Int. J. Econ. Environ. Geol. Vol. 8 (2) 9-20, 2017

Journal home page: www.econ-environ-geol.org

Open Access

ISSN: 2223-957X

Petrographic and Geochemical Analyses of Kirana Hills Shield Rocks around Sargodha and Economic Potential

Muhammad Waseem Khan*, Syed Abbas Sultan, Iftikhar Alam, Muhammad Saqib Izhar

Atomic Energy Minerals Centre, Lahore-54600, Pakistan

*Email: geo_waseem2005@yahoo.com

Received: *1August, 2016* ***Accepted:*** *15 February, 2017*

Abstract: The present study deals with geochemical and petrographic analysis of the Kirana Hill shield rocks of Punjab plains from Buland, Hachi, Shaheen Abad, Shaikh and Machh hills. On basis of the current studies certain modifications have been made in the classification and nomenclature of rocks exposed in the study areas. Chemical analyses have also been carried out in order to calculate Cross Iddings, Pirsson, and Washington (CIPW) norms", to strengthen nomenclature scheme and finally rocks are classified by using "MAGMA SOFTWARE". Rhyolites predominate over the basalts/dolerites, andesites, and phyllite/ slate. Rhyolitic rocks are light grey, greenish grey and light brown in color, aphanitic in nature. The observed microscopic textures are aphyric, phyric or porphyritic and micropoikilitc. Moreover, some rhyolitic rocks also show flow texture. They are either cryptocrystalline to microcrystalline or microcrystalline to cryptocrystalline. No glassy material has been observed in any thin section. Mafic rocks are characterized by the presence of ferromagnesian minerals with plagioclase. Andesites exhibit mainly porphyritic texture, but aphyric texture has also been observed in few samples. Hydrothermal alterations are also very common in these rocks. Other rock assemblages identified during laboratory studies from Kirana area include: tuffs i.e. (Lithic Crystal Tuff and Lithic Tuff), basaltic andesite, rhyodacite/ dacite, slate/ phyllite, ankeritic rocks/ veins and quartzofeldspathic veins. Our studies also reveal that no evidence of quartzite has been found in the samples collected from above mentioned areas of Kirana, although it has been reported in previous literature. Iron (Fe) has been observed in rhyolite as well as other volcanic rocks of Kirana hills, its presence suggests magma from deep mantle instead of crustal melting / anatexis. In the present analysis some primary and secondary copper minerals including chalcopyrite, atacamite and malachite have been identified. Some anomalous values of the Rare Earth Elements are also observed. Inclusive geological investigations are recommended for better studies to appraise the potential of Iron (Fe), Copper (Cu) and trace/Rare Earth Elements (REE) in the area.

Keywords: Mineral, petrographic, chemical analyses, rhyolite, hydrothermal alterations, Kirana Hills.

Introduction

The outcrops of this complex occur as isolated hillocks around Sargodha covering topographic sheets No. 44A/9, and 41A/3 and lie between longitudes 72˚38'39" to 72˚38'00" and latitudes 31˚51'00" to 32˚15'00" (Fig. 2). According to Ahmed (2000, 2004) the Kirana volcanics are a part of Neo-proterozoic Kirana complex. The Kirana Hills form the western extension of the Precambrian shield of India. It represents good example of bimodal continental magmatism. Although the presence of intermediate rocks have been confirmed by mineralogy division of Atomic Energy Minerals Centre Lahore.

However, these rocks are insignificantly small in comparison to the acidic and mafic rocks. Present investigation focuses on the chemical and petrographic analyses of shield rocks exposed in the form of Kirana Hills to classify the rocks on the bases of laboratory results of this research work. This study encompasses the collection of more than three hundred rock samples from surface and subsurface of the Kirana Hills. Subsequently these samples have been analyzed in the mineralogy laboratory of AEMC, Lahore.

Geological Setting

The present Punjab Foreland basin was developed as extensional basin within Late Proterozoic period of Northeast Gondwana part of the Greater India, named as Kirana-Malani Basin (Chaudhry et al., 1999). In this region the rhyolitic mass predominates over dolerite/ basalt, andesite and dacite outcrops (Ahmad and Chaudhry, 2009). Major outcrops of the Kirana Hills are located near the city of Sargodha, Chiniot, Shah Kot and Sangla Hills (Shah, 2009). These areas are solely occupied by the exposures of Proterozoic rocks without the occurrences of Phanerozoic lithologies.

However, it is supposed that this complex supports as basement horizon for the Paleozoic to Eo-Cambrian sedimentary cover sequence exposed 100 km north in the Salt Range (Fig. 1). The Kirana Hill rocks are very significantly economic sources of aggregates for the construction of road projects and civil super structures in the Punjab province of Pakistan (Khan and Chaudhry, 1991; Khan, 2004).

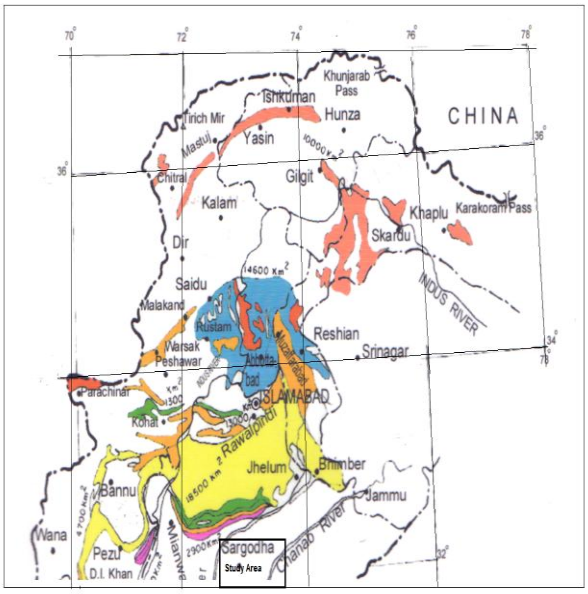

Fig. 1 Location map of North Pakistan, square showing the study area.

Materials and Methods

Petrographic Analyses

Detailed petrographic studies of three hundred samples collected from the study area were carried out by using standard petrographic Olympus BX 51 polarizing microscope fitted with Olympus DP12 camera. Several rock types have been described based on mineralogy and texture. The modal composition of hypabassal and microcrystalline volcanic rocks was volumetrically determined by recommended comparison charts, while composition of cryptocrystalline volcanic rocks was determined with the help of chemical analyses. Important features of rocks are illustrated by photomicrographs.

Chemical Analyses

Wet chemical analyses of more than two hundred volcanic as well as hypabassal rocks samples were carried out to classify the rocks based on twelve major oxides and Loss on ignition (LOI) content as these rocks are fine grained, but results of some of the representative samples of each rock type are selected for this research work. Wet chemical analysis is a destructive technique and following constituents were estimated by using this technique.

Silica (SiO_2) the main constituent of most of rocks was estimated by gravimetrically. The samples were digested with Nitric acid which removes all the soluble radicals except silica and separated through filtration. Finally the silica is estimated from residue with the treatment of Hydrofluoric acid gravimetrically.

