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Investigation of gold and base metals mineralization and the petrochemical studies of the associated host rocks, Shagari Bala area, Skardu Gilgit-Baltistan, Pakistan

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Abstract

The Shagari Bala area lies in the Skardu district of Gilgit-Baltistan province. It is located within the Kohistan-Ladakh island arc on the east side of Nanga Parbat Haramosh massif. Deosai volcanics and the meta-volcanics of the Burji-La Formation, mainly exposed in the study area are the focus of this study. The Deosai volcanics are partially to highly altered porphyrictic rocks while the meta-volcanics of the Burji-La Formation are metamorphosed to greenschist facies. The Deosai volcanics also have sulfides-bearing mineralized altered zones which exhibit leaching of chalcopyrite and pyrite to malachite, azurite and limonite.

The petrographic studies show that the Deosai volcanics have porphyritic texture and mainly comprised of plagioclase and hornblende phenocrysts. Plagioclase phenocrysts are generally partially altered but the completely altered phenocrysts are also not common. Hornblende phenocrysts are usually replaced by chlorite and epidote. Phenocrysts of plagioclase and hornblende along with alkali feldspar, quartz and ores are embedded in felsophyric groundmass. The feldspar phenocrysts and the groundmass are generally altered to kaolinite, sericite and saussurite. The meta-volcanics of the Burji-La Formation consists of amphibole (mainly tremolite/actinolite with lesser amount of hornblende), plagioclase, epidote, alkali-feldspar, chlorite and ores. Epidote and chlorite are the alteration products of hornblende while kaolinite, sericite and saussurite are the alteration product of feldspar.

The gain and loss in gold, silver and base metals in the hydrothermally altered sulfides-bearing mineralized altered zone have been evaluated on the basis of enrichment and depletion factors. Multifold enrichment of Au, Ag and Cu are found in these zones. However, this enrichment is not of economic importance.

The geochemical studies show that the Deosai volcanics are dacite to rhyodacite in composition while the meta-volcanics of Burji-La Formation show basalt to basaltic-andesite in composition. The spider diagrams of both Deosai volcanics and the meta-volcanics of the Burji-La Formation exhibit enrichment of large ion lithophile elements as compared to high field strength elements while well-defined negative and positive anomalies have been observed for Nb and Sr respectively. The major and trace elements data of Deosai volanics and the meta-volcanics of the Burji-La Formation were evaluated for identifying the paleotectonic environment of their formation. It has been noticed that the studied volcanics are of calc-alkaline character which have been originated in the island arc type of setting mainly involving subduction related magmatism.

Keywords: Gold; Base metals; Petrochemistry; Meta-volcanics; Gilgit-Baltistan.

1. Introduction

Study area is located in the Gilgit-Baltisatn province of the northern Pakistan (Fig. 1). It is famous for variety of mineral resources including gemstones and placer gold. Previous workers have reported the occurrence of gold in the stream sediments of the major rivers and their tributaries in the northern area of Pakistan. Calkin (1969) reported an average amount of 77ppm of gold from different places along the Chitral River. Tahirkheli (1974) carried out stream sediments survey along Indus River between Hunza and Skardu and reported occurrence of placer gold. According to him the stream sediments are heterogeneous in nature and primary source of these placers gold lies in the large granodiorite batholiths, which contain granite, pegmatite and hydrothermal quartz veins. These are widely distributed in the catchment areas of these rivers. The occurrence of placer gold has also been suggested by Austromineral (1978) through drilling and panning along the Indus River in northern areas of Pakistan. The major work on exploration of gold and base metals in Gilgit-Baltistan region was started in 1992 and completed in 2001 by Pakistan Mineral Development Company (PMDC) and Northern Areas Administration under the technical and financial assistance of Australian Agency for International Development (AIBAD). The occurrence of placer gold in the major rivers such as Gilgit, Ghizer and Indus of Gilgit Baltistan region have developed greater interest of identifying the source rocks and process involving in gold mineralization. Based on the systematic integrated drainage geochemical sampling program of PMDC, six prospect areas for the source of gold have been identified. The proposed study area is one of these identified areas (Fig. 1). No work has been carried out in the study area in regard to the petrochemical characteristics of the rocks of the area with gold and base metals investigation by the previous workers. However petrography of the Deosai volcanics has been discussed by Hamidullah et al. (1992). This study is, therefore, carried out for the petrochemical investigation of the rocks of the study area in the perspective of gold and base metal mineralization for further exploration and exploitation.assistance of Australian Agency for International Development (AIBAD). The occurrence of placer gold in the major rivers such as Gilgit, Ghizer and Indus of Gilgit Baltistan region have developed greater interest of identifying the source rocks and process involving in gold mineralization. Based on the systematic integrated drainage geochemical sampling program of PMDC, six prospect areas for the source of gold have been identified. The proposed study area is one of these identified areas (Fig. 1).

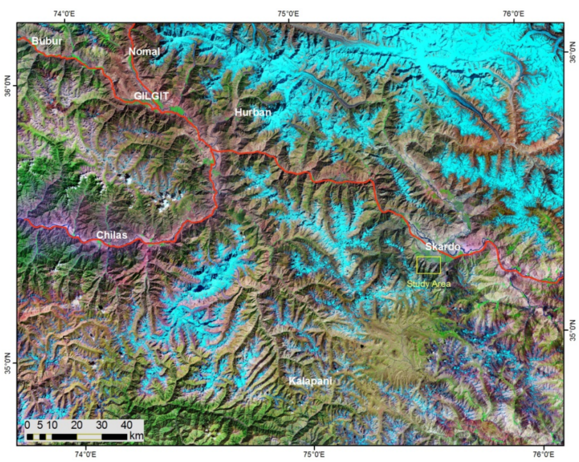


Fig. 1. Landsat 7 image of northern areas of Pakistan showing location of study area.

No work has been carried out in the study area in regard to the petrochemical characteristics of the rocks of the area with gold and base metals investigation by the previous workers. However petrography of the Deosai volcanics has been discussed by Hamidullah et al. (1992). This study is, therefore, carried out for the petrochemical investigation of the rocks of the study area in the perspective of gold and base metal mineralization for further exploration and exploitation.

2. Methodology

Landsat 8 remote sensing data was used for mapping the geology and sulfide mineralization zones in the study area. The Landsat 8 multispectral satellite data have eight bands measuring reflected energy from 0.42 micrometer to 2.29 micrometer range of electromagnetic spectrum. In 2012 field work was conducted in which two types of representative rock samples were collected. Bulk samples of 10-15 kg were collected from the sulfide-bearing altered zones and grab samples of about 1.00 kg were collected from the fresh looking host rocks such as Deosai volcanics and meta-volcanics of Burji-La Formation. These samples were transported to National Centre of Excellence in Geology (NCEG), University of Peshawar for preparation of thin sections and chemical analysis. Thin sections (both polished and unpolished) were prepared for studying the mineralogical, textural and alteration behavior of the rocks using polarizing and reflecting microscopes. The bulk and grab samples were crushed by jaw crusher and pulverized to -200 mesh size by the tungsten carbide ball mill. The representative portions of these samples were obtained by passing individual sample through splitter. The representative powdered samples were stored in the glass bottles and were heated at 110ºC overnight and then the bottles were stored in the desiccator for further processing. The chemical analysis of rock samples for Au, Ag and base metals such as Cu, Pb, Zn, Ni, Cr, Co, and Cd were carried out using the Perkin Elmer-700 graphite furnace atomic absorption spectrometer (AAS) in the Geochemistry Laboratory of the NCEG. Before analyzing the samples through AAS, the samples were digested by the methods of Macalalad et. al. (1988) and Jeffery and Hutchison (1986) using aqua-regia ($3HCl:1HNO_3$) and hydrofluoric acid (HF) for the analysis of Cu, Pb, Zn, Ni, Cr, Co and Ag. However, for the determination of gold, its extraction was made by the method of Hubert and Chao (1985) in methyle isobutyle ketone (MIBK). The loss on ignition (LOI) in each sample was determined by heating the sample at >950ºC for four hours. The grab samples of fresh volcanics of both Deosai volcanics and meta-volcanics of Burji-La Formation were analyzed for major and trace elements using Bruker S4 Pioneer x-ray fluorescence machine at the Ellington & Associates Houston, USA. The reagents and chemicals used during experimental work were of BDH AR-grade and the methods were validated by using the certified rock standards at the confidence limit 90-95%.

