PETROGRAPHY AND GEOCHEMICAL CHARACTERIZATIONS OF TANAWAL FORMATION (QUARTZOSE ROCKS FROM SWABI, KHYBER PAKHTUNKHWA, PAKISTAN; IMPLICATIONS FOR INDUSTRIAL SUITABILITY

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Abstract

The quartzose rocks of the Tanawal Formation, exposed in Topi area, district Swabi, in Khyber Pakhtunkhwa, Pakistan. This study evaluates the studied rocks for their suitability in glass and other industries using the techniques of petrography and geochemistry. Field observations and petrographic data leads to distinction of Tanawal Formation into two discrete lithologies a) Blasto-psammites and b) Blasto-pelites. These rocks have been slightly metamorphosed and foliation planes are well developed especially in pelitic rocks. In blasto-psammites quartz, feldspars, micas, ore minerals with minor amount of tourmalines and zircon occur as the framework minerals, while in pelitic rocks quartz and micas occurs as framework minerals. Blasto-psammites have variable modal percentage of quartz (93 —94%) but most of the samples fall in quartz arenite (quartzite) and sub-arkoses field in Quartz —Feldspar —Lithics (QFL) ternary diagram. Petrographic data revealed that all of the studied samples are very fine to medium grained quartzose rocks. A very low grade metamorphic event has slightly obliterated the original sedimentary fabric of these rocks but most of these are still intact. Quartz grains are present in monocrystalline as well as polycrystalline form.

Geochemical analysis of the Tanawal Quartzite indicates high contents of SiO_2 (93 —94 %) and fairly low percentage of other major oxide i.e MgO (0.023 wt.%), Na_2O (2.92 wt.%), K_2O (0.52 wt. %) thus endorsing their quartz-rich mineralogy.Both petrographic and geochemical data reveal that the studied rocks lie within the range of standard specifications required for glass industries (i.e SiO_2 93 —94%). The rocks are declared suitable for the manufacturing of low quality glass products i.e. soda-lime glass, flint glass, amber glass, green glass and glass-fiber insulation.

INTRODUCTION

General statement:

The quartzites are extensively used as dimension stones, construction material and also as a source of Silica sand (raw material for glass manufacturing). However, the suitability of materials for use in glass industry requires an adequate knowledge of their geo

chemical and sedimentological properties. These properties are directly related to petrographic characters including grain size, shape of grains, fabric and mineralogical composition.
The Tanawal Formation is extensively distributed and exposed in the various outcrops of the Lesser Himalayas. The Tanawal Formation is composed of a thin to thick bedded succession of quartzites and intercalations of quartzite and argillites with minor carbonate beds (Khan et al., 1994). Towards the middle part it has been intruded by dolerite dikes. The quartzite is brown to light brown, white, pinkish to greenish, hard and compact. Shearing is prominent in argillite beds. Dark grey, medium bedded, unfossiliferous, marbleized limestone is present in the mid upper part of Tanawal Formation. The disposition of this Formation is controlled by a WNW plunging cylindrical folds in the hill ranges area, north of Swabi (Khan et al., 1994).
Keeping in view the industrial importance of the quartzites, the Tanawal Formation exposed along Topi-Utla road in northern Swabi district will be evaluated for its feasibility in glass industries.

Location and Accessibility:
A road cut section of Tanawal Formation is well exposed in the Kabghanni area and its surrounding (between 34° 08.361 'N, 72° 40.711'E and 34° 14.837'N, 72" 39.274'E; Fig. 1) in the Swabi district, Khyber Pakhtoon khwa, Pakistan. The area is easily accessible through a network of metaled roads connecting Peshawar-Nowshera Swabi (N5), then Swabi Topi to Utla throughout the year.

