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Petrology and major element geochemistry of granitic rocks from Bela Ophiolite; economic implications

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Abstract

The Bela Ophiolite is one of the largest ophiolites in Pakistan. The ophiolite contains three different types of granitic rocks; epidote granite, albite granite and alkali granite. The outcrops of epidote granite are surrounded by crustal gabbroic rocks and are exposed at two different localities. Albite granite forms an isolated hill and is surrounded by diorite. While the alkali granite is exposed in the south of Bela Ophiolite and found as inlier in the sedimentary successions of Indian Plate passive margin sediments. The geochemistry of these granitic rocks shows that they have more than 60 wt% SiO_2 and lowest wt% of TiO_2 (0.03- 0.3), CaO(0.2-1) and P_2O_5(0.01-1), and relatively high Na_2O (7-10) concentrations which confirm their acidic nature. The nature and composition of alkali granite indicate that it may be a piece of the Indian continental crust and may be obducted during the emplacement of the Bela Ophiolite Complex. While the petrology of epidote granite and albite granite indicate that they are formed within the gabbro/diorite pluton by either hydrous melting of granulite-amphibolite beneath the peridotite slab or by wet anatexis of isotropic gabbros. Out of the studied granite, epidote and alkali granites have economic uses. They can be used as dimension stone, in buildings, bridges, footpaths, monuments, wall facing, floors, stair and many other designings.

Keywords: Ophiolite, crustal section, granitic rocks, alkali granite, dimension stone.

Introduction

Granites are acidic igneous rocks formed almost in all the tectonic setting of magma generation and are the product of extreme magmatic differentiation. Granite can be divided into orogenic granite, syncolisional granite, volcanic arc granite and oceanic granite.

In southern Balochistan, Pakistan, the Bela Ophiolite complex marks the suture zone between the Indian and Arabian Plates[1]. This suture zone is running parallel to the plate boundary defined by major sinistral transform fault known as Ornach–Nal fault[2]. The Bela Ophiolite has almost a complete ophiolite stratigraphy and is exposed in a north to south trending outcrop in southern Pakistan from district Khuzdar to Karachi[3]. The crustal part of Bela Ophiolite is exposed in Baran Lakh area in the Wadh sub-division of District Khuzdar, Balochistan. The Bela Ophiolite crustal part comprises of ultramafic to mafic cumulates that grade upwards into sheeted dyke complex[4]. The mafic cumulate reported are layered gabbros, foliated gabbros, isotropic gabbros and diorites[5]. The gabbroic rocks and diorites are containing larger bodies of granitic rocks (Figure-1)[6]. These granitic rocks are identified as epidote granite, albite granite and alkali granite. This paper discusses field features, petrography and major elements geochemistry of these granitic rocks.

Regional geological setting: The geology of Bela Ophiolite belt can be divided into three zones, from east to west: the Indian Platform sediments, the ophiolite suture zone (Bela Ophiolite and underlying mélange), and the overlying sediments (Figure-1). Each zone generally trends from north to south and is bounded by thrust faults.

The Indian platform sediments underlying the Bela Ophiolite range in age from Mesozoic to Cenozoic. They comprise of Shirinab Formation (Triassic to Jurassic)[7], consisting dominantly on shale with subordinate amount of limestone and marl which is overlain by Parh Group (Parh Limestone, Guru Formation and Sember Formation; Cretaceous)[7] mostly light grey, dark grey and olive-green shale and minor limestone.

Parh Group is succeeded by Pab Sandstone (Late Cretaceous)[7] is consisting mainly on brown sandstone with subordinate limestone and shale is overlying by Thar Formation (Late Cretaceous to Paleocene)[7] is consisting mainly on calcareous shale with maroon sandstone and mudstone that grades into Wadh Limestone (Late Paleocene)[7] mostly limestone with subordinate sandstone.

The Bela Ophiolite complex and its underlying accretionary Complex are described in next section.