Calcium (Ca) and Magnesium (Mg) were estimated in the fused sample either by volumetric analysis using EDTA as standard solution with different Ph and indicators or by atomic absorption spectrophotometer with the help of Z8000 Hitachi coupled with graphite furnace Japan, depending on the concentration and interfering environment of the matrix.

Alumina (Al_2O_3) was estimated in the sample prepared by fusion with Aizarin red-S as chromogenic reagent by spectrophotometer.

Titanium (TiO_2) and phosphorous penta oxide (P_2O_5) were also estimated from multiacid leach solution by using hydrogen per oxide and ammonium vanado molybedate as chromogenic reagents for the complexion of both constituents respectively in their analysis spectrophotometrically with the help of Helios Epsilon Thermospectronic, single beam USA.

Ferrous (Fe^{+2}) was leached with nitric acid and hydrofluoric acid without any heating by keeping the sample over night and estimated volumetrically by using potassium di chromate as standard solution using Barium Diphenyl amin Sulphonate (BADAS) as indicator.

Total iron (Fe) and manganese (Mn) were estimated through atomic absorption spectrometer (Z8000 Hitachi coupled with graphite furnace, Japan) in multiacid leach solution. However, the iron contents may also be determined volumetrically in the multiacid leach solution or fused sample using potassium dichromate as standard solution and BADAS indication depending on the concentration of the iron.

Sodium (Na) and Potassium (K) were determined in the multiacid leach solution of the sample on flame photometer (Jenway PFP-7) with appropriate filter of respective elements. It is an emission spectrophoto meter technique.

Carbon dioxide (CO_2) was estimated indirectly in the form of carbonates volumetrically. Carbonates present in the samples were digested with excess hydrochloric acid of known strength. The excess acid was titrated with standard solution of sodium hydroxide using phenolphthalein as indicator. Volume of hydrochloric acid used for the digestion of carbonates was determined from the volume of sodium hydroxide used in titration. Data obtained was used to calculate the amount of carbon dioxide present in the sample.

Loss on Ignition was determined gravimetrically by using Carbolite Furnace. The weighed sample was heated up to 900 ^{o}C for one hour. The loss on weight was calculated as percentage of LOI.

The oxides were converted to minerals, the calculated abundance of the minerals is known as norm. The first norm was devised by the four petrologists Cross, Iddings, Pirsson, and Washington, and thus it is commonly referred to as CIPW norms (Philpotts, 1989). Finally classification was done with help of "MAGMA SOFTWARE" by putting values of major oxides (Table 2). For this purpose fresh, unaltered and representative rock samples were selected to get fruitful results. "MAGMA" software follows IUGS classification scheme to classify the rocks (Fig. 8).

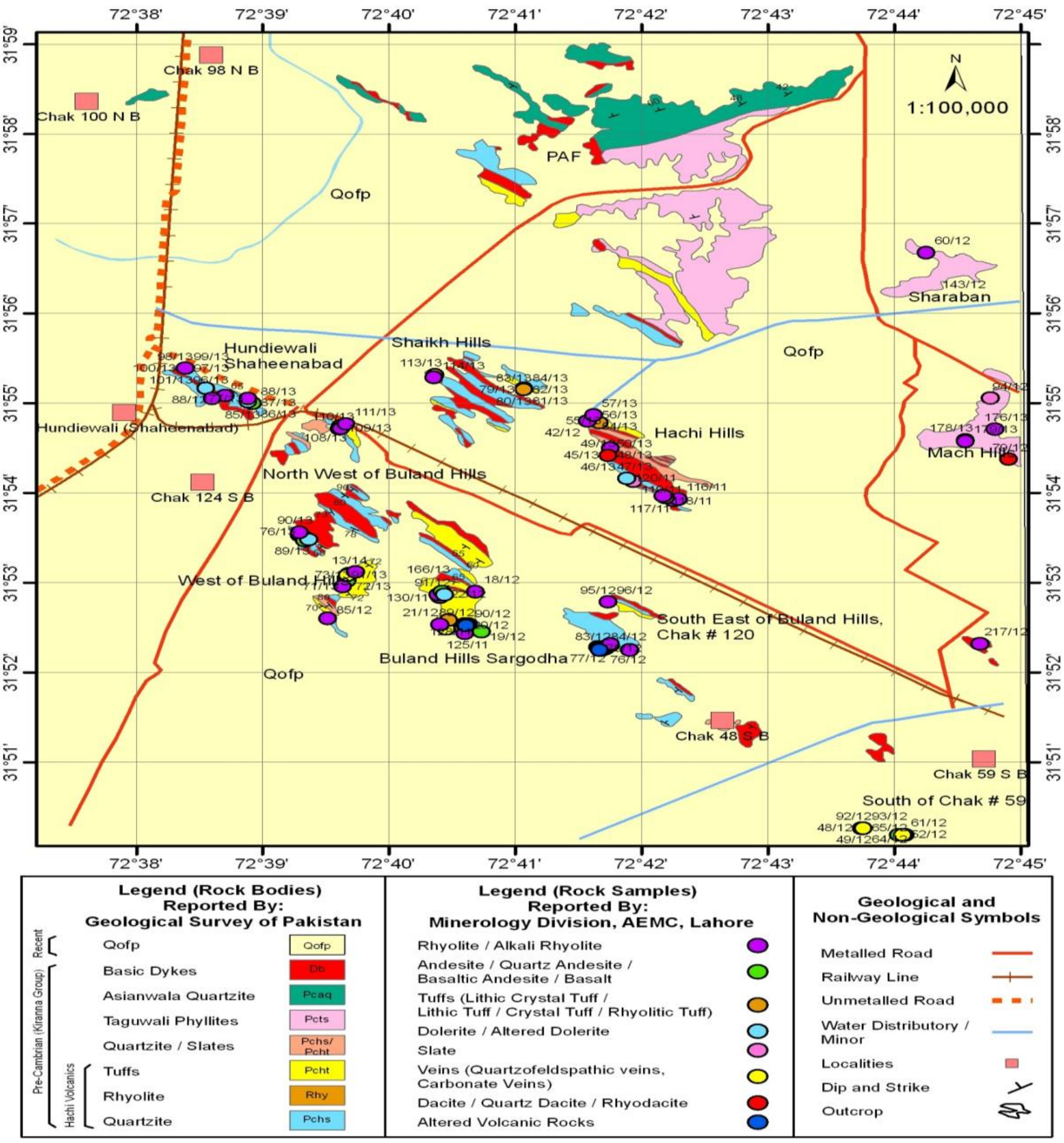

Fig. 2 Geological map of Kirana Hills. Colored rounded spots showing the locations of samples collected from the area, District Sargodha, Punjab (after Ahmed et al, 2007).

Table 1. Chemical analysis showing high percentage of Iron (Fe) and low Nickel (Ni) content.