Geological Setting :
In the northern Pakistan three distinct tectonic domains are present, namely:
(a) Indian plate
(b) Eurasian plate and
(c) Kohistan Island Arc (KIA).
The intra oceanic subduction of Indian plate resulted in the formation of Kohistan Island Arc during Cretaceous time (Searle, 1991). Kohistan Island Arc drifted northward and collided with Eurasian plate along the Main Karakoram Thrust (MKT) or Shyok suture (Searle et al., 1999; Shaltegger et al., 2002). The collision of Indian plate with the Kohistan Island Arc during early to middle Eocene ensued in the formation of Main Mantle Thrust (MMT) (Coward et al., 1986; Searle et al., 1999), and as a consequence, KIA has been obducted onto Indian plate rocks. This gigantic collision of India Eurasia has resulted in the one of the most distinct feature, the Himalayan mountain belt. Volcanism, magmatism, associated metamorphism and the formation regional scale fold and thrust belts are the characteristics of this gigantic collision (Treloar et al., 1989a). The north-south oriented stresses have resulted in extensive deformation along the northern margin of the Indo-Pakistan tectonic plate. The huge amount of stresses developed in the course of collision are gradually released by the development of southverging fold and thrust belts (North West Himalayan fold and thrust belt) at the northern margin of the Indian plate (Yeats et al., 1984).

Tectonic setup of Peshawar Basin:
The Northwest Himalayan fold-and-thrust belt includes all the terrain between the Main Mantle Thrust (MMT) in the north, and the Salt Range thrust (SRTe Main Mantle Thrust (MMT) in the north, and the Salt Range thrust (SRT) in the south (Treloar et al., 1989a). The NW Himalayan sequence has been divided by the Panjal-Khairabad fault into the southern deformed (unmetamorphosed) foreland zone and the northern deformed (metamorphosed) hinterland zone (DiPetro et al., 1999; Pivinik et al., 1996). The grade of metamorphism increases from the Panjal-Khairabad Fault northwards (Treloar et al., 1989a). The hinterland zone consists of the Himalayan crystalline nappe-and-thrust Belt, which is the visible northern margin of the Indo-Pakistan crustal plate (Treloar et al., 1989b). It is characterized by intensely deformed and tightly folded Precambrian to Early Mesozoic metamorphic and igneous rocks. These rocks are thrusted over the Kurrum-Cherat-Margalla Ranges in the south (Treloar et al., 1989a).
The study area crops out in the north-eastem part of the Peshawar Basin in Khyber Lower Hazara Metasedimentary fold-and-thrust belt. The Peshawar Basin lies in the southwestern part of the crystalline nappe and thrust belt of the hinterland zone. It has been classified as a piggy back-type basin because it has been carried passively on the back of low-angle

detachment faults and thrust sheets, some of which find surface exposure in the hill ranges to the south of the Basin (Ori et al., 1984). The Peshawar Basin is surrounded by low hill ranges comprised of Precambrian metasediments and an almost complete fossiliferous Paleozoic sequence (DiPetro et al., 1999; Pogue etal., 1999). The tectonic setting of basin is transitional between a sedimentary fold and thrust belt to the south and a metamorphic terrain to the north (DiPetro et al., 1999). The grade of deformation and metamorphism is gradually increasing from south to north across the Peshawar basin.

Stratigraphy of Tanawal Formation:

The arenaceous sequence which is widely distributed in south-eastern part of Peshawar basin, previously termed as Chamla quartzites by (Martin et al., 1962) is included in Tanawal Formation (Calkins et al., 1975; Latif, 1970). This Formation extends into the western part of the river Indus, near Tarbela dam (Calkins et al., 1969). Tanawal Formation is distributed to the west of Indus River, in the hill ranges north and north-east of Swabi. To the west of Tarbela area, in currently studied area, Tanawal Formation is interfolded between underlying Salkhala Formation and overlying Ambar Formation of Paleozoic age.

Many N-S running streams cut the northern hills of Swabi which show excellent sections and exposure of Tanawal Formation. Tanawal Formation is divided into three units;

i. Lower Quartzite Unit,
ii. Middle Argillite Unit,
iii. Upper Quartzite Unit (Khan et al., 1994).

The Lower Quartzite Unit consists dominantly of Quartzite with minor intercalations of argillite. The quartzite is brownish-grey to light-grey and white, medium to thick bedded, hard and compact. Sedimentary structures like crossbedding and graded bedding structures are well developed. Along the bedding planes, joints and fractured planes, iron staining is commonly observed. Dark-grey, thick bedded to massive, unfossiliferous and recrystallized limestone in the form of lenses is observed in the middle part. The Argillite Unit consists mostly of argillites with minor components of quartzite. The basal two third unit comprises predominantly of dull greyish black massive shale, with local horizons of laminated argillites defined by m scale alternating silt and clay. The quartzite is found in the form of lenses and is light grey, finegrained, thin bedded and hard.