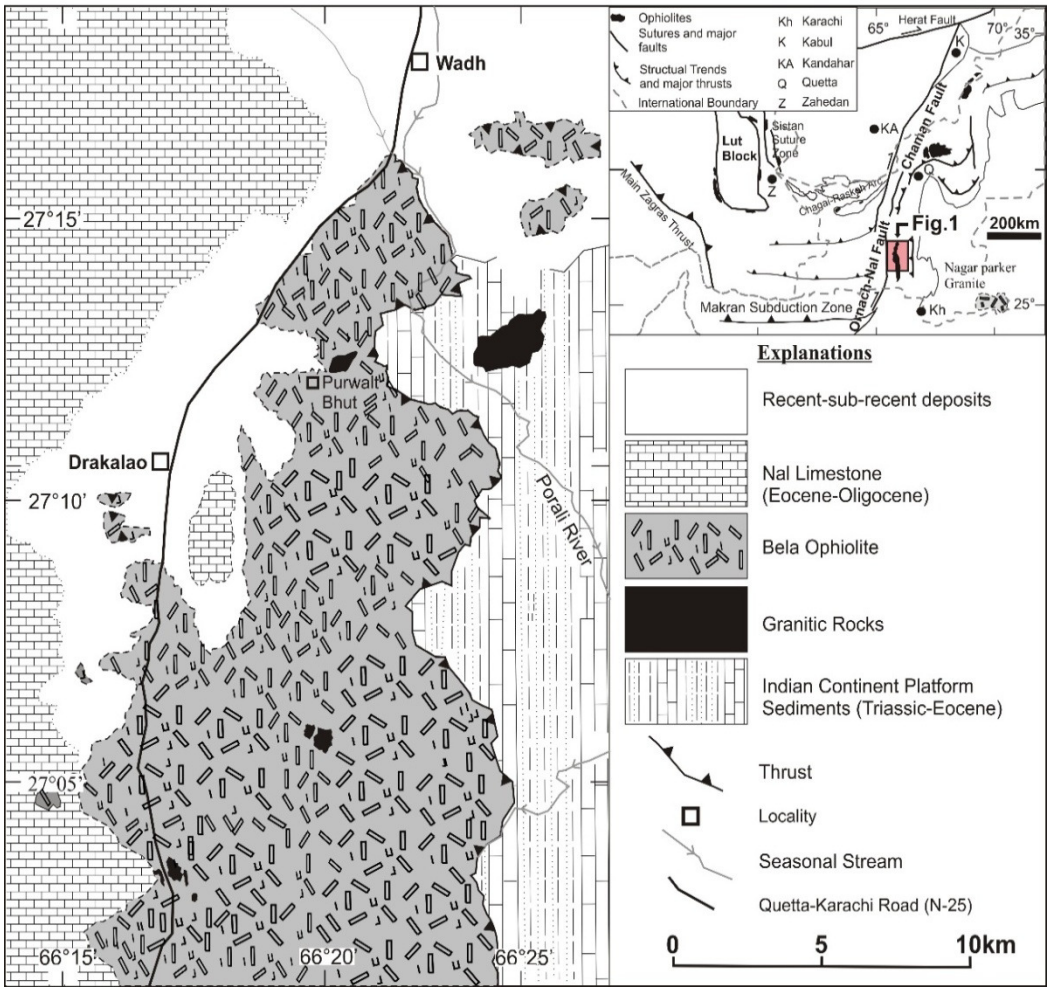

Figure-1: Geological map of Wadh area showing Bela Ophiolite, overlying and underlying rocks of the ophiolite and the locations of granitic rocks[6].

The Bela Ophiolite is overlain unconformabley by Nal Limestone (Eocene to Oligocene)[8], is a transgressive shallow marine sediment which consist of limestone with minor sandstone, shale and marl. The limestone of the formation is medium to thick bedded and highly fossiliferous and refoid. Nal Limestone is overlain by Hinglaj Formation (Miocene to Pleistocene)[7] mainly sandstone with minor shale and silt.

Bela Ophiolite: The Bela Ophiolite is the largest outcrop of oceanic lithospheres in Pakistan. The ophiolite is oriented north-south and exposed between Karachi and Khuzdar. The ophiolite is about 10 to 60 Km wide and 300 Km long. Mapped the Bela Ophiolite and divided it into two units named as upper unit and lower unit[4].

The upper unit (the Bela Ophiolite): is dismembered unit of Bela Ophiolite, forms one single over thrust. It is consisting of mantle peridotite, crustal mafic cumulates and sheeted dikes and this sequence is located between the villages of Wadh and Sunaro. The crustal part of Bela Ophiolite contains different types of granitic rocks.

The lower unit (accretionary wedge and trench sediments): consist of imbricated sheets, 50 to 1500 m thick and 500m long. Each imbricate contains a complete or partial sequence of oceanic ridge related pillow lavas with geochemical signature of E-MORB[5] setting and cover by a Mn-enriched horizon of sedimentary; pelagic to hemi pelagic chert, shale limestone and intruded by doleritic dikes and lava flows of various types.

The radiolarian chert, red shale and turbidite' sedimentary units which is directly overlying the pillow lava was dated as Aptian to lower Maastrichian[2].