Estimation Required	Min No. 267/13	Terrestrial Iron (Fe) From Blaafjeld Greenland	Clark Values
			Percentage % in crust
SiO_2%	10.97	-	28.2
Fe %	79.06	93.16	06.3
Ni%	0.16	2.01	0.0089
Co%	0.08	0.80	0.003
Cu%	<0.01	0.12	0.0068
P%	<0.10	0.32	0.099
Cl^{-1}%	0.56	0.02	0.017
S%	1.11	0.41	0.042

Contents of iron (Fe) sample were determined by using wet chemical analysis technique. Only carbon and sulfur contents were determined by using carbon/ sulfur analyzer. These contents were compared with terrestrial iron (Fe) from Blaafjeld Greenland (Anthony et al., 1990). Clark values are also listed in Table 1.

with the help of "Pro-trace software" in order to know earth (REE) / trace element contents. For this purpose, the rock samples were crushed and grinded up to -200# mesh size with jaw crusher and finally the materials

Table 2. Classification based on chemical analyses (CIPW norms).

Sample No.	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	Na_2O	K_2O	P_2O_5	CO_2	LOI	Classification
18/12	75.82	0.18	15.87	2.25	0.61	0.02	0.40	1.05	0.35	1.91	0.01	1.42	0.10	**Alkali Rhyolite**
40/12	76.69	0.18	15.03	2.53	1.73	0.03	0.11	0.86	0.43	2.16	0.01	0.13	0.11	**Alkali Rhyolite**
59/12	76.41	0.15	14.99	3.79	1.71	0.12	0.1	0.65	0.16	1.83	0.01	0.01	0.11	**Alkali Rhyolite**
84/12	72.13	0.11	12.19	0.44	3.04	0.05	1.04	0.76	1.85	3.52	<0.01	1.47	3.49	**Rhyolite**
85/12	73.12	0.1	11.68	1.56	2.57	0.02	0.99	0.45	1.83	3.78	0.01	1.58	2.39	**Rhyolite**
86/12	75.88	0.17	11.07	1.34	1.45	0.05	0.8	1.09	2.2	1.96	<0.01	1.06	3.04	**Rhyolite**
89/12	75.37	0.15	11.49	0.70	0.84	0.02	0.90	0.94	0.65	3.23	0.02	1.37	4.30	**Alkali Rhyolite**
42/13	77.12	0.20	16.04	0.90	0.31	0.01	0.20	0.72	0.35	3.30	0.07	0.67	0.10	**Alkali Rhyolite**
46/13	72.55	0.11	12.47	1.8	0.94	0.01	0.2	0.56	3.1	1.88	0.02	0.44	0.1	**Alkali Rhyolite**
67/13	74.61	<0.10	13.44	0.71	0.1	0.02	0.21	<0.10	6.34	0.1	0.19	0.86	0.1	**Alkali Rhyolite**
22/12	45.93	1.53	14.59	1.69	8.8	0.15	6.69	3.05	1.48	0.55	0.05	7.02	0.1	**Basalt**
76/13	45.22	0.52	17.22	4.52	1.53	0.17	8.25	5.87	0.51	2.06	0.10	13.92	0.10	**Basalt**
91/12	43.25	1.29	13.25	3.22	9.42	0.09	5.86	3.43	2.92	0.73	0.18	7.17	9.4	**Latite-Basalt**
20/12	55.14	0.23	24.53	2.13	0.39	0.01	0.13	1.46	0.16	2.59	0.01	1.19	0.1	**Basaltic Andesite**
52/12	52.92	0.37	28.39	2.34	0.6	0.01	0.1	1.14	0.15	2.53	0.01	0.96	0.1	**Basaltic Andesite**
19/12	58.81	0.24	22.53	2.73	0.67	0.01	0.18	1.87	0.19	1.54	0.01	1.16	0.1	**Andesite**
32/13	62.88	0.1	7.73	2.6	1.74	0.09	7.17	2.97	0.35	1.87	0.02	9.96	0.1	**Andesite**
79/13	61.96	0.17	15.87	4.56	0.55	0.08	0.84	1.08	1.7	3.57	0.16	0.55	0.1	**Andesite**
49/12	65.81	0.29	20.04	1.77	1.08	0.03	0.1	0.68	0.19	3.32	0.01	0.15	0.1	**Dacite**
50/13	66.5	0.1	12.51	1.56	3.58	0.08	2	0.63	2.83	3.2	0.11	3.26	0.1	**Dacite**
68/13	64.82	0.1	11.92	8.99	1.17	0.02	1.57	0.13	0.19	0.82	0.11	0.98	0.1	**Dacite**
29/13	5.12	0.11	5.53	11.17	0.10	0.34	33.94	4.61	0.44	0.12	0.01	35.06	0.10	**Carbonate Rock**
30/13	1.68	0.10	0.47	14.08	0.10	0.29	46.23	2.28	0.33	0.10	0.01	34.21	0.10	**Carbonate Rock**
31/13	1.40	0.10	0.41	0.10	20.42	0.84	36.36	11.25	0.55	0.10	0.01	28.35	0.10	**Carbonate Rock**

Table 3. REE / Trace elements.

Sr. No.	Elements	Rock Names and Estimations of Elements					Clark Values
		Alkali Rhyolite	Alkali Rhyolite	Vein Filling Material	Quartzofeldspathic Material	Only XRD & Chemical Analyses	
		Min. No. 53/12	Min. No. 63/13	Min. No. 87/13	Min. No. 100/13	Min. No. 259/13	
1	**Cr (ppm)**	243	341	433	433	439	102
2	**Ni (ppm)**	5	21	519	14	160	84
3	**Cu (ppm)**	31	30	165	36	215 (malachite)	60
4	**Zn (ppm)**	1097	468	681	476	486	70
5	**Y (ppm)**	502	66	8	101	20	33
6	**Zr (ppm)**	706	295	6	407	29	165
7	**Nb (ppm)**	73	13	ND	29	<1	20
8	**Mo (ppm)**	ND	5	1	2	10	1.2
9	**Ag (ppm)**	ND	2	3	ND	ND	0.075
10	**Cs (ppm)**	15	8	3	8	3	3
11	**La (ppm)**	112	36	7	45	191	39
12	**Ce (ppm)**	114	41	5	53	207	66.5
13	**Sm (ppm)**	24	ND	15	ND	34	7.05
14	**Yb (ppm)**	33	ND	ND	ND	ND	3.2
15	**W (ppm)**	211	1	ND	4	ND	1.25
16	**Pb (ppm)**	450	8	118	4	20	14
17	**Bi (ppm)**	2	<1	3	3	<1	0.0085

Few samples of alkali rhyolite and vein filling material were also subjected to non-destructive technique by using Panalytical XRF spectrometer ($Axios^{Max}_{Mineral}$) were grounded with disc pulverizer to make the sample homogenous. Pellets of powder samples were made using hydraulic assembly (ENERPAC) by applying a pressure of about 700 bar / 8000 psi. Afterwards, pressed pellets of required dimensions were presented for analysis through X-Ray Fluorescence (XRF) Spectrophotometer. Some anomalous values of different rare earth element have been observed compared with Clark values, which are listed in Table 3.