The upper most unit of Tanawal Formation comprises dominantly of quartzite and intercalated phyllites. The quartzite is brownish-grey, thick bedded, cross-bedded, hard, compact and forms high ridges. A characteristic feature of this quartzite is the abundance of ferruginous material often present in the form of leaching in fractures.

The Tanawal Formation is unconformably overlain by Ambar Formation of Cambrian age which occurs at the base of the Paleozoic succession of the Peshawar (Hussain et al., 1991; Pogue et al., 1992a). The upper contact of Tanawal Formation is unconforrnable with Ambar Formation while its lower contact is transitional with Salkhala Formation (Khan et al., 1994).

The Tanawal Formation is devoid of fossils and thus lacks direct evidence of age. Its extension in the Hazara area, east and northeast of the presently studied area, is extensively intruded by a granite of batholith dimension, which has been radiometerically dated to be 516 Ma (Le Fort et al., 1980). This suggests a Cambrian or older age for the Tanawal Formation. Stratigraphically, the Tanawal Formation is overlain by Abbottabad Formation in the Hazara area. The Hazira member of this Formation has produced an early Cambrian fauna (Rushton, 1973; Talent et al., 1979) which implies a late Proterozoic age for Tanawal Formation (Khan et al., 1994).

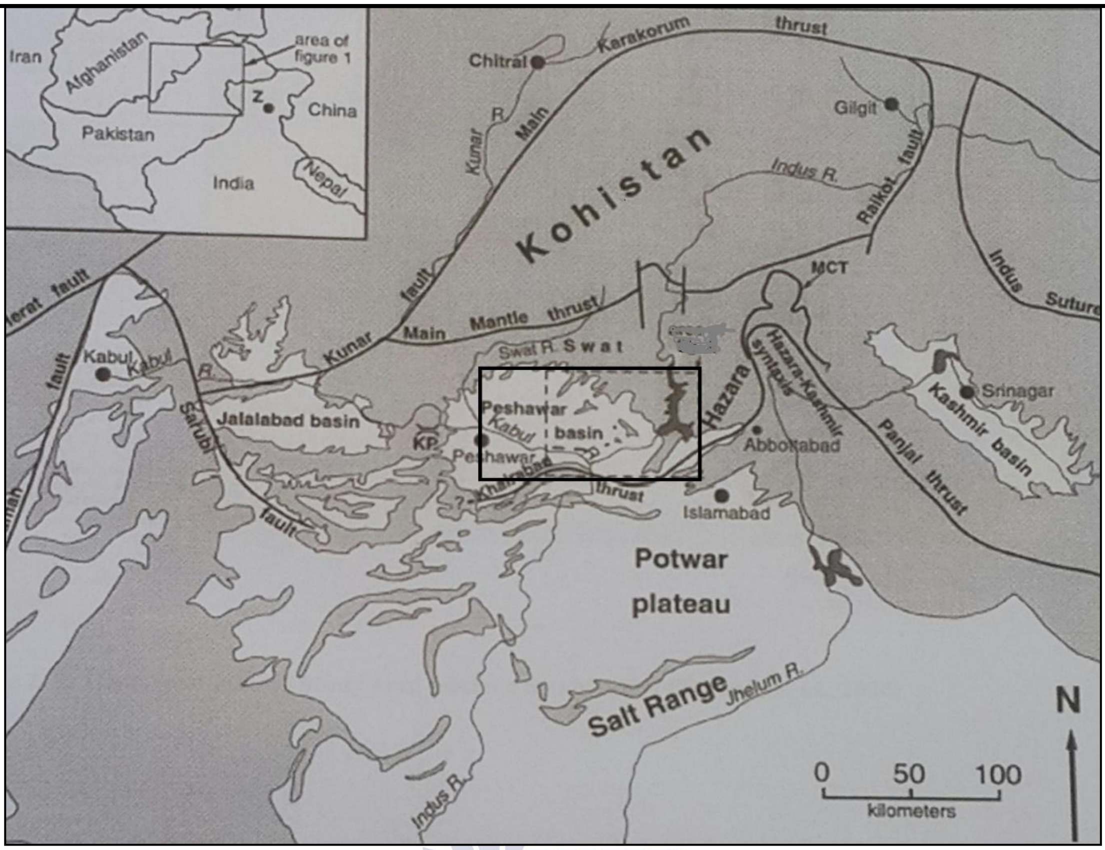

Figure 1 : Map of Peshawar basin showing major Himalayan faults after (Pogue, 1994)

