/vein of quartz ranges in width from 7-10 centimeters is also observed in the gabbroic rocks of the crustal plutonic section of the Naweoba block. Basaltic dykes decrease towards the east of the gabbroic section of the block. Mafic contents observed in the gabbros of the Sangi Ghar area increase toward the east compared to the western portion.

Granitic rocks are the second rock type of crustal plutonic section of the Naweoba block Zhob Ophiolite. The exposures of these granitic rocks are nearly continuous and consist of prominent hills that cover a vast area of the Naweoba block next to the gabbro of the crustal plutonic section (Figure 4G). These rocks are quite altered and fractured in the research area. In outcrop and hand specimen, the fresh color ranges from creamy white to white-green while weathered color is light green, black to dull earthy. Granitic rocks observed in the field area are divided into three types based on their grain size and mineralogical composition (1) More felsic granites (rich in felsic minerals), (2) shear zone and (3) More mafic granites (rich in mafic minerals). In the eastern portion of granitic rocks, grain size is quite coarse enough to be seen with naked eyes at places and is mineralogically more mafic. This zone possesses many irregular fractures of many millimeters in size and is filled by quartz and calcite. Basaltic dykes running east-west in the eastern portion of granitic rocks are also observed in the research area.

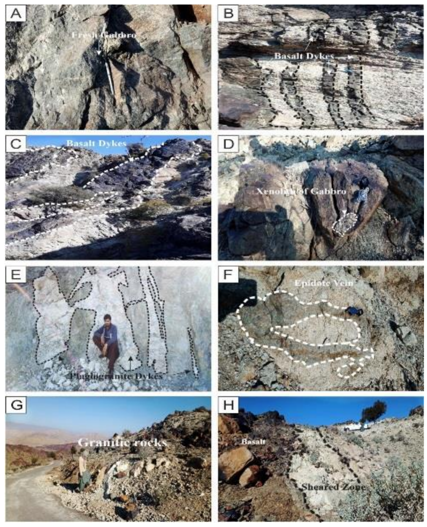

Figure 4: Field features of the crustal rocks of Naweoba block, Zhob Ophiolite. **(A)** Fresh gabbro. **(B)** Small basaltic dykes in gabbroic rocks. **(C)** Large basaltic dykes in gabbroic rocks. **(D)** Xenolith of gabbro in basalt. **(E)** Dykes of granitic rocks intruding through gabbro. **(F)** Epidote vein in granitic rocks. **(G)** Granitic rocks. **(H)** Sheared zone.

By the granitic rocks, a shear zone is running toward the west with a mixed portion of mafic and felsic minerals (Figure 4H). Their grain size confirmed through petrographic studies is medium and the portion itself shows sheared traces. Xenolith-type basalt is present in the sheared zone. Moving further toward the west, more felsic content bearing granitic rocks is encountered. The grain size of this western portion is quite fine compared to the eastern side. Epidote veins making pinch and swell structure are quite prominent in the western portion of the granitic rock body (Figure 4F). Granitic rocks in the western side of the area are quite altered and shattered as compared to the eastern side which is massive in the habit. Granite makes faulted contact with basalt on both sides of the body, however, contact between gabbro and granite is transitional, bearing multiple exposers of ultramafic rocks.

4.2 Petrography

4.2.1 Gabbro (12)

Plagioclase is the most abundant mineral in the studied samples of the gabbroic rocks. The modal proportion of these grains is 45 to 55%. Their grain size varies from 182μm to545μm whereas average grains ranging in the domain of 400 to 800μm. Texturally, plagioclase grains are well developed ranging from euhedral to subhedral (Figure 5A). These grains are slightly altered into sericite. Both simple twinning and albite polysynthetic twinning is present. Enclosed opaque phases into these grains are also encountered in the studied samples. The clusters of plagioclase are also encountered during the microscopic study. Texturally clinopyroxene grains in the studied samples are not even partially developed. They all are almost subhedral to anhedral (Figure 5A). The modal proportion of these grains is 20 to 30%. Clinopyroxene grains range in size from 152μm to 626μm with dominant grains ranging from 400μm to 800μm. Few zoned grains of clinopyroxene are also present.