Results and Discussion

Rhyolite

Rhyolites are light grey, greenish grey and light brown in color (Fig. 3 a, b). The observed microscopic textures are aphyric, porphyritic and micropoikilitc (Fig. 5: a, b, c). Moreover, some rhyolites also show flow texture and spherulitic texture (Fig. 5 e, f), which are either cryptocrystalline to microcrystalline or microcrystalline to cryptocrystalline. However, glassy material has not been observed in any thin section so far due to devitrification. Hydrothermal alterations are also very common in rhyolites. Common observed minerals are quartz, orthoclase, sericite, calcite/ ankerite, hematite/ goethite, pyrite, iron (Fe) and minor amount of sodic plagioclase, which have been reported from the outcrops as well as sub crops of South East of Buland Hill, Chak #120B, Shaikh Hill,

Fig. 3 Field photographs showing a) greenish grey rhyolite at SE of Buland Hill (Pen for scale). b) Brown colored boulder of rhyolite at SE of Buland Hill. c) Core sample showing black color mineral "Chevkinite", confirmed through XRD in rhyolite at SE of Buland Hill. d) Core sample showing wavy shape, brown color material; identified as "Goethite", through XRD in rhyolite at SE of Buland Hill. e) Dendritic Pyrolusite in rhyolite boulder at SE of Buland Hill (Pen for scale). f) Outcrop view of the slate at Machh Hill.

Buland Hill, Sharaban Hill, South of Chak # 59, Hachi Hill and Shaheen Abad.

Rhyodacite/ Dacite

Microscopic texture is weakly aphyric. The rock consists mostly of plagioclase laths, which are randomly oriented and exhibit alterations into epidote / zoisite, chlorite, and muscovite at some places. Pyroxene shows alterations into chlorite (Fig. 6 a, b), which are reported from Mach Hill, Sargodha. Dacite is reported from South East of Buland Hill, Chak# 120, and South of Chak # 59.

Fig. 4 Field photographs showing (a) Xenolith in rhyolite at Shaheenabad. (b) Outcrop view of milky white colored pegmatitic veins of Quartzofeldspathic material (south of Chak #59). (c) Ankeritic vein in boulder. (Geological hammer for scale) (d) Outcrop view of dark grey colored dolerite at Buland Hill.

Andesite/ Basaltic Andesite

Andesites are dark grey in color and exhibit mainly porphyritic texture, but aphyric texture has also been observed in few samples. They are intermediate volcanic rocks, hence felsic minerals as well as mafic minerals have been observed. Phenocrysts consist of plagioclase laths of oligoclase to andesine composition and minor biotite is present in some samples. Groundmass includes chlorite, quartz, sericite/ muscovite, hematite/ goethite, calcite, pyrite and iron (Fe), which have been reported from the Buland Hill, core samples of hole drilled at Chak #120B. Basaltic andesite is reported from South of Chak # 59, Buland Hill and Hachi Hill, Sargodha (Fig. 6 c, d).

Altered Dolerite/ Basalt

The dolerites are generally fine to medium grained and dark green to dark grey in color, which have been extensively altered due to hydrothermal activity. The observed microscopic textures are interstitial and weakly doleritic (Fig. 6e). In doleritic texture, plagioclase join each other and interstitial spaces are filled with high temperature minerals (olivines, pyroxenes, amphiboles), while intersertal texture is characterized by filling interstitial spaces with low temperature minerals such as epidotes and chlorites (Bard, 1986). The rock consists mainly of plagioclase laths, chlorite, epidote and ilmenite. Pyroxene includes hypersthene and augite. Few augite grains show concentric zonation. Carbonate minerals, pyrite and uralite (fibrous actinolite) have been observed in minor amount. Olivine and hornblende are occasionally observed in few samples. Plagioclase laths show hydrothermal alterations into sericite, epidote and sodic plagioclase. Chlorite and carbonate are formed by the alteration of pyroxene as well as other ferromagnesian minerals. Dolerites have been reported from the core drilled at South East of Buland Hill,

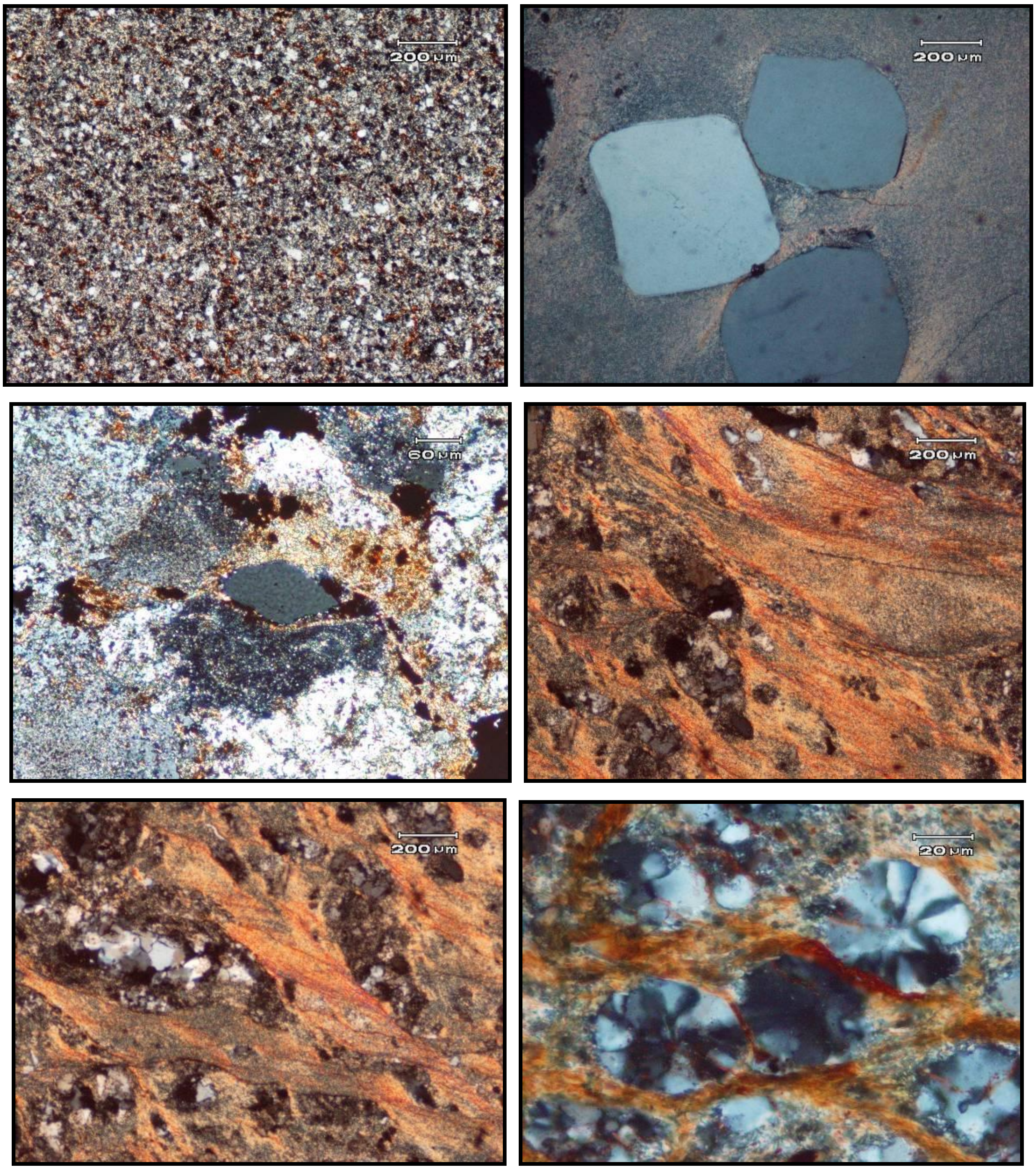

Fig. 5 Photomicrographs showing a) aphyric texture dominantly cryptocrystalline material of felsic nature in rhyolite. (XPL) b) Porphyritic texture (quartz and orthoclase phenocrysts are embedded in groundmass) in rhyolite (Min No. 85/13A). (XPL) c) Micropoikilitic texture in rhyolite. Optically continuous quartzofeldspathic patches with boundaries clearly defined by the concentration of sericitized feldspar (Min No.76/12). (XPL) d) flow texture in rhyolite (Min No. 49/12). Cross Polarized light (XPL) e) Another photomicrograph showing flow texture in rhyolite (Min No. 49/12). (XPL) f) spherulitic texture in rhyolite at high magnification (Min No. 70/13). (XPL)