PETROGRAPHICAL ANALYSIS

General statement:

An adequate knowledge regarding modal mineralogy, micro-textures and textural relationships is required for the proper characterization of sedimentary rocks. The modal mineralogy and the textural relationships within a rock are best described with the help of petrographic studies. These include observation of important field features as well as detailed microscopic examination of rocks. In this study petrography of the Tanawal Formation has been carried out to evaluate its suitability as raw material for Glass industry.

Methodology:

Samples were collected from a road-cut section of the Tanawal Formation at different locations along the road. Samples were selected on the basis of lithological variations, were cut and made into thin sections for microscopic studies. Frame work mineral composition (modal analysis) and textural properties were quantified through visual estimation charts (Terry et al., 1955).

a) Petrography:

Petrographic data (Figs 2 and 3_ revealed that all of the studied samples are very fine to medium grained quartzose rocks. A very low grade metamorphic event has slightly obliterated the original sedimentary fabric of these rocks but most of these are still intact. Quartz grains are present in monocrystalline as well as polycrystalline form. Feldspar grains consists of orthoclase and plagioclase with minor microcline (Figure 2 A, Figure 3 A,). Majority of the feldspar grains have been altered to clay minerals and the biotite grains alteres to sericite (Figure 3 A). Details of mineralogy and textural properties are given below:

b) Mineralogy:

The microscopic study of these rocks revealed precise information about the volume percentage abundances of various essential and accessory minerals as shown in (Table 1). Following are the main constituent minerals of the studied rocks.

Essential minerals:
Quartz FeldSpar (Orthoclase, Microcline, Plagioclase and Albite) Mica (Muscovite, Biotite and Chlorite)

Accessory minerals:
Opaque minerals (Hematite and Magnetite) Tourmaline Rutile Zircon

Description of minerals :

i. Quartz :
Quartz is the most abundant mineral present throughout the Formation. It is present in both Monocrystalline and polycrystalline form and as overgrowths. Hydrothermally formed quartz veins of less than a millimeter size are present (Figure 2 A). Monocrystalline quartz exhibits undulose extinction, which shows deformation of the grains due to compaction or stresses . Quartz generally occurs as rounded to sub-rounded grains, but, it is also present in the form of angular, elongated/stretched grains (Figure 3 D). In some thin section fine-grained recrystallized quartz also occurs, which surrounds large detrital quartz grains. Quartz grains are generally free of inclusions and the modal abundance ranges from 79 % max (to 25 % min. The average modal abundance is 55.64 ° 0 (Figure 1).

ii. Feldspar
Feldspar is the second most abundant constituent mineral in the studied samples (Figure 2 A). The modal composition ranges from 40 % max to 2 % min with the mean value of 11.64 ° 0 (Table 1). Plagioclase generally exceeds in amount than alkali feldspar. Alkali feldspar is mostly orthoclase. In some thin sections, feldspars have completely altered to kaolinite, thus making their proper recognition very difficult.

iii. Mica
Albite type and combined Carlsbad-albite Mica grains are present in all the studied thin sections. Muscovite exceeds biotite in abundance, probably, because biotite has been altered to chlorite (Figure 2 C, D). The flakes of mica show preferred orientation in majority of thin sections (Figure 2 C, D). This orientation of mica is more prominent in thin sections argillaceous beds of Tanawal Formation (TLQ 17, 20 and 24). Some muscovite grains seems to be authigenic because they are undeformed and are fine as compared to other muscovite flakes present in the same thin section. Mica is more abundant in fine-grained section than in coarse-grained sections. Modal abundance range of mica is 25 % max while minimum is 1 %, with and average modal abundance of 6% (Table 1).

iv. Opaque Minerals:
Opaque minerals are present in all thin sections in variable amount (Table 1). Opaque minerals largely consists of hematite and magnetite (Figure 3 C, D). Hematite appears as dark-brown pigment and thin coating around grain boundaries of quartz and feldspars (Figure 3 E, F). Magnetite is black in color and found as small opaque grains, more commonly in very fine-grained samples. Extensive hematite leaching in fractured lower part of Tanawal Formations has imparted a reddish color.