Granitic Rocks: Field Features: Epidote granite is exposed in Bakhalo area, situated about 35 Km south of Wadh town (Figure-2a). The granite is located by the National Highway from Quetta to Karachi. The granitic rocks are exposed and are divided into two bodies; eastern body and western body. The western body is low in height covering an area of about 3km^2, while the eastern body is the larger one, forming high hill covering an area of about 15km^2. The granitic rocks have gradational contact with gabbro and lenses of granite can be

found within gabbro especially in the contact zones. Epidote granite is mostly altered and deformed. The granite is dirty-white to white on weathered surfaces and white on fresh surfaces. Epidote granite has large grains of epidote which is light green to dark green in color. Another outcrop of epidote granite is exposed in Usth Garh area, located about 30 km south of Wadh town and 6km east of Quetta–Karachi National Highway. These granitic outcrops comprise two rounded bodies forming high peaks. The larger body is 170m in diameter while the smaller one is 60m in diameter (Figure-2b). These granites are mostly altered and deformed. They are dirty brown on weathered surfaces and brown on fresh surfaces.

The albite granite is located near Purwalt Bhut village, about 17 km south of Wadh town and 3km SE of Quetta–Karachi National Highway (Figure-2c). The granite comprises a rounded hill of 700–800 m in diameter and is surround by diorite with transitional contact. The granite is light brown to white on weathered surfaces, while white on fresh surfaces.

Alkali granite is exposed about 25 km south of Wadh town and covering an area of about 4-5 km^2. The granite is associated with basalt and serpentinized-peridotite and is surrounded by the Thar Formation (Late Cretaceous to Paleocene). At most places, the granite is covered by sediments of the formation. The contact of granite with sediments is thrusted and is concealed by alluvium in most part of the investigated area. The sedimentary formation in immediate contact with the granite is Thar Formation (Early Paleocene), forming higher mountains in the area. The alkali granite is brown, dirty brown and dirty grey on weathered surfaces and pink on fresh surfaces (Figure-2d). Basalt and peridotite associated with it are deformed and in places large blocks of granite are embedded in them.

Petrography: Epidote Granite: Epidote granite consist of quartz, plagioclase, orthoclase, epidote and opaque grains. The accessory minerals are zircon, biotite and sphene (Figure-3a). The secondary minerals identified are sericite and saussurite. Epidote granite exhibits interlocking, myrmekite and porphyritic textures (Figure-3b).

Quartz grains are unaltered, white to gray in color, fine to coarse-grained in size. Quartz give undulose extinction. Few small grains of quartz and feldspar can be seen in the form of inclusions in orthoclase. The estimated volume percentage of quartz is about 40– 50% in epidote granites of Bakhalo area and it goes up to 65% in the samples from Usth Ghar area.