3. Results and discussion

3.1. Geology, remote sensing and field observation

The lithological units in the study area, after comparing with the regional lithologies proposed by Rolland et al. (2000) and Robertson and Collins (2002), have been classified as the Deosai volcanics (Desio, 1978) and Katzarah Formation (Rolland et al., 2000) or Burji-La Formation (Robertson and Collins, 2002) (Fig. 2).

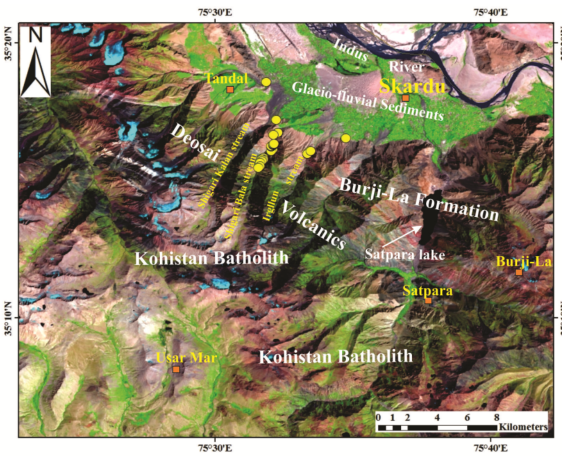


Fig. 2. Landsat 8 images of Shagari Bala and surrounding areas (A) Landsat 8 true color image with bands 4,3 and 2 displayed as red, green and blue (b) Landsat 8 bands 7, 5, 4 displayed as red, green and blue.

In this paper, the classification of Robertson and Collins (2002) has been followed. On this basis the two main lithologies i.e., Deosai volcanics and the meta-volcanics of the Burji-La Formation are described here. The Deosai volcanics occur as dacite-rhyodacite porhyritic rocks with sulfide bearing phases in the form of alteration zones. On the basis of age assigned to Deosai volcanics (Wadia, 1937; Hamidullah 1992), these can be considered the extension of Late Jurassic to Early Cretaceous Dras volcanics (Frank et al., 1977; Honegger et al., 1982; Dietrich et al., 1983; Sharma 1990). The Burji-La Formation consists of meta-volcanic rocks (greenschist) of basalt to basaltic-andesitic composition and grey to black slate in the study while dark grey phyllite, thin bedded argillaceous limestone, volcanoclastic siltstone, feldspathic sandstone, quartz schist and chlorite schist have also been reported in this formation in other places (Robertson and Collins, 2002). This formation has been assigned an age of Late Cretaceous (Desio, 1965; Robertson and Collins, 2002).

Two Landsat 8 images are presented in Figure 2. Both these images discriminate major geological units, Deosai volcanics, Burji-La Formation and Kohistan Batholith. Also a plutonic intrusion possibly diorite in composition can be seen at mid lower part of Figure 2 and is labeled as diorite. This site is located at top of the peak with glaciers in the surrounding that can be seen in cyan color in Figure 2b. Northwest of this intrusive body, a white colored linear feature can be seen that extends from northwest to southeast. Although because of the high altitude this body was not checked in the field but this could be pegmatite\quartz vein with alteration zones and may be a potential site for mineralization.

Due to high relief and steep slopes in the study area, it was not possible to have access to the upstream exposures. However, it was tried to do field work along the stream sections where the area was accessible. To understand the geology of the area and to target the source rock for gold and base metals, the field work was carried out along the two tributaries (i.e., Shagari Bala lungma and Irgllun lungma) of Indus River.

Shagari Bala Lungma (stream): The entering point of Shagari Bala Lungma is covered with thick sequence of glacio-fluvial sediments along both side of the stream (Fig. 3a), which are generally covering volcanoclastic and meta-sediments of Burji-La Formation. The contact of the rocks of this formation with the Deosai volcanics is sharp and exhibit very fine-grained grey to black slate (Fig. 3b) but at places the meta-volcanics, attaining greenschist texture, are also exposed. Sulfides-bearing mineralized altered zones (<1 m to 10 m thick), showing yellowish-brown leaching, are common along shear zones within these rocks (Fig. 3c,d). These zones are highly sheared along local faults and exhibit quartz veining along foliation planes. Towards further south in the upstream section, the porphyritic Deosai volcanics are exposed in a vast area. In hand specimens, these rocks are having fine to coarse-grained texture due to greater amount of phenocrysts, embedded in a fine-grained matrix.