Chlorite is a secondary mineral product that is quite prominent in the studied samples. It shows its typical anomalous blue interference color (Figure 5B). Chlorite is also present in the interstitial spaces. Few grains contain inclusions of opaque phases. The grain size of opaque phases is almost less than 100μm while the largest grain is 371μm. opaque materials are quite clear as inclusions in some plagioclase grains (Figure 5B). Opaque phases present in the studied thin sections may be of two generations. Well-developed grains show early formation while anhedral forms indicate late formation in the crystallization sequence.

4.2.2 Gabbro-norite (72, 308)

In the gabbro-norite samples, the grain size ranges from 182μm to 3936μm, however prevailing grain size population is 400μm to 800μm. The bulk of the grain size population is subhedral to euhedral and therefore exhibit hypidiomorphic texture. Principally the essential minerals of gabbroic rocks in the studied samples are plagioclase, clinopyroxene, and orthopyroxene, whereas amphibole and opaque minerals mark their presence from the accessory to trace amount. Chlorite, sericite, epidote, zoisite, and zeolites are present as secondary phases. These secondary phases are typically the alteration products after essential minerals. The modal abundance of all phases is variable; however, their distribution is uniform and at thin section-level, any of the segregated domains are not seen.

The modal proportion of plagioclase is slightly variable from sample to sample and ranges from 30 to 40%. Plagioclase in the studied samples is lath to equidimensional shaped and is partially developed ranging from euhedral to subhedral. Its grain size ranges from 404μm to 1564μm and most grains fall in the range of 400μm to 800μm. majority of plagioclase grains show albite polysynthetic twinning pattern (Figure 5C). Carlsbad twinned grains and undulose-extinct grains are also present (Figure 5D). The contact relationship of plagioclase grains to clinopyroxene shows that they are simultaneously formed. Few minute inclusions of opaque mineral(s) are also observed in plagioclase grains.

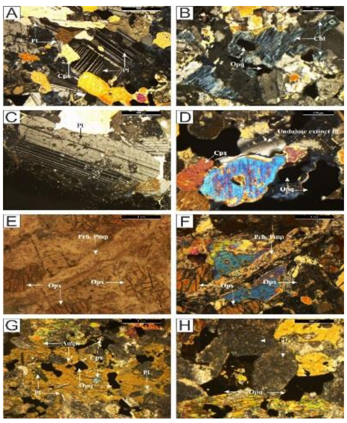

Figure 5: Microphotographs of the Gabbroic rocks of the Naweoba block, Zhob Ophiolite. **(A)** Plagioclase (Pl), Clinopyroxene (Cpx). **(B)** Opaque phase(s) (Opq), Chlorite (Chl). **(C)** Plagioclase (Pl). **(D)** Undulose extension in plagioclase (Pl), Opaque phase(s) (Opq), Clinopyroxene (Cpx). **(E,** PPL and **F,** XPL**)** Orthopyroxene (Opx), Prehnite (Prh), Pumpellyite (Pmp). **(G)** Amphibole (Amp), Clinopyroxene (Cpx), Opaque phase (s) (Opq), Plagioclase (Pl). **(H)** Plagioclase (Pl), Opaque Phase (s) (Opq).

Clinopyroxene is the second essential mineral of the studied samples after plagioclase. These grains are partially developed and ranging from subhedral to anhedral while euhedral gains are also encountered (Figure 5D). The modal proportion of these grains is 25 to 35%. Clinopyroxene grains range in size from 405μm to 1294μm with dominant grain size ranging from 400μm to 800μm. few very clear exolusions are also present in the clinopyroxene grains in the studied samples. These exolusions are usually in the form of blebs. Some grains of clinopyroxene exhibit prominent zoning. These zoning patterns are well-developed from the core to the rim. These grains are also fractured whereas amphibole is present as fracture filling material. The contact relationship of clinopyroxene grains with plagioclase and orthopyroxene show that these grains are simultaneously formed in the crystallization sequence. A few grains may also include very clear plagioclase inclusion.