Texture

i. Grain size:
A three-fold division on the basis of grain size is used as the starting point to classify and name terrigenous elastic sediments and sedimentary rocks: gravel and conglomerate consists of clasts greater than 2 mm in diameter; sand-sized grains are between 2 mm and 1/16 mm (62.5 um) across; mud (silt + clay) is made up of particles less than 63 pm in diameter. In this study grain sizes have been named by using Wentworth scale (Wentworth, 1922). The studied samples of Tanawal Formation vary in size range from silt size to coarse sand size, however most of the sample are very fine to medium sand size (Table 2).

ii. Grain shape:
i.Sphericity: Sphericity refers to the degree to which a particle approaches a sphere (Pettij ohn et al., 1987). The sphericity of detrital grains in the studied thin sections is low to high, but the mean sphericity is moderate (Table 2).

ii. Roundness: Roundness of a particle refers to the sharpness or smoothness of its edges and corners (Pettijohn et al., 1987). The roundness of clasts in the studied samples ranges from sub-angular through sub-rounded to rounded (Table 2).

iii. Fabric:

Spatial arrangement of sedimentary particles is termed fabric of a rock. The shape of individual particle is important factor in determining the fabric of sedimentary rocks. Fabric results from depositional processes, some of which give rise to preferred orientation of sediments while others yield completely random particle orientations. In the studied thin section of Tanawal Formation, the boundary contacts among detrital grains are sutured, long, and concavo-convex (Figure 3A — D). The elongated grains of quartz, feldspar and micas are oriented parallel to the direction of shear stresses. The fabric of both blasto-psammites and blasto-pelites is grain supported.

iv. Matrix:

Matrix is generally fine-grained material less than 63 pm in size. In the studied thin sections, it is evident that, fine-grained matrix has been derived from the alteration of feldspars i.e. it is authigenic in nature. It is composed of mixture of clay minerals, sericite, and very fine-grained muscovite .

v. Cement:

Cement is the material deposited by circulating fluids in the pore spaces. It binds the detrital grains and destroys the primary porosity of sedimentary rocks. The major cementing material in Tanawal Formation is in the form of quartz overgrowths and ferruginous material, also carbonate cement occurs in some thin section having very fine-grained texture.

vi. Sorting:

Sorting is the selective deposition of sedimentary particles by transporting agents with respect to their size, specific gravity and shape (Sanders et al., 1978). Sorting in the Tanawal Formation is variable, it is difficult to establish a relationship between sorting and other textural features, however, grains with medium to high sphericity are generally well to very well sorted (Table 2).