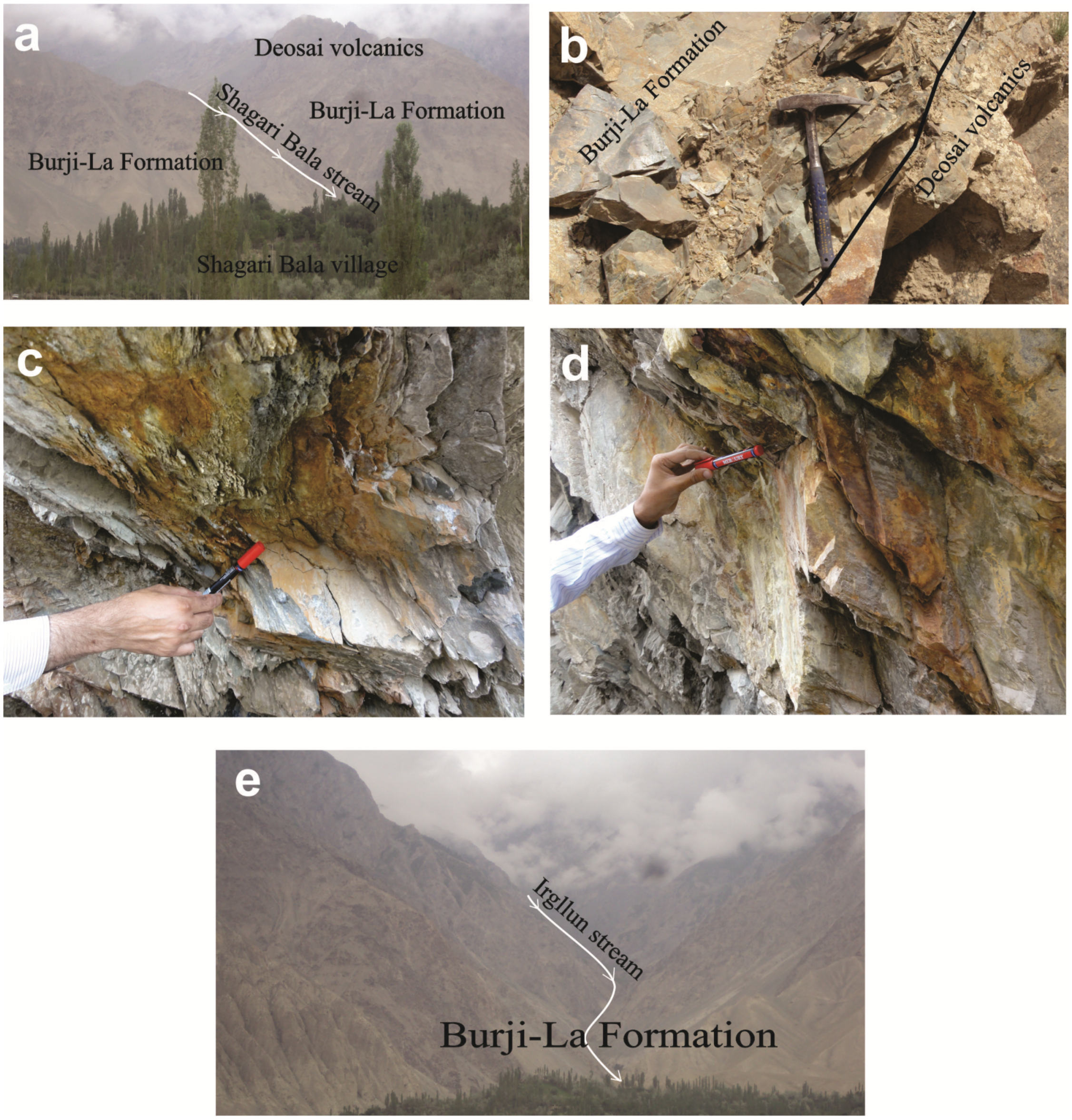


Fig. 3. Photographs showing (a) the frontal view of Shagari Bala Lungma, (b) contact between Burji-La Formation and Deosai volcanics, (c & d) sulfide-bearing zone in Shagari Bala Lungma section and (e) frontal view of Irgllun Lungma.

Due to rough and steep topography of the area, the upper parts of the hill were inaccessible. However, it was found in the boulders fallen down from porphyritic Deosai volcanics that these volcanics are hosting sulfide mineralization in the form of pyrite, chalcopyrite and other sulfide-bearing disseminated grains which are generally leached out in the form of malachite and azurite. This is suggesting the presence of copper prospects in the upstream areas.

Irgllun lungma (stream): Along Irgllun lungma most of the stream sides are covered with alluvium overburden shown in Figure 3e. On both sides of stream, various exposures of highly deformed meta-volcanics (greenschist) of Burji-La Formation similar to Chalt volcanics are exposed. The upstream areas are generally inaccessible; therefore, the boulders in the stream were studied carefully. It was noticed that the boulders, pebbles and scree material were mainly of meta-volcanics and grey to black shale of Burji-La Formation and porphyritic Deosai volcanics. This suggests that the upstream inaccessible area is mainly having the same lithologies as were found along Shagari Bala Lungma.

3.2. Petrographic and spectroscopic characteristics

3.2.1. Deosai volcanics (Porphyritic rocks)

In thin sections, these rocks have porphyritic texture. The phenocrysts of plagioclase, hornblende, alkali feldspar and quartz are set in a felsophyric groundmass in a variable amount.

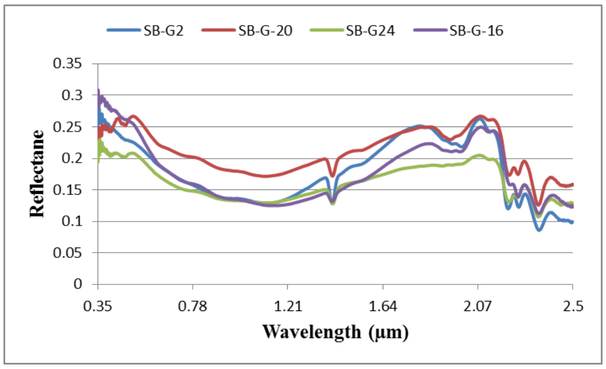
Plagioclase phenocryst, euhedral to tabular in form, is the dominant phase which in some cases is partially or completely sauceritized. The fresh looking plagioclase phenocrysts exhibit simple, polysynthetic and pericline twining. At places zoned plagioclase phenocrysts are also noticed.Hornblende phenocrysts are highly paleochrioc from green to yellowish-green. The hornblende also shows alteration to chlorite, epidote and tremolite/actinolite along margins and fractures. In most cases the hornblende is completely altered to chlorite and epidote and pseudomorphs after hornblende are well noticed. Minor amount of quartz and alkali feldspar are also found in some thin sections. Ore minerals are present in lesser amount and are mainly associated with epidotes. This is indicating the release of iron during hornblende + plagioclase transformation to epidote. Groundmass is fine-grained with felsophyric composition exhibits alteration to sericite, epidote, carbonates, kaolinite and saussurite etc.

3.2.2. Meta-volcanics (Greenschist) of Burji -La Formation

In thin sections, these rocks are dominantly containing amphibole, epidote and chlorite with subordinate amount of phenocrysts of plagioclase, alkali feldspar and quartz set in a fine-grained groundmass. On the basis of mineral assemblages and preferred orientation, these rocks are termed as greenschists. The phenocrysts of plagioclase are partially or completely altered to sericite, edpidoteand carbonates. Alkali feldspars are generally altered to sericite. In many cases the pseudomorphs after feldspar are well noticed. Hornblende is generally showing complete alteration to Tremolite/actinolite and chlorite.

Tremolite/actinolite is assicular in form and is green to yellowish-green in color. The fine fibers of tremolite/actinolite in association with epidotes spread over the groundmass are generally following the fabric direction. Chlorite is the alteration product of hornblende in these rocks. In plain polarized light it shows green color and is present in patchy form. At places the complete transformation of hornblende to chlorite is visible in the form of pseudomorph left after hornblende. Groundmass is mainly composed of epidote, chlorite, trimolite/ actinloite, sericite, kaolinite, carbonates and ore phases.

Though the primary and some of the secondary phases have been recognized during the petrographic studies under the polarizing microscope but to confirm the presence of alteration products, the spectroscopic studies on the altered rocks have been carried out. The spectroscopic studies were carried out for the highly altered four samples of porphyritic volcanic rocks of Deosai volcanics (Fig. 4a) and meta-volcanic rocks of Burji-La Formation (Fig 4b). The spectroscopic features of both porphyritic volcanics and meta-volcanic rocks can be easily differentiated on the basis of their absorption features (Figs. 4a&b). These figures show that both types of rocks have different amount of iron, clay and carbonate minerals.



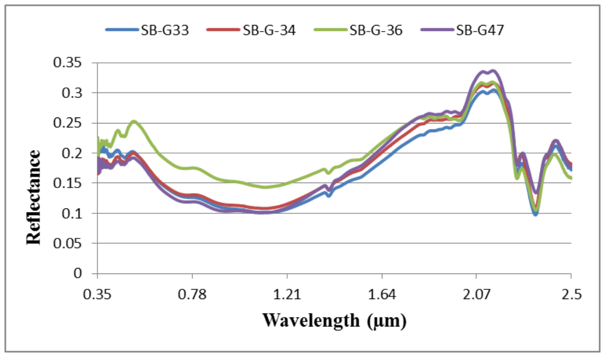


Fig. 4. Spectral reflectance curves for the selected samples of (a) Deosai volcanics and (b) meta-volcanics of Burji-La Formation.