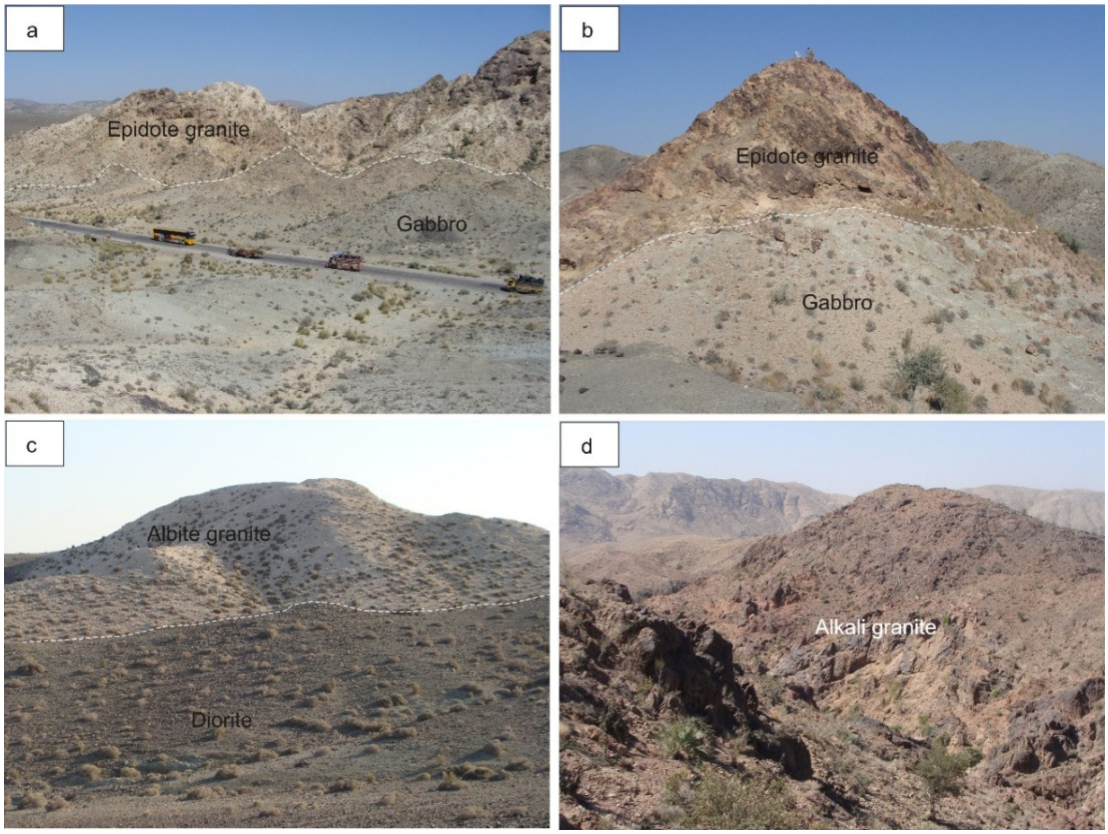

Figure-2: Field features of granitic rocks: a) An epidote granite body surrounded by gabbro, Bakhalo area, Quetta to Karachi road in the foreground, looking NE; b) Epidote granite surrounded by crustal gabbro, forming high peaks in Usth Garh area, looking NW; c) A far view of an isolated hill of albite granite near Purwalt Bhut village, looking S; d) Alkali granite in Kheeson Bandi area, south of Wadh town, the sedimentary rocks is looking in the far.

Plagioclase are euhedral to subhedral in shape, medium to coarse-grained in size. They are lath in shape and give albite twining. The estimated volume percentage of plagioclase is about 20–30 %.

Orthoclase is euhedral to subhedral and rectangular. While orthoclase gives Carlsbad twining. Estimated volume percentage of orthoclase is about 20 – 25 %.

Epidote are medium to coarse-grained, they are fractured, and giving second to third order interference color. The estimated volume percentage of epidote is about 10%.

Albite Granite: Albite granite consists of quartz, plagioclase, orthoclase, chlorite, epidote and opaque grains (Figure-3c) while the accessory minerals are apatite and zircon. The secondary minerals identified are sericite and saussurite. The rock depicts poikilitic to sub-poikilitic, ophitic to sub-ophitic and granophyric textures.

Quartz are subhedral to anhedral and have an estimated volume percentage as 50–55%. Feldspars are subhedral to anhedral in shape with an estimated volume percentage is about 40–45%. Orthoclase gives Carlsbad twining and shows oscillatory zoning (Figure-3d). Estimated volume percentage of opaque grains are about 10%.