Orthopyroxene is the third essential mineral after plagioclase and clinopyroxene in the studied thin sections. These grains are usually partially developed ranging from subhedral to anhedral (Figure 5E, F). The modal proportion of these grains is 10% to 20%. Orthopyroxene grains range in size from 401μm to 2511μm with dominant grain size ranging from 400μm to 800μm. These grains are quite fractured and are altered. Orthopyroxene grains give pinkish pleochroism in the PPL view. In few orthopyroxene grains, amphibole is present along grain boundaries and intra-grain fractures. The orthopyroxene grains may have crystallized simultaneously with clinopyroxene and plagioclase.

In the miner mineral phases, chlorite present in the studied samples gives its anomalous low blue interference color. It is present along the grain boundaries and in the interstitial spaces. The opaque phases are also present in a trace amount. Texturally, these materials mark their presence as anhedral and euhedral in the studied thin sections. Anhedral form present in the interstitial spaces indicates their late formation in the crystallization sequence while euhedral forms state that these are early formed in the crystallization sequence. Prehnite and Pumpellyite are also present in the veins. These two minerals are present as minute crystals. Their presence marks the initiation of low-grade metamorphism and the increase of pressure and temperature. They are secondary products found in trace to the accessory amount (Figure 5E, F).

4.2.3 Hornblende Gabbro (307, 09)

Amphibole is the most abundant and essential mineral in the studied samples. Its modal abundance varies from sample to sample and ranges from 40% to 50%. Most of the grains are partially developed and range from subhedral to anhedral. Its grain size ranges from 184μm to 3936μm while the majority of the grains range from 400μm to 800μm. These grains are quite fresh where in some places, cleavage planes are quite visible. Many inclusions, such as plagioclase, clinopyroxene, and opaque phases are commonly observed in the amphibole grains (Figure 5G). Amphibole has almost concave contact with plagioclase and alkali feldspar which conclude that amphibole is early formed in the crystallization sequence (Figure 5G). Plagioclase having convex contact relationship with amphibole (Figure 5G)

Plagioclase is the essential mineral after amphibole in the studied samples of gabbroic rocks. The modal proportion of these grains in the studied samples is 45% to 55%. These grains are highly altered into sericite (Figure 5H). These grains are partially developed range from subhedral to anhedral. Their grain size varies from 193μm to1011μm whereas average grains ranging in the domain of 400 to 800μm. Both equidimensional and lath-shaped grains exist where rather than equidimensional grains lath shaped grains are usually found as inclusions in amphibole grains. (Figure 5H) Equidimensional grains appear to be fully altered into sericite where twinning is invisible while lath-shaped grains exhibit simple twining (Figure 5H). Many pseudomorph grains are also present. Most plagioclase grains have convex contact with amphibole while concave contact was rarely observed. Owing to the intense alteration application of Michel Levy method for classifying plagioclase solid solution members was unable to apply.

Clinopyroxene is an essential mineral in the studied samples is feebly altered to chlorite as compared to plagioclase and more altered than amphibole. These grains exist as partially developed from subhedral to anhedral (Figure 5G). The grain size of clinopyroxene is usually smaller than amphibole and ranges from 128μm to 890μm. Most of the grains range in size from 400μm to 800μm having modal abundance from 5 to 15%. Its convex contact with plagioclase reveals that these grains are early formed in the crystallization sequence. Clinopyroxene itself was examined as inclusion in the large amphibole grain.

Sericite is a secondary mineral product is present after plagioclase. The grains are not that much developed, so grain size is not possible to be measured. Opaque phases in the studied samples are quite visible. Texturally, opaque phases are partially developed ranging from anhedral to subhedral. The grain size of opaque in most of the samples is less than 100μm while the largest grain is 702μm in size. Normally there are two generations of opaque phases, few well-developed grains and the ones formed in interstitial spaces (Figure 5G). Chlorite is present mostly along the grain boundaries while some grains also mark its presence in interstitial spaces