3.3. Geochemistry

3.3.1. Gold, silver and base metals in the sulfide-bearing altered zones

The bulk samples (10-15kg) have been collected from the sulfide-bearing mineralized altered zones. These were analyzed for the precious metals i.e. gold (Au), silver (Ag) and for base metals like copper (Cu), lead (Pb), zinc (Zn), nickel (Ni), chromium (Cr), cobalt (Co) and Cadmium (Cd). The concentrations of Au, Ag and base metals in the sulfide-bearing altered zones have been given in Table 1. The data in this table shows that precious metals such as concentration of Au varies from <0.05 ppm to 0.35 ppm with an average amount of 0.14 ppm and concentration of Ag varies from <0.05

ppm to 5.15 ppm with an average amount of 1.75 ppm. Among the concentrations of base metals, Cu varies from 8 ppm to 412 ppm with an average amount of 127 ppm, Zn varies from <0.02 ppm to 131 ppm with an average amount of 35 ppm, Ni varies from 2 ppm to 41 ppm with an average amount of 16 ppm, Cr varies from 4 ppm to 88 ppm with an average amount of 44 ppm, Co varies from 2 ppm to 82 ppm with an average amount of 32 ppm, Cd varies from <0.02 ppm to 3.65 ppm with an average amount of 1.83 ppm and Pb varies from <0.02 ppm to 9.45 ppm with an average amount of 4.09 ppm.

It is common understanding that alteration in any kind of rock brings changes in the chemical composition of the rock. The hydrothermal alteration and precipitation of sulfides within the studied rocks may have added or leached out the precious and base metals in these rocks. In order to see the gain and loss of metals in the studied sulfide-bearing altered rocks as compared to the unaltered rocks, the enrichment and depletion factors have been calculated for the average values of metals by using the formula such as:

$$[(a-b)/b \times 100]$$

Where "a" is the concentration of a metal in the altered rocks and "b" is the concentration of a metal in the unaltered rocks. The unaltered rocks in this case are considered as the Deosai volcanics which are not affected by the alteration and are devoid of sulfide phases.

Table 1. Gold, silver and base metals concentrations in the bulk samples of the rocks of Shagari Bala area.

Sample No	**Cu (ppm)**	**Zn (ppm)**	**Ni (ppm)**	**Cr (ppm)**	**Co (ppm)**	**Cd (ppm)**	**Pb (ppm)**	**Ag (ppm)**	**Au (ppm)**
SB-B1	37	7	41	85	2	1.75	2.31	2.23	0.13
SB-B2	92	2	40	88	19	0.55	4.05	0.75	0.14
SB-B3	72	<0.02	32	87	34	2.05	9.32	2.72	0.11
SB-B4	12	<0.02	13	81	8	0.55	1.45	0.65	0.12
SB-B5	17	<0.02	13	48	5	<0.02	5.65	<0.05	0.11
SB-B6	245	<0.02	18	84	28	1.35	8.05	3.15	0.25
SB-B7	153	<0.02	23	76	24	0.55	<0.02	3.13	0.35
SB-B8	221	<0.02	7	54	37	1.25	<0.02	0.41	0.21
SB-B9	90	<0.02	8	67	31	1.15	<0.02	2	0.09
SB-B10	412	<0.02	7	44	52	0.32	<0.02	<0.05	0.15
SB-B11	217	<0.02	7	21	42	1.51	4.93	2.22	0.09
SB-B12	195	<0.02	7	27	34	2.64	<0.02	5.15	<0.05
SB-B13	254	<0.02	17	22	36	3.13	9.45	0.82	0.12
SB-B14	234	<0.02	15	11	42	3.52	2.43	0.91	0.09
SB-B15	102	1	8	7	39	2.74	<0.02	0.84	0.11
SB-B16	138	<0.02	9	4	38	0.45	4.44	1.32	0.19
SB-B17	30	<0.02	11	11	48	3.35	1.05	<0.05	0.29
SB-B18	100	<0.02	28	49	34	1.55	6.95	<0.05	0.11
SB-B19	14	131	15	10	34	2.05	0.25	<0.05	0.14
SB-B20	15	<0.02	2	24	82	2.51	0.05	<0.05	0.07
SB-B21	8	<0.02	6	17	27	3.65	1.13	<0.05	0.09
Minimum	8	<0.02	2	4	2	<0.02	<0.02	<0.05	<0.05
Maximum	412	131	41	88	82	3.65	9.45	5.15	0.35
Average	127	35	16	44	32	1.83	4.09	1.75	0.14
Std	?								

The enrichment and depletion values obtained for Au, Ag and base metals have been plotted in Figure 5. It is clear from this figure that there is multifold increase in Cu, Co, Ag and Au while the rest of the elements are depleted in the sulfide-bearing altered rocks. This is indicating that the hydrothermal solutions may have precipitated Cu and Fe-bearing sulfides such as chalcopyrite and pyrite (well noticed in hand specimens). The enrichment of Au and Ag in the studied sulfide-bearing altered rocks can be attributed to their presence within the sulfide-phases as no native gold has been observed in these rocks. The depleted phases may have been leached out during alteration in these rocks or the hydrothermal solution was devoid of these metals.

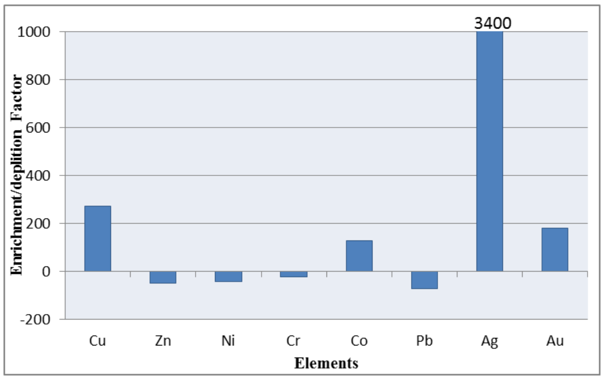


Fig. 5. Diagram showing the enrichment and depletion of gold, silver and base metals in sufide-bearing mineralzed/altered zones.

A very low amount of gold (up to 0.35 ppm) in the sulfide-bearing altered rocks of the area suggests that these rocks have no promising prospects which can be economically viable. However, further detailed work, including drilling to collect the samples at depth, is required to fully understand the economic viability.

3.3.2. Whole rock geochemistry

For the whole rock geochemistry a total of elevenrepresentative samples were selected, eight from the Deosai volcanics and three from the meta-volcanics (greenschists) of Burji-La Formation. The major and trace element data along with CIPW norms of these volcanics are presented in Table 2. The Deosai volcanics are of dacite-rhyodacite composition while the meta-volcanics of the Burji-La Formation are basalt to basaltic-andesite in composition.