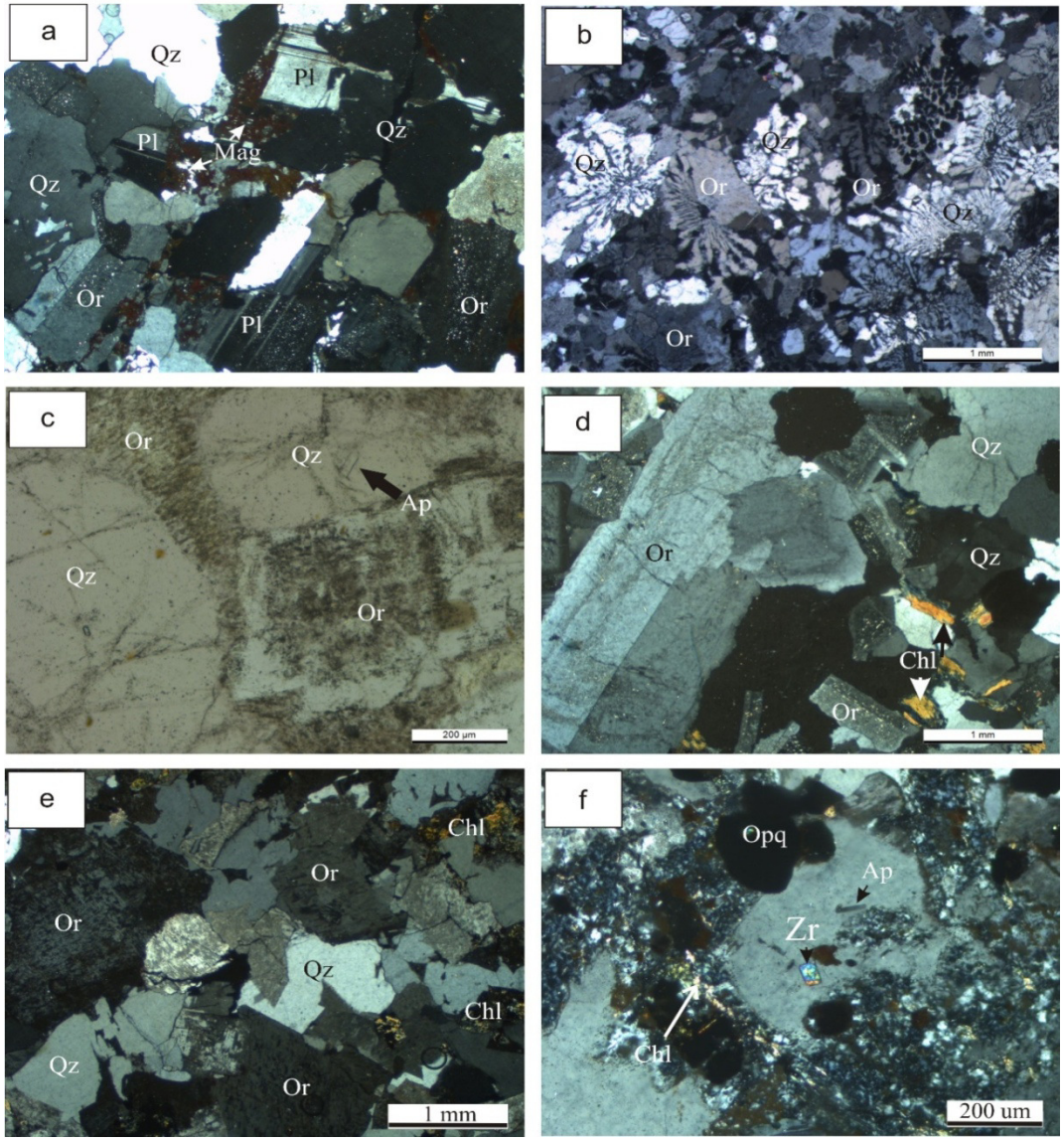

Figure-3: Petrographic features of granites: a) Epidote granite Consists of quartz, plagioclase, orthoclase, epidote and opaque grains; b) Epidote granite exhibits interlocking and myrmekite textures; c) Albite granite consists of quartz and altered orthoclase, tiny apatite grains are also seen; d) Albite granite showing subhedral to anhedral quartz, orthoclase and chlorite, quartz is giving undulose extinction; e) Alkali granite consists of large to medium grains of potash feldspar (orthoclase and microcline) and quartz, with minor chlorite; f) Alkali granite showing accessory minerals such as zircon and apatite.

Alkali Granite: Alkali granite consists of large to medium grains of potash feldspar (orthoclase and microcline) and quartz, with minor plagioclase, hematite, chlorite and opaque grains (Figure-3e). And the accessory minerals found are zircon and apatite (Figure-3f). The secondary minerals are sericite and chlorite. The textures identified in the rock are sub-poikilitic, sub-ophitic and granophyric.

Orthoclase is coarse to medium-grained, euhedral, subhedral to anhedral, brown to dark gray in color. Orthoclase is easily recognized by its striations and simple twining, few grains of orthoclase show zoning. The dominant potash feldspar is orthoclase but few grains of microcline can easily be seen in the rock. Microcline can be differentiated from orthoclase by its cross-hatched twining. Potash feldspar has an estimated volume percentage is about 50 – 60%.

Quartz is medium to fine-grained, subhedral to anhedral and white to dark grey in color. Quartz is giving granophyric texture and is unaltered giving undulose extinction. The estimated volume percentage of quartz is about 40–45%. Plagioclase is found as small grains and as inclusions in orthoclase and between quartz and orthoclase. It gives albite twining. It's quite altered into sericite and is not possible to recognize in most thin sections of alkali granites. The estimated volume percentage of plagioclase is up to 10%. Opaque grains are dark brown to black in color and may be magnetite that is filling in the fractures and veins. The estimated volume percentage of opaque grains are up to 5%.

Methodology

Geochemistry (Analytical Method): Fifteen sample of granitic rocks are analyzed for major elements geochemistry. Before analysis, weathered surfaces were removed then the samples were crushed in a jaw crusher and made the power by using a mill to the size of < 0.074 mm. The powder was dried and heated up to 900°C in a porcelain crucible for two hours to determine Los on ignition (LOI). To determine major element, concentrations sample powder was mixed with flux of lithium tetra-borate (sample flux ratio of 1:5) and the resultant glass was pressed into a disc. Major elements composition were determined using Philips Wave Dispersive X-ray Fluorescence (WD/XRF) at the National Center of Excellence in Geology, University of Peshawar, Pakistan. The geochemical data are reported in (Table-1a, 1b).

Results and discussion

Geochemical Characteristics: The Bela Ophiolite' granites are classified by plotting on Alkalies versus SiO_2 diagram (Figure-4). All the samples fall in the trachydacite and rhyolite fields confirming their granitic characteristics (Figure-4).