Chak #120B and Buland Hills, Sargodha. Scapolite and vermiculite have been reported from highly altered metamorphosed dolerite exposed at North eastern part of Shaheenabad. Basalt has been reported from Chak # 59, south of Chak # 59. It consists dominantly of cryptocrystalline material, while quartzofeldspathic material occurs in very minor amount (Fig. 6 f). It has also been reported from Shaikh Hill, Sargodha.

Tuff

Two types of tuffs have been observed i.e. lithic crystal tuff and lithic tuff. Lithic crystal tuff consists of cryptocrystalline material and phenocrysts. Phenocrysts include i.e. quartz, orthoclase, lithic fragments, perthite, magnetite and hematite. Lithic fragments are rhyolitic in nature. Lithic tuff consists of lithic fragments are usually of cognate pyroclasts (juvenile fragments derived from solidified parts of the erupting magma), occasionally fragments of country rocks, dislodged from the conduit walls and vent during explosion/eruption are also seen. These fragments are consolidated with ferruginous clays / hematite/goethite (Fig. 7 a, b). Tuffs have been reported from Chak#120, Hachi Hill, Sargodha. Tuffs

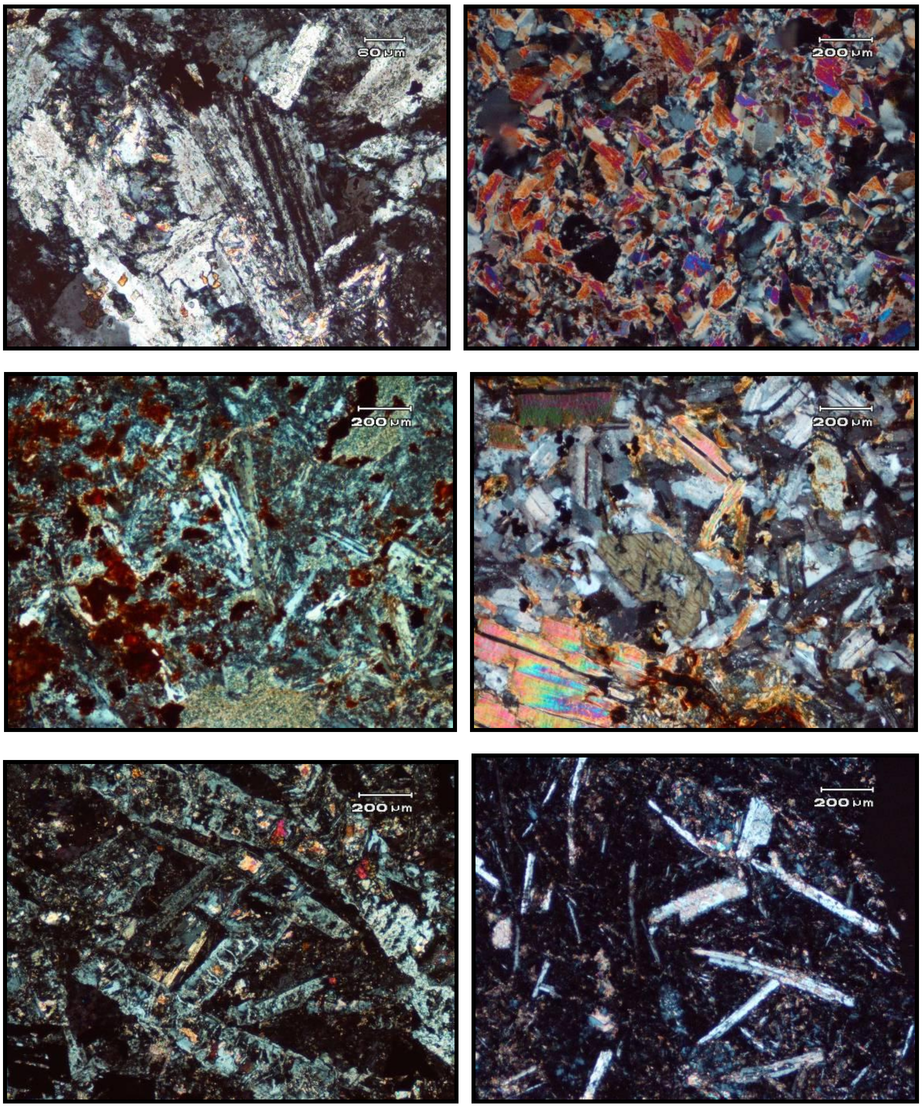

Fig. 6 Photomicrographs showing a) rhyodacite, plagioclase laths are seen in the thin section, epidote / zoisite are visible in upper left corner (Min No. 79/12). (XPL) b) Intense muscovitization in dacite (Min No. 86/13). (XPL) c) Andesite, feldspar laths, chlorite and cryptocrystalline material are clearly visible (Min. No. 43/13). (XPL) d) plagioclase and ferromagnesian minerals (hornblende and biotite) in basaltic andesite (Min No. 72/13). (XPL) e) altered dolerite, plagioclase laths and epidote can be seen (Min. No. 41/13) (XPL) f) plagioclase laths embedded in groundmass in basalt (Min No. 27/13). (XPL)

are classified on the basis of their fragmental composition (Fig. 9)

Slate

Slates are grayish in color and fine grained in nature with slaty cleavage. The thin section studies reveal that the rocks consist of quartz, muscovite, feldspar (orthoclase), hematite and carbonaceous matter. Clay minerals/chlorite occur as minor minerals. The alignment of carbonaceous matter in one direction has been observed (Fig. 7 c). It has been reported from Hachi Hill and Mach Hill, Sargodha.

Ankerite

Ankerite gives reddish coloration in thin section study due to iron content (Fig. 7 d). It has also been confirmed through X-ray diffraction analysis

Quartzo feldspathic and Carbonate Veins

Two types of veins of quartzo feldspathic and carbonate material have been observed, which are normally cutting the host rock. Quartzofeldspathic material consists of quartz and orthoclase, while carbonate consists mainly of calcite (Fig. 7 e, f).