Deosai Volcanics

Major Elements: Major element data of the Deosai volcanics show that these volcanics have wider range of SiO_2 contents (61.67-69.47 wt%). The TiO_2 is low in concentration and is ranging from 0.37-0.64 wt%. These volcanics have a narrow range of Al_2O_3 (14.05 - 16.47 wt%). Fe_2O_3 exhibits very low concentration with a range of 2.51 to 5.43 wt%. The MgO and CaO concentrations are ranging from 0.73 to 2.54 wt% and 3.25 to 7.79 wt% respectively, while Na_2O (1.20-4.99 wt%) and K_2O (0.35-3.09 wt%) have moderate to wider range in these volcanics. P_2O_5 is ranging from 0.14-0.25 wt%. The loss on ignition (L0I) is ranging from 2.03-3.56 wt%. The moderate loss on ignition could be due to the post-magmatic alteration as also observed in the petrographic studies. The Mg # [100×MgO/(MgO+Fe_2O_3t)] is very low with a range of 16-39%. The normative composition of these rocks indicates that all the samples are quartz normative with a range of 22.17 to 36.01%. Plagioclase (29.11%-58.51%), having albite (Ab) in the range 10.46 to 38.30% and anorthite (An) in the range of 15.47 to 25.09%, are the dominant normative phases with subordinate normative composition of orthoclase ranging from 2.10 to 18.40%. All the samples of Deosai volcanics, except two samples, are hypersthene (Hy) normative (6.56-11.72%) while three samples having diopside (Di) up to 15% are deficient in corundum (C). The rest of the samples have corundum in the range of 0.12 to 3.55%. These rocks also have normative ilminite (Il), magnetite (Mt) and apatite (Ap) in the range of 0.72 to 1.22%, 0.67 to 1.37% and 0.31 to 0.57% respectively.

Trace Elements: The trace elements concentrations of the Deosai volcanics show that there is a variable range of Sc (8-14 ppm), V (55-103 ppm), Co (3-14 ppm), Cr (35-96 ppm), Ni (16-48 ppm), Cu (5-63 ppm), Pb (6-35 ppm), Zn (29-89 ppm), Rb (12-137 ppm), Ba (102-413 ppm), Sr (172-990 ppm), Th (3-15 ppm), U (1-3 ppm), Nb (6-13 ppm), Y (10-29 ppm), Zr (134-287 ppm) and Hf (6-12 ppm) in these volcanics. However, concentration of Au and Ag is found below the detection limit (<0.05ppm). It can be noticed that the large ion lithophile elements (LILEs) such as Sr, Rb and Ba are enriched relative to high field strength elements (HFSEs) such as Th, Pb, Nb, Zr and Y in these rocks which is suggesting the calc-alkaline nature of these rocks.

Meta-volcanics of the Burji-La Formation

Major Elements: The major element data of the meta-volcanics of the Burji-La Formation indicate that there is no significant variation of all the major oxides. The SiO_2 varies from 50.24 to 51.23 wt%, Al_2O_3 from 16.45 to 16.89 wt%, TiO_2 from 1.28 to 1.40 wt%, Table. 2. Major and trace elements data of the rocks of the Shagari Bala, Gilgit-Baltistan

	Deosai Volcanics								Meta-vocanics of Burji-La Formation		
	SBG-10	SBG-2	SBG-14	SBG-24	SBG-16	SBG-19	SBG-7	SBG-31	SBG-47	SBG-34	SBG-33
SiO_2	67.46	61.67	65.89	63.12	65.34	64.78	69.47	64.75	50.24	51.23	50.89
Al_2O_3	15.80	16.05	16.78	15.89	14.89	15.24	14.05	16.03	16.45	16.89	16.58
TiO_2	0.47	0.50	0.47	0.43	0.37	0.49	0.64	0.63	1.40	1.34	1.28
Fe_2O_3	2.51	4.67	2.76	4.78	3.87	3.95	4.84	5.43	10.29	9.45	9.75
MnO	0.02	0.05	0.02	0.05	0.04	0.06	0.04	0.07	0.18	0.18	0.17
MgO	1.63	1.72	1.78	1.67	0.73	1.78	2.54	2.25	6.99	5.78	5.93
CaO	3.54	5.11	3.26	4.99	7.79	3.25	3.40	4.52	8.10	7.89	8.10
Na_2O	4.13	3.17	4.23	3.34	4.42	4.99	1.54	1.20	2.99	2.34	2.75
K_2O	1.49	1.85	1.65	1.76	0.35	1.01	3.09	2.52	0.79	0.68	0.63
P_2O_5	0.19	0.25	0.19	0.21	0.20	0.25	0.14	0.14	0.20	0.20	0.18
L.O.I	2.17	3.23	2.67	3.56	2.90	3.50	2.03	3.07	3.20	3.43	3.78
Total	**99.41**	**98.27**	**99.70**	**99.75**	**100.91**	**99.31**	**101.79**	**100.61**	**100.84**	**99.42**	**100.04**
Trace elements in (ppm)											
Sc	8	10	8	10	8	8	12	14	26	32	29
V	68	76	78	72	55	68	103	101	262	256	260
Co	4	6	4	6	3	3	8	14	30	42	38
Cr	46	35	47	38	43	49	96	94	63	58	57
Ni	17	16	24	18	17	16	37	48	35	39	37
Cu	61	30	63	34	30	5	31	20	36	32	38
Pb	20	14	18	12	35	6	13	23	5	5	5
Zn	83	38	89	41	51	29	57	78	85	97	89
Sr	778	772	657	745	990	389	339	172	319	267	267
Rb	55	71	59	68	12	46	137	131	7	6	6
Ba	286	379	312	216	102	184	413	310	42	48	45
Th	9	8	9	9	3	10	14	15	3	3	3
U	2	3	2	3	1	2	2	2	0	0	0
Nb	7	7	7	7	6	9	11	13	4	4	4
Y	10	16	10	18	24	23	24	29	41	49	45
Zr	135	140	143	165	134	177	287	213	117	134	128
Hf	10	9	10	12	9	6	10	6	5	5	5
Ag	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Au	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mg#	39	27	39	25	16	31	34	29	40	38	38
C.I.P.W Norms											
Q	28.07	22.17	25.48	23.06	23.51	23.46	36.01	33.82	-	6.92	6.93
Ab	35.96	28.3	36.99	29.49	38.29	38.3	13.09	10.46	26.21	20.82	20.78
An	16.86	25.09	15.47	24.16	20.22	20.2	16.02	22.09	30.05	35.22	35.26
Or	9.06	11.57	10.07	10.86	2.08	2.1	18.40	15.38	4.88	4.22	4.23
Hy	6.56	9.85	7.85	9.65	-	-	11.35	11.72	24.33	23.38	23.41
C	1.45	0.1	2.62	-	-	-	2.35	3.55	-		-
Il	0.91	0.99	0.91	0.86	0.72	0.73	1.22	1.22	2.74	2.68	2.68
Mt	0.67	1.20	0.73	1.19	0.95	0.96	1.21	1.37	2.67	2.51	2.51
Ap	0.42	0.57	0.42	0.48	0.46	0.46	0.31	0.33	0.46	0.46	0.46
Di	-	-	-	0.22	15.29	15.29	-	-	8.24	3.68	3.64
Ol	-	-	-	-	-	-	-	-	0.38	-	-

Fe_2O_3 from 9.45 to 10.29 wt%, MnO from 0.17 to 0.18 wt%, MgO from 5.78 to 6.99 wt%, CaO from 7.89 to 8.10 wt%, Na_2O from 2.34 to 2.99 wt%, K_2O from 0.63 to 0.79 wt% and P_2O_5 from 0.18 to 0.20 wt%. Loss on ignition (L0I) is ranging from 3.20 to 3.78 wt%. These rocks are olivine (0.32%) and quartz (up to 6.93%), plagioclase with albite normative (20.78-26.21%) and anorthite normative (30.05-35.26%) is the dominant feldspar phase with very low (4.22-4.88%) normative orthoclase. Pyroxene is generally hypersthene normative (23.38-24.33%) with lesser normative composition of diopside (3.64-8.24%). Normative ilmenite, magnetite and apatite are in the range of (2.68-2.74%), (2.51-2.67%) and (0.46%) respectively. The Mg of the studied meta-volcanics is low and ranges from 38-40%.