The Bela granites have the concentration (wt. %) of SiO_2 (63–72), Na_2O (0.3–3), K_2O (0.01–0.6), Na_2O (7–10), K_2O (0.01–4), P_2O_5 (0.01–1), Al_2O_3 (13–25), Fe_2O_3 (0.2–2.63), MgO (0.14–1.13), CaO (0.3–4), TiO_2 (0.03–0.32). The SiO_2 concentration (wt. %) of the studied granite samples are higher than 60 wt%, and the most SiO_2-rich granites have the lowest TiO_2, CaO and P_2O_5 concentrations and relatively high Na_2O concentrations (Table-1).

To determine the fractionation index in the granite's analyses, selected major elements data are plotted against SiO_2 (Figure-5). In Figure-5; SiO_2 shows negative correlation with MgO, Fe_2O_3, CaO and TiO_2 and no such correlation with Na_2O+K_2O and Al_2O_3, in these plots four samples of epidote granite have clustered.

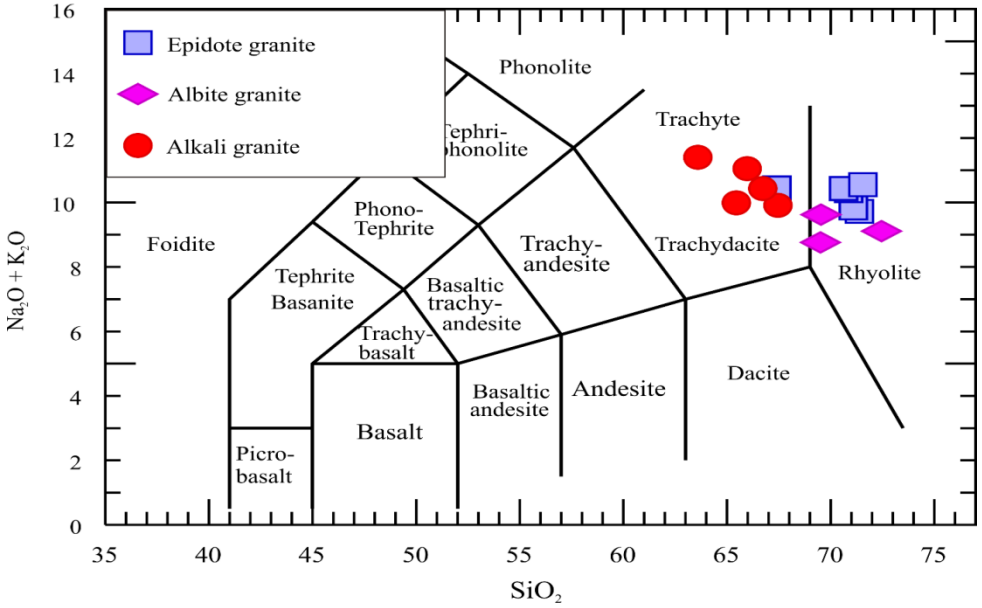

Figure-4: Total alkali versus SiO_2 plot of the granitic rocks from Bela Ophiolite[9].

Table-1a: Major elements (wt %) concentration of granitic rocks from Bela Ophiolite.

Rock type	Ep-Gt	Ep-Gt	Ep-Gt	Ab-Gt	Ab-Gt	Ab-Gt	Ep-Gt	Ep-Gt
Sample no.	BOG 1	BOG 3	BOG 7A	BOG 11	BOG 11A	BOG 12	BOG 16	BOG 17
SiO_2	71.39	67.41	71.1	72.46	69.54	65.83	70.87	70.63
TiO_2	0.08	0.15	0.08	0.05	0.09	0.03	0.09	0.07
Al_2O_3	17.39	18.93	16.41	16.91	17.55	12.86	17.29	17.72
Fe_2O_3	0.56	0.91	0.49	0.41	1.58	2.63	0.97	0.54
MnO	0.02	0.01	0	0.02	0.03	0.04	0	0
MgO	0.48	0.36	0.17	0.43	0.45	1.13	0.2	0.14
CaO	0.58	1.73	1.91	0.6	1.13	3.74	0.38	0.45
Na_2O	8.56	10.17	9.75	8.04	9.34	9.2	9.62	9.53
K_2O	1.16	0.28	0.08	1.07	0.28	0.01	0.74	0.9
P_2O_5	0.02	0.04	0.01	0.02	0.02	0.13	0.01	0.02
Total	100.24	99.99	100	100.01	100.01	95.6	100.17	100

Table-1b: Major elements (wt %) concentration of granitic rocks from Bela Ophiolite.