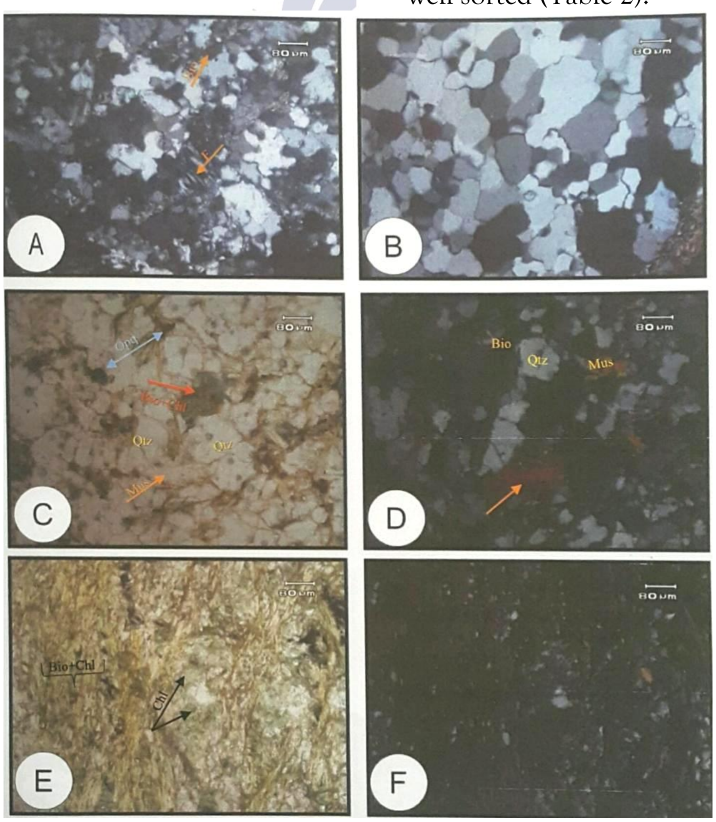

Figure 2: A. (XPL) Photomicrograph showing Plagioclase Feldspar exhibiting lamellar twin (F) and Biotite grain (Bio), highly compacted polycrystalline quartz grains with sutured boundaries. B. (XPL) Photomicrograph of recrystallized subhedral quartz crystals. Contacts between crystals have been sutured. C. (PPL), D. (XPL) Photomicrograph showing fractured quartz grains (Qtz), Muscovite (Mus), Biotite (Bio) and Biotite grain altering to Chlorite (Bio+Chl). Most of the quartz grains have undulose extinction, straight sutured contacts and Iron oxide precipitation around grain boundaries. E. (PPL) Photomicrograph showing Chlorite (Chl) and alteration of Biotite to Chlorite (Orange bracket). Micas are oriented in preferred direction. F. (XPL) same view as E**.**

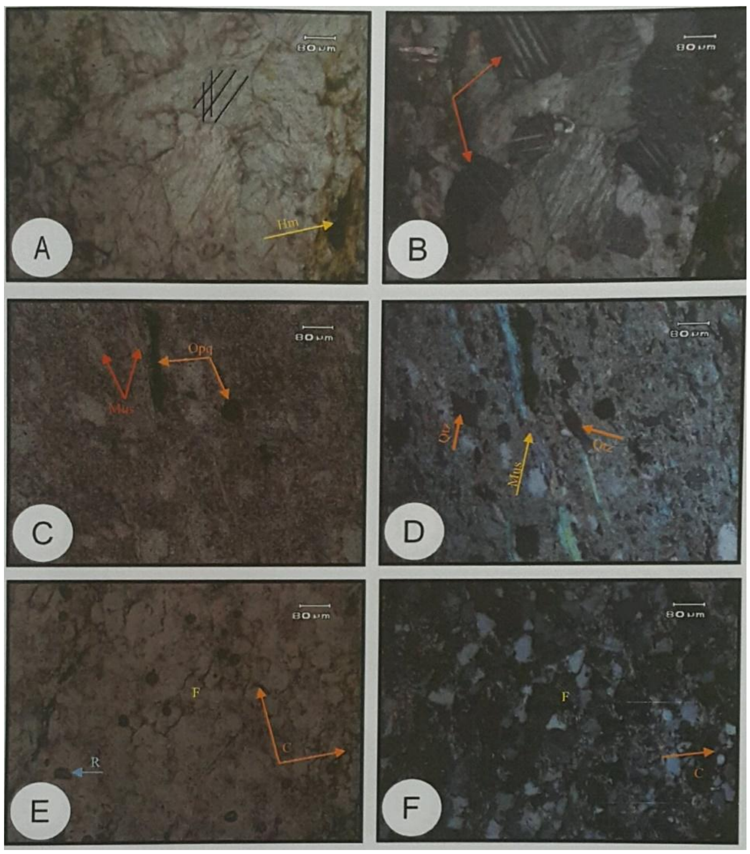

Figure 3: A. (PPL) Photomicrograph showing Tourmaline grain (T) and Biotite (Bio). Feldspars have dirty appearance due to alteration. Straight grain boundary contacts shows that the rock has been compacted. B. (XPL) Photomicrograph showing Strained and altered FeldSpar (F), finegrained material around the grains is mixture of sericite and overgrowth quartz cement. Same view as A. C. (PPL), D. (XPL) Photomicrograph showing detrital Quartz grains (Qtz) exhibiting undulose extinction, fine-grained recrystallized quartz (Qr) and opaque minerals (Opq). E. (XPL), F. (PPL) Photomicrograph showing Hematite (Hm), Perthitic Feldspar (F), Sericite (alteration product of feldspar) (S) and Chlorite (Chl) formed by alteration of Biotite. Sutured grain boundaries represents that rock has been highly compacted. Cement is mostly Chalcedony (fine grained silica) and some sericite With iron oxide around detrital grains boundaries.