Trace Elements: The studied meta-volcanics of Burji-La Formation contain Sc in the range of 26 to 32 ppm, V in the range of 256 to 262 ppm, Co in the range of 30 to 42 ppm, Cr in the range of 57 to 63 ppm, Ni in the range of 35 to 39 ppm, Cu in the range of 32 to 38 ppm, Pb up to 5 ppm, Zn in the range of 85 to 97 ppm, Sr in the range of 267 to 319 ppm, Rb in the range of 6 to 7 ppm, Ba in the range of 42 to 48 ppm, Th up to 3 ppm, Nb up to 4 ppm, Y in the range of 41 to 49 ppm, Zr in the range of 117 to 134 ppm and Hf up to 5 ppm. The values for Au and Ag are below the detection limit (<0.05 ppm). From the trace elements it is evident that the large ion lithophile elements (LILEs) are enriched as compared to the high field strength elements (HFSEs) in the studied meta-volcanics as has also been noticed in the Deosai volcanics.

Spider diagrams

The trace elements data of Deosai volcanics and the meta-volcanics of Burji-La Formation for both large ion lithophile elements (LILEs) and high field strength elements (HFSEs) are plotted on chondrite,primodial mantle, ocean island arc and MORB normalized spider diagrams by using normalization values of Sun (1980), Taylor and Mclennan (1985), Sun and McDonough (1989) and Bevins et al. (1984) in Figure 6. It is clear from these diagrams that the meta-volcanics of Burji-La Formation have lower concentration of both LILEs and HFSEs as compared to that of Deosai volcanics. But both the rock types have similar pattern.

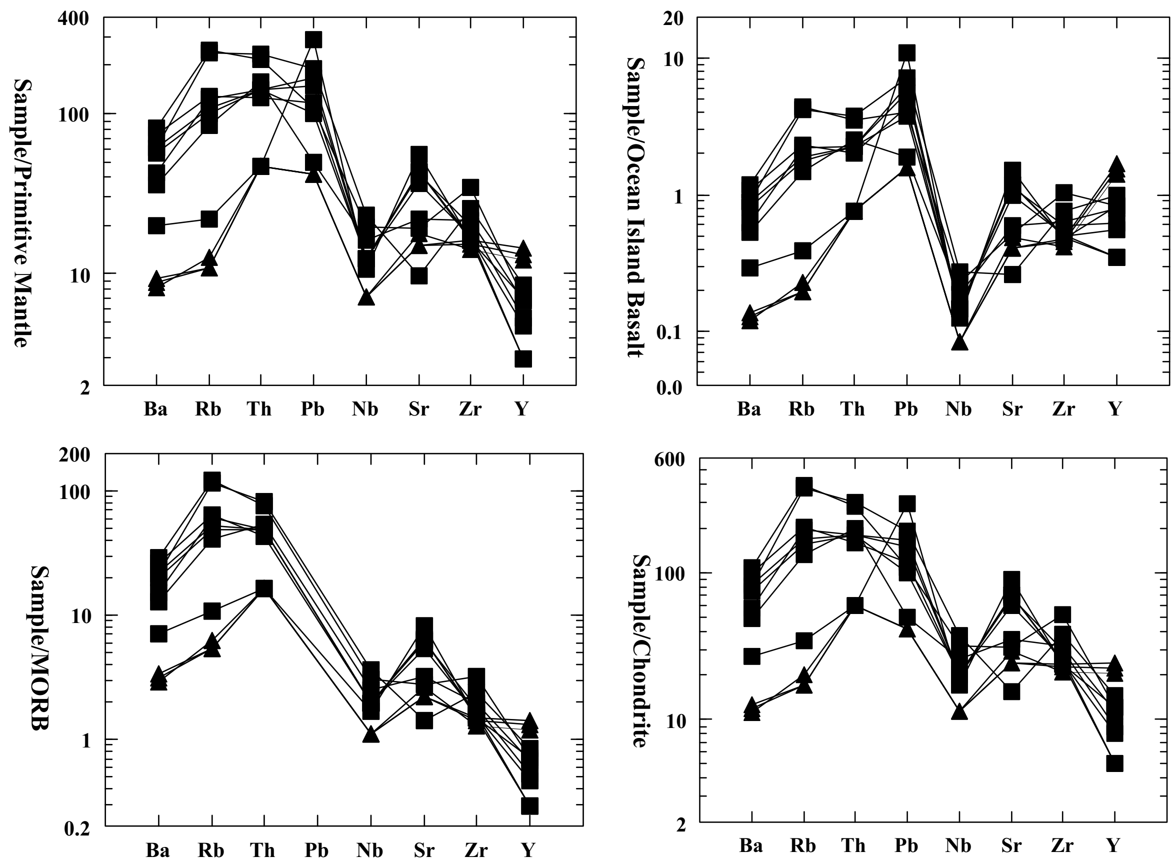


Fig. 6. Spider variation diagram for Deosai volcanics and meta-volcanics of Burji-La Formation normalized to primative mantle, MORB, OIB and Chondrite values after Taylor and Mclennan (1985), Bevins et al. (1984), Sun and McDonough (1989) and Sun (1980).

All the four diagrams show the sloping trend towards the right which is suggesting that these volcanics are enriched in large ion lithophile elements (LILEs) compared to high field strength elements (HFSEs). The elements Ba, Rb, Pb and Sr show positive peaks while the Nb is marked by negative anomalies which conforms the island arc setting (Wilson, 1989).

3.3.3. Tectonic setting of magma generation

Geochemical composition of igneous rocks has made a significant contribution in understanding the paleotectonic history of igneous rocks. The pioneer work of Pearce and Cann (1971, 1973) has provided the basis for fingerprinting magmas from different tectonic settings. They have, therefore, provided a base for what have become known as the tectono-magmatic discrimination diagrams. The geochemistry based binary and ternary diagrams on the basis of which the magma produced in different tectonic environments can be differentiated from one another. It is commonly understood that the igneous rocks formed in a particular type of environment have geochemical characteristics specific to that environment. Therefore, the characteristics of modern igneous rocks originated in specific type of environment can be correlated with their ancient counterparts formed in the same type of tectonic setting. These petrogenetic and paleotectonic studies are, therefore playing an important role in understanding the magma generation in specific type of tectonic environment in the past.

To understand the formation of the volcanic rocks of the study area in paleotectonic environment, the major and trace element data have been plotted in various tectono-magmatic discrimination diagrams. Few diagrams such as AFM diagram (Fig. 7) of Irvine and Barager (1971), MnO-TiO_2-P_2O_5 of diagram (Fig. 8) of Mullen (1983), Hf/3-Th-Nb/16 diagram (Fig. 9) of Wood (1980), and Ti/40-Si/1000-Sr (Fig. 10) and 2Nb-Zr/4-Y (Fig. 11) diagrams of Vermeesch (2006) are presented. In all these diagrams, the studied samples of both Deosai volcanics and meta-volcanics of Burji-La Formation plot in the field of volcanic arc basalts with calc-alkaline character formed in island arc type of settings.