4.2.4 Granitic Rocks

After plotting values on IUGS classification scheme granitic rocks are classified as quartz-rich granite (30, 31, 45, 46, 47, 52), Granodiorite (48, 49, 50, 51, 54, 55, 56, 57, 58) and plagiogranite/tonalite 67 (Figure 3C). Texturally, granitic rocks of Naweoba Block of Zhob Ophiolite are inequigranular and are categorized into three different textural types. These are (i) seriate (ii) cumulophyric and (iii) graphic textures. In seriate texture, a gradual increase of quartz, alkali feldspar and plagioclase occur. There is a continuous range of sizes of more than one mineral, however, fine-grained minerals dominate here (Figure 6A). In cumulophyric texture, the type (ii) category, phenocrysts of quartz, alkali feldspar and plagioclase feldspar are present (Figure 6A). These microphenocrysts range in size from 256μm-2425μm. Microphenocrysts in clusters include quartz, plagioclase, and alkali feldspar, where their modal abundance is 34-64%. Several minerals mark their presence as groundmass including quartz, plagioclase, and alkali feldspar, whereas the average size of mentioned minerals, is less than 150μm. The modal abundance of grains in groundmass is 64-34%. Type (iii) category of the studied sample is graphic texture, where intergrowth of quartz and alkali feldspar occurs (Figure 6C).

A few samples of granite are dominantly Plagiogranite, which is primarily composed of quartz, plagioclase and alkali feldspar as essential minerals (Figure 6A, B). Opaque phases, clay minerals, sericite, chlorite, zoisite and epidote range from trace to accessory amounts. These minerals, except chlorite and opaque phases, are the secondary mineral product of plagioclase and alkali feldspar. A trace amount of rutile is also present in the studied samples. Clay minerals, sericite, and zoisite are observed as an alteration product of alkali feldspar, plagioclase and other minerals that mostly exist along the grain boundaries. Epidote veins with variable thickness are also present. These rocks are highly fractured owing to stress factor and undulose extinction in some quartz grains confirm it petrographically.

Quartz is the most dominant mineral in the studied samples. The modal abundance of quartz grains is 50-65%. As quartz is the most resistant mineral to alteration, so its grains are mostly fresh and texturally subhedral to anhedral (Figure 6C, D). These grains are mostly equidimensional whereas prismatic grains are also present but, rarely encountered. Intergranular fractures between quartz grains are usually filled by secondary mineral product sericite. In type (i) category quartz ranges from 181μm-3256μm with the dominant size of 400μm-900μm. The modal abundance of quartz grains in type (i) ranges from 55-56%. Quartz grains present as phenocrysts, in type (ii) category, ranges from 422 μm -2425μm, whereas the size of the groundmass is less than 150 μm. Their modal abundance ranges from 40-60%. In the third category quartz grains ranges in size from 125μm-1510μm with dominant grains falling in the vicinity of 400μm-900μm having a modal abundance of 65-85%.

Plagioclase is the second dominant mineral after quartz and is distributed equally in the studied samples. The modal abundance of plagioclase grains ranges from 20-30 %. Plagioclase grains are well-developed range from euhedral to subhedral. They exhibit albite polysynthetic twinning while simple twinning is rarely observed (Figure 6B). Owing to their susceptibility to alteration, these grains appear to be feebly altered into clay minerals sericite. Structural deformation of plagioclase observed in some samples unfold that these grains are subjected to stress at some point. Very few samples also showed zoned plagioclase grains. In seriate texture, plagioclase range from 114μm-2800μm with the dominant population falling in the vicinity of 400-900μm having a modal abundance of 20-30%. Plagioclase in type (ii) ranges from 325μm-1783μm with dominant grains ranging from 400-900 μm having modal abundance15-25%. In the third category, plagioclase range from 321-1507μm with dominant a population ranging from 400-900μm having a modal abundance of 10-15%.

Alkali feldspar is the third essential mineral after quartz and plagioclase in granites. The modal proportion of these grains is 10 to 15%. Their grains are generally well-developed and range from euhedral to subhedral (Figure 6B). Alkali feldspar grains are mostly equidimensional. Few alkali grains are also present as inclusions in quartz sericite is present as an alteration product of alkali grains. Alkali feldspar grains range in size from 112-1815μm in type (i) category. Most of the grains range in size from 400 μm-900 μm having a modal abundance of 10-20%. Type (ii) grains of alkali feldspar range from 353-1224 μm with average grains ranging in the domain of 400-900 μm having modal abundance10-20%. The third category shows that alkali feldspar grains range from 314-1365μm with dominant grains ranging from 400-900μm having a modal abundance of 20-30%.