Rock type	Ep-Gt	Ep-Gt	Alk-Gt	Alk-Gt	Alk-Gt	Alk-Gt	Alk-Gt
Sample no.	BOG 18	BOG 19	BOG 22	BOG 23	BOG 23A	BOG 24	BOG 25
SiO_2	71.56	65.51	67.46	66.73	65.97	65.45	63.59
TiO_2	0.06	0.22	0.16	0.28	0.31	0.28	0.32
Al_2O_3	17.02	25.02	19.13	19.45	19.46	19.45	20.77
Fe_2O_3	0.37	0.2	0.4	1.29	1.23	1.59	1.32
MnO	0	0	0.04	0.03	0.02	0.08	0.04
MgO	0.14	0.24	0.94	0.65	0.79	0.9	0.8
CaO	0.29	2	1.85	1.06	1.07	2.17	1.67
Na_2O	9.87	7.04	7.05	7.13	7.22	6.82	7.43
K_2O	0.68	0.01	2.86	3.3	3.83	3.17	3.97
P_2O_5	0.01	0.14	0.11	0.1	0.1	0.1	0.1
Total	100	100.38	100	100.02	100	100.01	100.01

Note: Fe_2O_3 is total iron, the analyses are calculated to 100 % on LOI-free basis, Ep-Gt = epidote granite, Ab-Gt = albite granite, Alk-Gt = alkali granite.

Discussion: Oceanic granites also called as plagiogranites/ trondhjemites are generally associated with gabbros and sheeted dykes of ophiolites[10-12]. They are found as dykes, inclusions and larger xenoliths in the host dolerites, diorites and gabbros[13]. The granitic rocks from the Bela Ophiolite is rare in nature they comprise of larger isolated bodies covering an area of tens of meters across and are surrounded by the crustal plutonic rocks. Bela Ophiolite granites is divided into epidote granite, albite granite and alkali granite.

Epidote granite is exposed at two different locations of crustal gabbroic rocks, albite granite is exposed away from the main crustal section of Bela Ophiolite and is surrounded by diorite. While the alkali granite is exposed away from the Bela ophiolitic rocks and found as inlier in the sedimentary successions of Indian platform sediments. Alkali granite may be a fragment of the Indian plate shield and may be obducted with emplacement of Bela Ophiolite complex. It may be correlated with Naghar Parker granite exposed in southernmost Pakistan[14]. The origin and nature of epidote granite and albite granite is discussed below.

Geochemistry shows (Table-1a, 1b) that all the three types of granite have 60 wt%, and above SiO_2 and lowest TiO_2, CaO and P_2O_5 concentrations and relatively high Na_2O concentrations which is due to their acidic nature. Negative correlation of SiO_2 with MgO, Fe_2O_3, CaO and TiO_2 and no such correlation with $Na_2O + K_2O$ and Al_2O_3 (Figure-5), show the fractionation trends in these granites while the clustering of four samples of epidote granite may be due to the accumulation of plagioclase.

The literature reports different models for the genesis of granitic rocks in ophiolite complexes. They are formed as residual liquid of magma chamber crystallized under hydrous conditions[15], by hydrous melting of granulite-amphibolite metamorphic rocks beneath the peridotite slab[16]. Wet anatexis of isotropic gabbros[17]. Wet melting of gabbro; crystallization either as a late-stage process in an axial magma chamber, or the remelting of gabbros of axial magma-chamber, hydrated by seawater[11]. The petrology of epidote granite and albite granite from the Bela Ophiolite shows that these rocks are mainly composed of the intergrowth of feldspar and quartz. They may be formed within the gabbro/diorite pluton by either hydrous melting of granulite-amphibolite beneath the peridotite slab[16] or by wet anatexis of isotropic gabbros[17]. The same origin has been proposed, for these granites[3] and for the trondhjemites of Muslim Bagh Ophiolite[13].

Out of the three types of granites, epidote granite and alkali granite have economic significance. They can be used in building industry as dimension stone. The alkali granite can be cut into tiles, the pink tiles of alkali granite is very attractive while the epidote granite is also very beautiful in which large grains of green epidote is embedded in white feldspar and quartz. The dimension stone of both the granites can be used in buildings, bridges, footpaths, monuments, and various additional outdoor projects. For inside decoration, polished granite blocks and tiles are used in wall facing, floors, stair and many other designings.