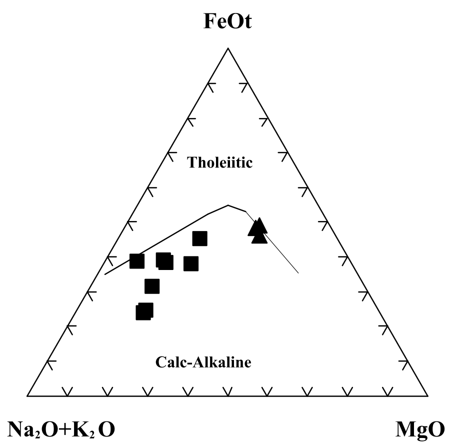


Fig. 7. Plotting of the rocks of the study in AFM diagram (after Irvin and Barager, 1971) discriminating between calc-alkaline and tholeiitic rocks.=Deosai volcanics =Meta-volcanics of Burji-La Formation.

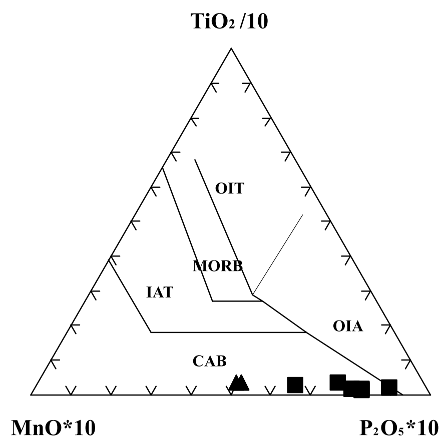


Fig. 8 The discrimination diagram of Mullen (1983) is showing that the rocks of the study area are calc-alkaline in nature, classification is based on major oxides MnO, P_2O_5 and TiO_2. CAB= calc-alkaline basalts, IAT= island arc tholeiites, MORB= mid-oceanic ridge basalts, OIT= oceanic island tholeiites and OIA= oceanic island alkali basalts. Symbols as shown in Figure 6.

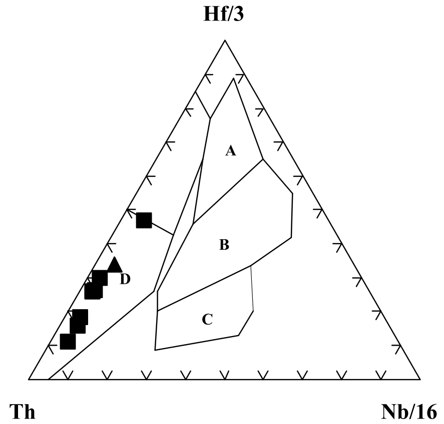


Fig. 9 The ternary discrimination diagram (after Wood, 1980) for the rocks of the study area, classification is based on trace elements (HFSE) Th, Hf and Nb. A= N-type MORB, B= E-type MORB and within plate tholeiites, C= alkaline within plate basalts, D =volcanic arc basalts (island-arc tholeiites if Hf/Th > 3.0 and calc-alkaline basalts where Hf/Th < 3.0. Symbols as shown in Figure 6.

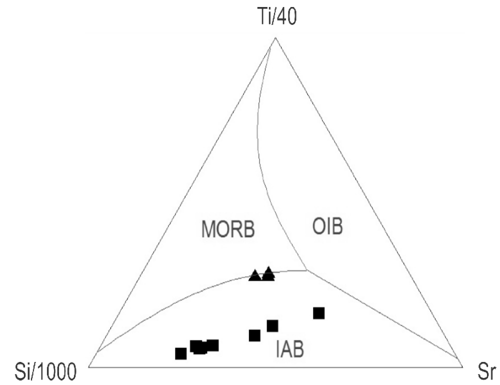


Fig. 10 The ternary discrimination diagram (after Vermeesch, 2006) for the rocks of the study area classification is based on Si, Ti and Sr. IAB= island arc basalts, MORB= mid-oceanic ridge basalts, OIB= ocean island basalts. Symbols as shown in Figure 6.

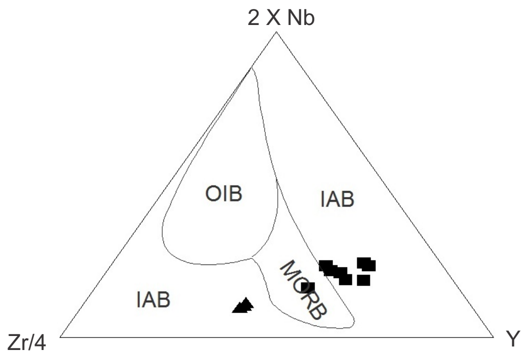


Fig. 11. Plotting of the rocks of the study in the ternary discrimination diagram (after Vermeesch, 2006) on the basis of trace elements Zr, Nb and Y. IAB= island arc basalts, OIB= ocean island basalts and MORB= mid-oceanic ridge basalts. Symbols as shown in Figure 6.

The major and trace element chemistry of the volcanic rocks of the study area when evaluated on the basis of tectono-magmatic discrimination diagrams and the spider diagrams (i.e., Nb anomaly and enrichment of LILEs relative to HFSEs), it can be concluded that the studied volcanic rockshaving calc-alkaline character, typical of subduction related environment, have been formed in the island arc type of settings. This suggests that both Deosai volcanics and the meta-volcanics of Burji-La Formation have been formed within the Kohistan-Ladakh island arc during different episodes due to the subduction of Indian Plate underneath the Kohistan-Ladakh island arc.

The geochemical data of the study area are correlated with the results of previous workers who worked on various types of volcanic rocks in the region, to understand the chemical composition of the rocks. The chemical composition of the both Deosai volcanics and the meta-volcanics of Burji-La Formation are compared to the Chalt volcanics and Teru volcanics studies in detail by Petterson and Windley (1990, 1991), Danishwar et al., (2001), Khan et al., (2004), Sheikh (2013) and Sadaf (2013). The average major and trace elements data with some previous geochemical data is presentedin the Table 3 which shows that the meta-volcanics has low low-intermediate MgO similar to the calc-alkaline volcanics of Chalt volcanic group of Petterson and Windley (1991) and Teru volcanics formation of Khan et al. (2004). The average trace element data is also plotted in spider diagrams (Fig. 12) with the previous data which also show similar geochemical behavior.

Table 3. Comparison of average major and trace elements data of the study area with previous studies.