Major rock types are rhyolites, while minor rock types are basalts/ dolerites, andesites and slate. Rhyolites of Kirana Hills are holocrystalline i.e. no glassy material has been observed. The observed microscopic textures are aphyric, porphyritic, micropoikilitc and flow texture. Moreover, some rhyolitic rocks also show spherulitic texture. They are either crypto crystalline to microcrystalline or microcrystalline to crypto crystalline. Porphyritic texture originates in different ways (polygenetic). Probably the most common origin involves two stage cooling history for the melt. An initial episode of slow cooling rate results in relatively large phenocrysts. After this the magma experiences an episode of relatively rapid heat loss in a small intrusion in the shallow cool crust, which creates aphanitic matrix around phenocrysts (Best, 2003). Spherulitic and micro poikilitc textures are characteristic product of high-temperature devitrification of silicic glass (Lofgren, 1971 a, b). The rate of devitrification is dependent on temperature and on the presence and composition of aqueous solutions (Marshall 1961, Lofgren, 1970). Minerals observed in rhyolites during laboratory analyses are quartz, orthoclase, sericite, calcite/ ankerite, chlorite, hematite/ goethite, pyrite, iron (Fe) and minor amount of sodic plagioclase.

Mafic rocks are characterized by the presence of chlorite, hypersthenes, augite and occasional olivine and ilmenite usually associated with plagioclase. Amphibole {hornblende, fibrous hornblende (uralite)} is also encountered in basalts/ dolerites. Uralitic hornblende is derived from the pyroxene (Moorhouse, 1959).

Andesites exhibit mainly porphyritic texture, but aphyric texture has also been observed in few samples. Phenocrysts are of plagioclase, ranging from oligoclase to andesine in composition with minor biotite in some samples. Its groundmass includes chlorite, quartz, sericite/ muscovite, hematite/ goethite, calcite, pyrite and iron (Fe).

Minor rock assemblages identified during laboratory studies from Kirana area include: tuffs i.e. (lithic crystal tuff and lithic tuff), basaltic andesite, rhyodacite/ dacite, slate/ phyllite, ankeritic rocks/ veins and quartzo feldspathic veins.

Davies and Crawford (1971) have interpreted that ankeritic carbonate bodies are produced by late stage autometasomatic concentrations developed by the cooling doleritic magmas. Studies were carried out to determine the possibility that the ankeritic carbonate bodies may have been carbonatites but according to authors 87Sr/86Sr ratios determined, were very important from those in typical carbonatites.

Sericitization, carbonatization and chloritization have been observed in rhyolites. The alterations observed in andesites and dolerites include i.e. sericitization, carbonatization, chloritization, albitization and saussuritization. These alterations are either deuteric or hydrothermal. In dolerites, occasionally metamorphism has also been observed, which resulted in vermiculite and scapolite minerals. In intermediate and mafic rocks, carbonate and chlorite formed from the alteration of pyroxene, as well as from other ferromagnesians. Olivine shows alteration into chlorite. Ilmenite shows alteration into leucoxene and uralitic hornblende is derived from the pyroxene. Zoned plagioclases have been observed in a few rock samples. Zoning in augite has also been observed occasionally, it usually indicates a change in the chemical composition of the crystal (Mackenzie and Adams, 2003). Slates are normally considered to be formed by low grade metamorphism of mudstone. However, some may also be derived from low grade metamorphism of volcaniclastic rocks. Evidences of metamorphism have been observed such as development of scapolite, vermiculite and occasionally green schist facies. The igneous rocks of the Kirana Hills exhibit sub-alkaline trend and range in composition from tholeiite basalt, basaltic andesite, andesite and dacite to rhyolite. However, the intermediate rocks are a minor component and the complex falls into two distinct sets of rocks i.e. mafic suit (dolerite/ basalt) and felsic rocks (dacite and rhyolite). Thus, the volcanics show bimodality of dolerite-rhyolite association (Ahmad and Chaudhry, 2008).

Petrographic studies and comparison of lithologies in geological map of Kirana Hills, reveal that quartzite has not been observed in the samples collected from Buland, Hachi, Shaheen Abad, Shaikh and Machh hills, although it was reported by Ahmed et al (2007).

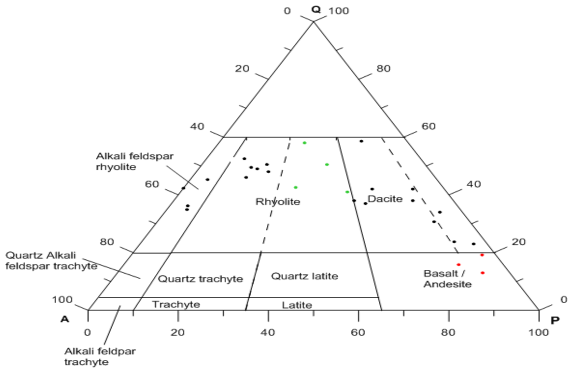

Fig. 8 Q-A-P-F Normative classification of volcanic rocks based on IUGS (after Le Maitre, 1989).

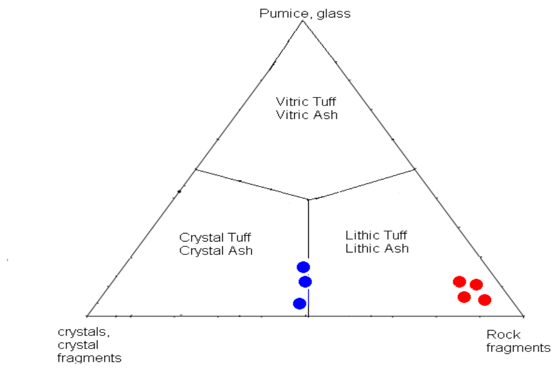

Fig. 9 Classification and nomenclature of tuffs and ashes based on their fragmental composition (after Schmid, 1981).

Economic Significance

Kirana Hill rocks are economically very important because iron has been observed in most of the samples i.e. maximum up to 10% in thin section study. It can be mined from Kirana Hills economically, for steel making and other purposes. Copper minerals have also