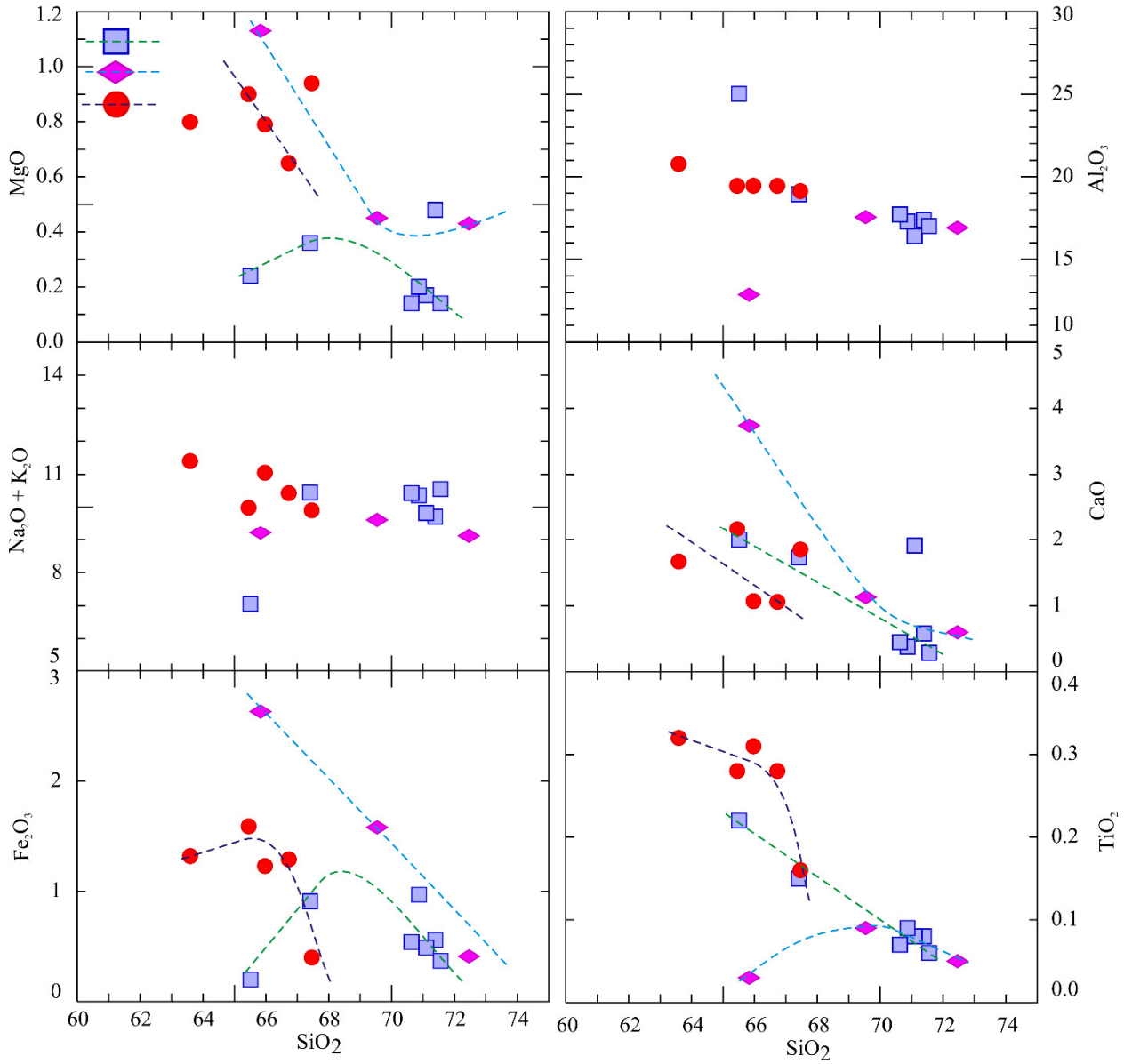

Figure-5: SiO_2 versus selected major element plots of the granitic rocks from Bela Ophiolite. Key: The symbols are the same as in figure-4.

Conclusion

The granites of Bela Ophiolite can be divided into epidote granite, albite granite and alkali granite. Epidote granite is associated with crustal gabbroic rocks, albite granite is exposed in the northernmost part of crustal plutonic rocks and is surrounded by diorite. While the alkali granite is exposed away from the Bela ophiolitic and is found as inlier in the sedimentary successions of Indian platform sediments.

Major elements geochemistry indicates that these granites have 60 wt. %, and above SiO_2 concentrations and lowest in TiO_2, CaO and P_2O_5 concentrations and relatively high Na_2O concentrations which confirm their acidic nature.

The nature and occurrence of alkali granite indicate that it may be a fragment of the Indian continental shield and may be obducted with emplacement of Bela Ophiolite Complex. While the petrology of epidote granite and albite granite indicate that these rocks may be formed within the gabbro/diorite pluton by either hydrous melting of granulite-amphibolite beneath the peridotite slab or by wet anatexis of isotropic gabbros.

Alkali and epidote granites can be used as dimension stone, their dimension stone can be used in buildings, bridges, footpaths, monuments, wall facing, floors, stair and many other designing.

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