Chlorite is present as an alteration product in most granite samples. The modal abundance of chlorite ranges 3-10%. The presence of chlorite reveals that it has been formed after amphibole, as relic amphibole is optically quite clear in the studied samples. Few grains of relic amphibole are fully preserved and are some are partially chloritized, while others are completely altered to chlorite. Well-developed grains are not present, however, few grains show the development of some faces (Figure 6D). Green biotite is also observed in a few samples with flaky habit and brownish pleochroic phenomenon. At some places, chlorite has been partially developed and contains the inclusion of opaque material. Few crystals of tourmaline are also present in the studied thin section. The presence of a minor amount of relic amphibole and relic biotite reveals that at some point, there was a mafic and intermediate phase, which has now been almost completely altered to chlorite.

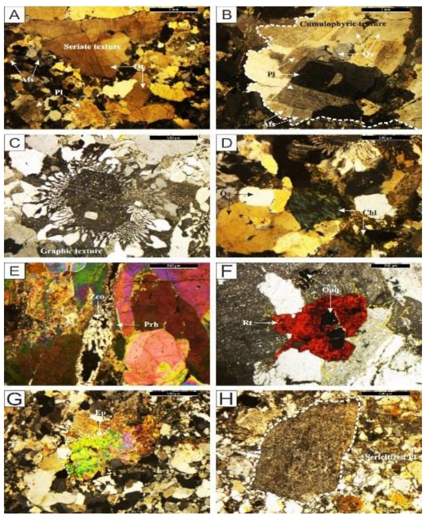

Figure 6: Microphotographs of the Granitic rocks of the Naweoba block, Zhob Ophiolite. **(A)** Plagioclase (Pl), Quartz (Qz), Alkali feldspar (Afs). **(B)** Phenocrysts and ground mass of Plagioclase (Pl), Quartz (Qz), and Alkali feldspar (Afs). **(C)** Intergrowth of Quartz (Qz), Alkali feldspar (Aps). **(D)** Quartz (Qz), Chlorite (Chl). **(E)** Zeolite (Zeo), Prehnite (Prh). **(F)** Opaque Phase (s) (Opq), Rutile (Rt). **(G)** Epidote (Ep) **(H)** Sericitized Plagioclase (Pl).

Another important alteration product zeolite is also present. It is present as a fibrous variety. A mixture of zeolite and prehnite is also present in veins (Figure 6E). The mixture of prehnite-pumpellyite, zeolite and epidote are present. The modal abundance of zeolite ranges from 1-8%. Opaque material marks its presence in an accessory amount. They have two generations. Well-developed is formed early in the crystallization sequence. Partially developed grains show their late formation in crystallization history. They are present as discrete grains, in the interstitial spaces and as inclusions in different minerals (Figure 6F). The modal abundance of opaque material ranges from 1-3%.

Epidote is also present in few samples having high relief. It is present in trace amounts. They are present as discrete grains. These grains are usually found in the interstitial space between plagioclase and quartz (Figure 6G). Few epidote grains contain partially chloritized rim around them. Rutile is also present in some samples in trace amounts. Texturally these grains are subhedral, but few well-developed grains are also developed. Its grain size ranges from 72μm-269. Few rutile grains contain inclusions of opaque material (Figure 6F). Sericite, the alteration product after plagioclase is quite visible in the studies samples.

5. Discussion

The Naweoba is the largest of three blocks present in Zhob Ophiolite. It is differentiated from Muslim Bagh ophiolite (Kakar et al. 2014) in the absence of an ordered ophiolitic sequence. Naweoba block consists of a variety of ultramafic, mafic, andesitic, and granitic rocks. Crustal plutonic rocks of Naweoba blocks are studied petrographically in detail. These rocks are granitic and gabbroic in nature (see Figure 2). Gabbro's formation in ophiolites is always associated with crustal fractionation in the magma chamber (Reference). It has been the fundamental portion of the crustal plutonic vicinity. Naweoba Ophiolitic body is part of Zhob Valley ophiolite, possessing a fairly developed crustal plutonic segment. Well-known ophiolites around the globe have this specified crustal portion such as Kizildag and Pozanti-Karsanti Turkey, Semail Oman, Pindos Greece and Muslim Bagh (Dilek and Eddy, 1992; Parlak et al., 2000; Nicolas, 1989; Coogan et al., 2002; Saccani and Photiades, 2004; Kakar et al., 2013; Gnos et al., 1998).