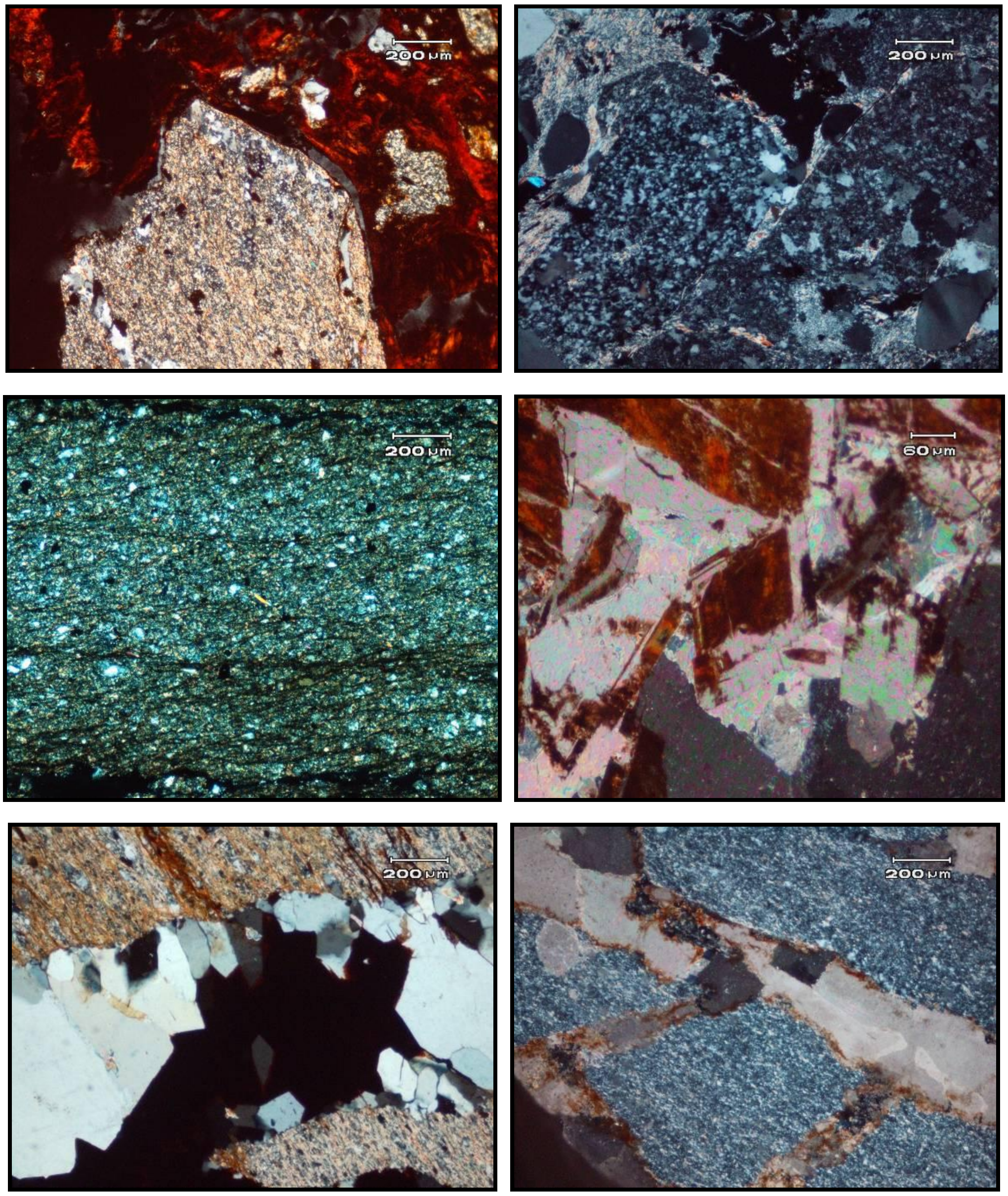

Fig. 7 Photomicrographs showing a) cognate pyroclasts embedded in goethite / hematite in lithic tuff (Min No. 221/12). (XPL) b) lithic fragments of rhyolitic composition (volcaniclastic texture) in "Lithic Crystal Tuff/ Rhyolitic Tuff" (Min No. 84/13). (XPL) c) slaty texture, alignment of clay minerals and carbonaceous matter is clearly visible (Min No. 94/12). (XPL) d) ankerite (Min No. 31/13). (XPL) e) vein of quartzofeldspathic material (Min No. 186/12). (XPL) f) cryptocrystalline material and carbonate veins (Min No. 32/13). (XPL)

been identified through XRD analysis which needs further geological investigation to know its potential in the area. Some anomalous values of REE/ trace elements have been reported in chemical analyses. Rare earth elements are being used in hybrid vehicles and electronic devices. Kirana Hill rocks, especially dolerites are most suitable as aggregate/road construction material in terms of durability, strength against abrasive wear and disintegration.

Native Iron (Fe)

First time in Pakistan, native iron is discovered from Kirana Hills, Sargodha area. The source of this iron is not meteoritic due to fact that meteoritic origin iron has high contents of Ni (Riyabov and Lapkovsky, 2010). However, in present study iron has very low content of Ni, as found by chemical analysis of the samples (Table 1). Due to strong magnetic property, iron is easily separated from rock samples by using magnetic separation technique. Pure iron particles are collected. Observed colors of the grains are metallic black with bluish tinge (Fig. 8 a, b). Native iron has been confirmed through X-ray diffraction studies (XRD). In few samples, iron shows alteration into hematite (Fig. 8 c, d).

Copper Minerals

Three types of copper minerals have been identified through XRD from Kirana Hill area, Sargodha, i.e. Chalcopyrite (primary mineral), and two secondary minerals (atacamite, and malachite) (Fig. 8 e, f). Atacamite is dark green in color, while malachite is light green in color under stereomicroscope.

Conclusion

Variety of textures has been observed in rhyolite, indicating multi phase volcanic eruptions. Although,