Trace Elements	Deosai volcanics (This study)	Met-volcanics of Burji-La Formation (This study)	Porphyritic volcanics (Sadaf, 2013)	BASD volcanics of CVG (Sheikh, 2013)	IVC volcanics of CVG (Sheikh, 2013)	Teru volcanics (Khan et al., 2004)		Calc-alkaline volcanics (Petterson and Windley, 1991)		Tholeiitic volcanics of CVG (Khan, 1994)
						42B	**7-4**	**IK679**	**K681**	**ST33**
SiO_2	65.31	50.78	49.89	47.30	53.20	50.0	54.00	53.80	54.20	49.37
Al_2O_3	15.59	16.64	11.77	17.45	16.87	18.0	17.00	19.00	16.60	15.73
TiO_2	0.50	1.33	0.54	0.60	0.38	1.70	0.70	0.75	0.62	1.07
Fe_2O_3t	4.10	9.82	10.87	9.04	8.77	11.0	9.40	10.30	9.90	10.85
MnO	0.04	0.17	0.16	0.14	0.18	0.20	0.10	0.19	0.19	0.19
MgO	1.75	6.23	6.92	4.07	6.40	5.70	7.00	3.80	4.90	7.73
CaO	.48	8.02	11.08	11.49	8.63	9.40	9.30	10.10	7.40	11.67
Na_2O	3.37	2.69	1.76	3.17	2.34	4.20	2.10	1.80	3.50	2.09
K_2O	1.71	0.70	0.45	0.41	0.86	0.60	1.00	0.12	2.01	0.22
P_2O_5	0.19	0.19	0.13	0.22	0.37	0.40	0.10	0.23	0.21	0.10
L.O.I	2.89	3.47	4.48	5.00	2.07	-	-	-	-	-
Total	99.98	100.10	98.33	98.89	100.10	100.0	101.0	100.10	99.53	100.72
Trace elements in ppm										
Sc	10	29	28	22	26	-	-	-	-	-
V	78	259	279	215	230	-	-	197	293	270
Co	6	37	10	21	45	-	-	-	-	-
Cr	56	59	53	85	275	-	-	30	21	283
Ni	24	37	18	40	84	-	-	9	16	68
Cu	34	35	66	76	52	-	-	-	-	-
Pb	18	5	5	6	5	-	-	-	-	-
Zn	58	90	146	82	100	-	-	-	-	-
Sr	605	284	288	986	638	832	799	1657	698	170
Rb	72	6	34	8	18	9.5	184	3	27	6
Ba	275	45	417	80	177	182	388	23	411	26
Th	10	3	2	2	3	-	-	-	-	-
Nb	8	4	1	2	1	3.11	20	1.2	1.7	4
Y	19	45	23	22	16	14.7	43	20	15	32
Zr	174	126	91	48	26	66.8	175	100	53	136
Hf	9	5	3	7	5	1.9	4.8	-	-	-

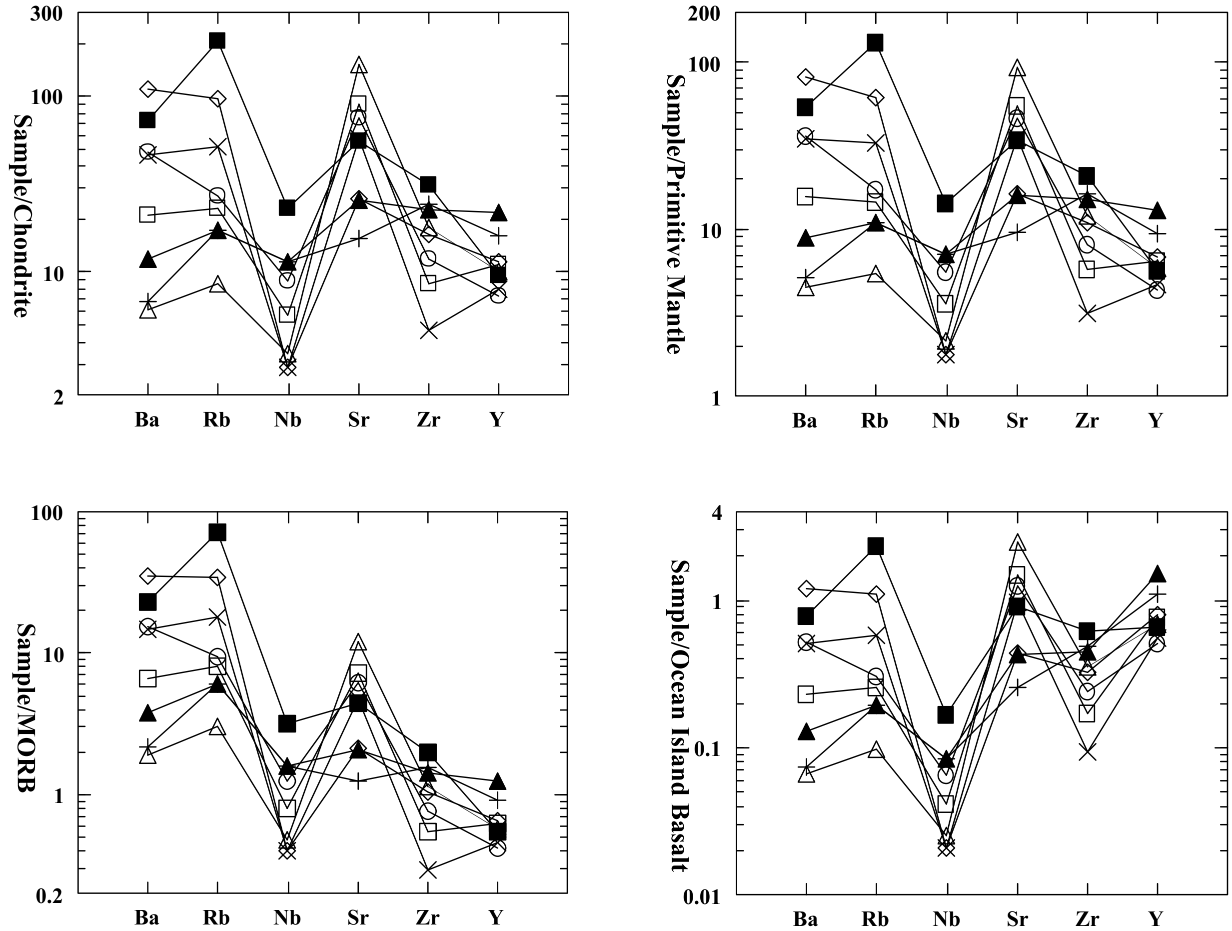


Fig. 12. Spider diagrams showing the comparison between the average trace elements values of Deosai volcanics and meta-volcanics of Burji-La Formation with the similar volcanic rocks of Ghizer Formation

4. Conclusions

Two types of volcanics i.e., Deosai volcanics and meta-volcanics of Burji-La Formation, exposed in the study area, are present within the Kohistan-Ladakh island arc. The Deosai volcanics are the porphyritic rocks showing mild to severe alteration while the meta-volcanics of Burji-La Formation are metamorphosed to greenschist facies. The Deosai volcanics also have sulfides-bearing mineralized altered zone where the chalcopyrite and pyrite are well observed. Petrographically, the Deosai volcanics mainly contain plagioclase and hornblende phenocrysts within the felsophyric groundmass. Both the phenocrysts and groundmass show alteration to kaolinite, sericite, saussurite, epidote and chlorite. The meta-volcanics of Burji-La Formation have greater amount of tremolite/actinolite with lesser amount of hornblende and plagioclase phenocrysts. These phenocrysts of ? are mostly altered to chlorite, epidote, kaolinite and sericite. On the basis of whole rock geochemistry the rocks of Deosai volcanics are classified as dacites to rhyodacite and the meta-volcanics of Burji-La Formation have basalt to basaltic-andesite composition. There is an enrichment of Au, Ag and Cu in the sulfides-bearing mineralized altered zone within the Deosai volcanics. The major and trace elements chemistry suggests that the Deosai volcanics and the meta-volcanics of the Burji-La Formation have calc-alkaline affinity suggesting the formation of these rocks in Kohistan-Ladakh island arc type of setup with subduction related components mainly contributed by the subduction of Indian plate underneath the Khistan-Ladakh island arc.

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