Gabbro, gabbro-norite, hornblende-gabbro and granitic rocks are found in the crustal plutonic vicinity of Naweoba block of Zhob Valley Ophiolite. These variations in the rock types is associated with different magmatic episodes in different times (Cannat et al., 2006). Sheeted dykes found in Bela Ophiolites of and Muslim Bagh of are missing in the Naweoba block (Khan et al., 2018; Kakar et al., 2014). Granitic rocks of the studied area are classified as quartz-rich granitic-rocks, granodiorites, and Ophiolite complexes of different ages contain felsic to intermediate rocks in different parts of an ophiolitic suit (Furnes and Dilek, 2015). Initially introduced the term 'oceanic plagiogranites' for recently used plagiogranites (Thayar, 1977;Coleman and Peterman, 1975; Koepke et al., 2007; Rollinson, 2019). Most of researchers have used plagiogranite as a reference to quartz diorite, trondhjemite, tonalite and to some extent for diorite as well. The presence of large bodies of granitic rocks are much similar of that the Bela Ophiolite. 80% out of 104 ophiolitic, intermediate to felsic rocks contain plagiogranites, trondhjemite, in Phanerozoic Eon both in subduction-related and unrelated domains (Furnes and Dilek, 2017).

The graphic texture present in granitic rocks is quite interesting. A group researchers used a technique based on the combination of computerized tomography, image analysis and CT scanner (Ikeda et al., 2000). He examined graphically formed quartz rods, which were 89.9 connected, and led him to propose that these quartz rods are deviated and have more than one direction and generation. Rao corresponds to the growth of graphic texture as silica enrichment and eutectic crystallization of K-feldspar and quartz followed by more than one generation, the low temperature undercooled silica, late-stage growth, and nucleation (Rao, 2002). This crystallization variation is quite visible in the field in granitic rocks of the Naweoba block. It is coarse-grained in the western portion followed by a shear zone of medium size crystals. The eastern portion is quite compact and fine-grained. The mineral composition also varies as the eastern portion of the studied area is more mafic compared to the more felsic western portion. Fractional crystallization is suggested as the main culprit for the formation of felsic and intermediate rocks in the subduction-related and unrelated rocks. It is assumed that the magma chamber has acted as a closed system for enough time for crystals to fractionate.

Compositional zoning is also associated with a closed system. Plagiogranite may be formed by reheat and crystallization of basal part of early formed magma, through upward migrating melt (Flager and Spray, 1991; France, 2010; Grimes, 2013). The paragenetic sequence of mineralization on the basis of contact relationship show that plagioclase grains are euhedral and are convex in contact with quartz and alkali grains, indicating that these grains are early formed in the crystallization sequence. On the other hand, quartz and alkali feldspar grains are formed simultaneous in the crystallization sequence. The presence of well-developed and partially developed opaque material also point out their two different stages of formation. Well-developed discrete and enclosed grains state that these grains have been formed early in the crystallization sequence, while others may be formed simultaneous with the remaining mineral grains.

6. Conclusion

Based on the above discussion the following conclusions are drawn:

1. The crustal plutonic rocks of the Naweoba block of Zhob Ophiolite are composed of prominent hills of gabbroic rocks and granitic rocks. Petrographically, gabbroic rocks are gabbronorite, pyroxene-hornblende gabbronorite and pyroxene-hornblende norite. The granitic rocks are quartz-rich granitic rocks, granodiorite, and plagiogranite and tonalite.
2. The gabbros may have formed in a magma chamber as a result of cyclic upward movement of magma and fractional crystallization. The felsic rocks may be frictionally crystallized.
3. The formation of gabbro-norite may be suggested as in the supra subduction zone. From the close correlation of gabbroic and granitic rocks of Naweoba block with that of Muslim Bagh, Khanozai and Bela ophiolites, it can be assumed that these rocks are formed in supra subduction zone environment.

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