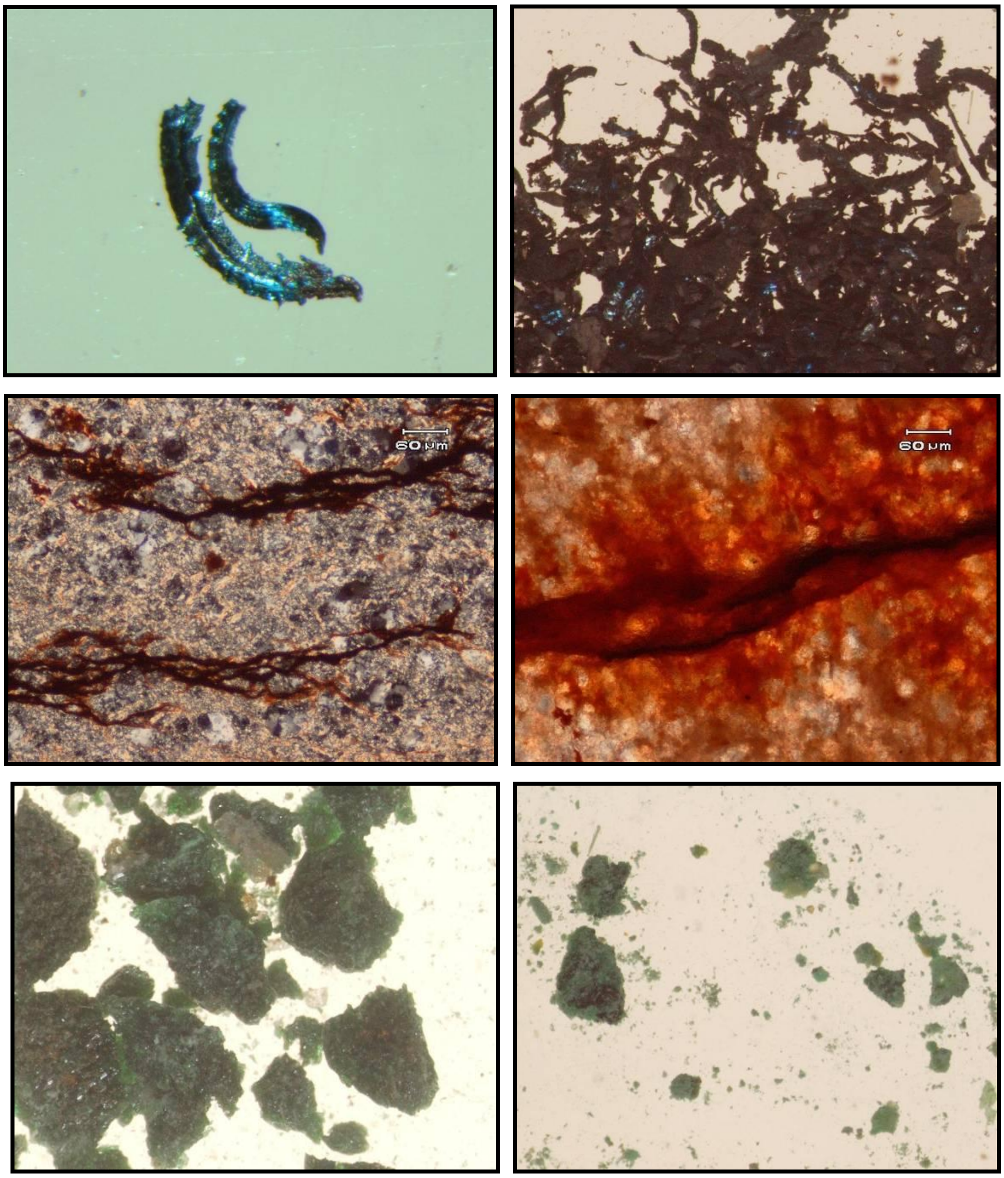

Fig. 8 Photomicrographs showing a) twisted lamellar shaped native iron (Fe), under stereomicroscope (Min No. 93/12). (Reflected light) b) another view showing twisted lamellar shaped native iron (Fe), under stereomicroscope. (Reflected Light) c) Iron (Fe) in the form of lamellae in rhyolite. (XPL) d) alteration of native iron (Fe) into hematite. (PPL) e) dark green colored "Atacamite" under stereomicroscope (Min No. 266/13). (12.5 times magnification) f) light green colored "Malachite" under stereomicroscope (Min No. 259/13) (10 times magnification).

quartzite has been reported by Ahmed et al. (2007). In some of above mentioned areas of Kirana, but no evidence of quartzite has been found in the samples collected from these areas. The presence of iron (Fe) suggests magma / lava from deep mantle instead of crustal melting/anataxis. Systematic sampling is proposed for exploration of REE/ trace elements. Kirana Hills shield rocks are very important for the exploration of different economic minerals/ metals.

Acknowledgement

The authors would like to cordially express gratitude to Director General (exploration) for providing opportunity for research work. Authors also acknowledge suggestions and comments made by reviewers to improve the quality of manuscript. Messers Ahsan Amin Bhatti and Adrees Safdar are acknowledged for their contribution in chemical analyses. We also appreciate Syed Irfan Ali Zaidi and Mr. Sadakat, AEMC Lahore, for their constant help during field work.

References

Ahmad, S. A. (2000). Geology and geochemistry of Neoproterozoic Kirana volcanic, Sargodha district, Pakistan. *Geol. Bull. Punjab Univers*., **35**, 59-71.

Ahmad, S. A. (2004). Geology, geochemistry and petrogenesis of Neoproterozoic Indian Shield extension in Pakistan. Unpublished Ph.D thesis, Ins. Geol. Univers. Punjab, Lahore, Pakistan, 425 pages.

Ahmad, R., Dasti, N., Faridi, G. S. K. (2007). Geological map of Shaheen abad (Hundiewali) quadrangle, district Sargodha, Punjab. Issued by DG, Geological survey of Pakistan, Scale: 1: 50,000.

Ahmad, S. A., Chaudhry, M. N. (2008). Kirana volcanics, Pakistan, geochemical characterization and origin. *Geol. Bull. Punjab Univers.*, **43**, 49-57.

Anthony, J. W., Bideaux, R. A., Bladh, K. W., Nichols, M.C. (1990). *Handbook of mineralogy*, Vol. 1. Mineral data publishing, Tucson, Arizona, 588 pages.

Bard, J. P. (1986). *Microtextures of igneous and metamorphic rocks*. D. Reidel publishing company, Holland, 264 pages.

Best, M. G. (2003). *Igneous and metamorphic petrology*, Second Edition, Blackwell Science Ltd., 729 pages.

Davies, R. G., Crawfold, A. R. (1971). Petrography and age of Buland Hill Kirana, Hills Sargodha district, West Pakistan. *Geol. Mag*., **108** (3), 235-246.

Chaudhry, M. N., Ahmed. S. A., Mateen, A. (1999). Some postulates on the tectono-magmatism, tectono-stratigraphy and economic potential of Kirana-Malani-Basin, Indo-Pakistan. Pakistan. *J. Hydrocarbon. Res.*, **11**, 52-68.

Khan, Z. K., Chaudhry, M. N. (1991). Engineering geological and petrographic evaluation of metadolerite of Buland Hill and Chak 123 Quarries of Kirana Hills, District, Sargodha, Pakistan. *Kashmir Journal of Geology*, **8-9**, 181-184.

Khan, Z. K.., Ahsan, N., Mateen, A., Chaudhry, M. N. (2009). Petrography and mineralogy of dolerites of Hachi volcanics, Kirana Hills area, Pakistan. *Geol. Bull. Punjab Univ.*, **44**, 55-67.

Khan, Z. K. (2004). Classification of base and sub-base of road aggregates in Kirana area, districts Jhang and Sargodha, Punjab. Workshop on Geological Materials/ Aggregates of Pakistan.

Le Maitre, R.W. (1989). A classification of igneous rocks and glossary of terms. Oxford, Blackwell Scientific, 232 pages.

Lofgren, G. (1970). Experimental devitrification rate of rhyolitic glass. *Geol. Soc. Am. Bull*., **81**, 553-560.

Lofgren, G. (1971a). Spherulitic textures in glassy and crystalline rocks. *J. Geophys. Res*., **76**, 553-560.

Lofgren, G. (1971b). Experimentally produced devitrification textures in natural rhyolitic glass. *Geol. Soc. Am. Bull.*, **82**, 111-124.

Mackenzie, W.S., Adams, A.E. (2003). *A colored Atlas of Rocks and Minerals in Thin Section*, Manson Publishing Ltd, Barcelona, Spain, 192 pages.

Marshall, R. R. (1961). Devitrification of natural glass. *Geol. Soc. Am. Bull*., **72**, 1493-1520.

Moorhouse, W.W. (1959). *The Study of Rocks in Thin Sections* Harper and Row, New York, 514 pages.

Philpotts, A. R. (1989). *Petrography of igneous and metamorphic rocks*. The University of Connecticut. Prentice Hall, Enhlewood Cliff, New Jersey, 178 pages.

Riyabov, V.V., Lapkovsky, A. A. (2010). Native iron (platinum) ores from the Siberian Platform trap intrusions. *Australian Journal of Earth Sciences*, **57**, 707-736.

Schmid, R. (1981). Classification and nomenclature of tuffs and ashes based on their fragmental composition. British Geological Survey Research Report, No. RR-06, Nottingham, **1**, 1-52.

Shah, S. M. I. (2009). *Stratigraphy of Pakistan*, Geological Survey of Pakistan, Memoir, **22**, 381pages.