Table 1 : showing textural features of the analyzed study samples, from bottom TLQ2 to top TLQ29

Sample no.	Grain size(wentworth 1922)	Roundness	Sphericity	Sorting
TLQ 29	Fine - coarse sand	Rounded	High	Very well
TLQ28	Fne - medium sand	Rounded	High	Very well
TLQ25	Fne - medium sand	Subrounded-rounded	Medium-high	Well
TLQ24	silt/mud size	Angular-subrounded	Low	moderate
TLQ23	Very fine - fine sand	Subrounded-rounded	Medium-high	Very well
TLQ22	Fine – medium sand	Rounded	High	Moderate
TLQ21	Very fine - fine sand	Subangular-subrounded	Low	Moderate
TLQ20	silt/mud size	Subangular-subrounded	Low	Moderate
TLQ19	Very fine sand	Subangular	Low	Moderate
TLQ1	Fine – medium sand	Subangular-subrounded	Low	Very well
TLQ13	Fine – medium sand	Subangular-subrounded	Medium	Very well
TLQ12	Fine – medium sand	Rounded	Medium	Very well
TLQ11	Fine – medium sand	Sub rounded	Medium	Well
TLQ10	Fine sand	Sub rounded- rounded	Low-medium	Well
TLQ 7	Very fine - fine sand	Sub angular- sub rounded	Low-medium	Well
TLQ 3	Very fine - fine sand	Angular- sub rounded	Low	Moderate
TLQ 2	Fine sand	Sub rounded	Low	Moderate

Table 2 : Showing Normalized values of quartz , feldspar and lithics data of samples (QFL)

sample no.	Quartz	Feldspar	Lithics
TLQ 29	73.53	26.47	0.00
TLQ 28	111.76	2.94	0.00
TLQ 25	100.00	2.94	1.47
TLQ 24	26.47	11.76	0.00
TLQ 23	83.82	22.06	1.47
TLQ 22	88.24	4.41	1.47
TLQ 21	70.59	8.82	1.47
TLQ 20	36.76	2.94	0.00
TLQ 19	116.18	2.94	1.47
TLQ 17	22.06	7.35	0.00
TLQ 13	66.18	17.65	0.00
TLQ 12	116.18	4.41	1.47
TLQ 11	80.88	22.06	1.47
TLQ 10	95.59	7.35	0.00
TLQ 7	29.41	58.82	0.00
TLQ 3	36.76	14.71	1.47
TLQ 2	76.47	44.12	1.47

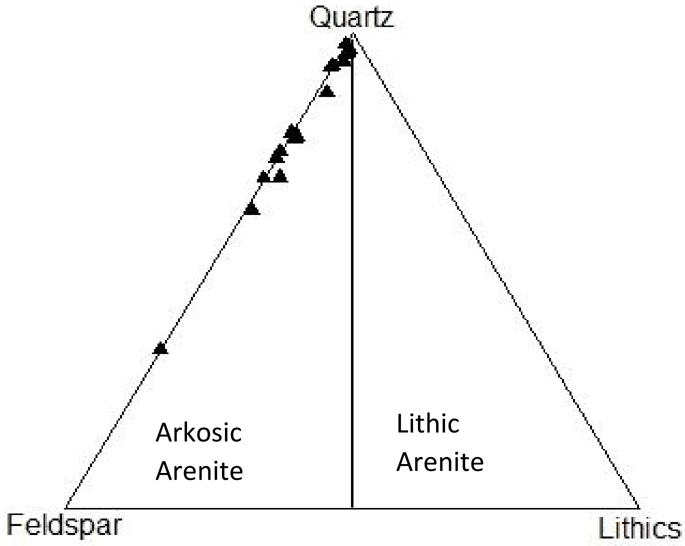

Figure 3 : Showing modal composition of Blasto psammites plotted on QFL triangular diagram after (Pettijohn et al., 1987)

Table 3 : Showing modal composition of the studied samples, From Bottom (TLQ2) to Top (TLQ29) of Tanawal Formation

sample no.	Quartz	Feldspar	Lithics	Mica	Matrix	Cement	heavy minerals
TLQ 29	50	18	0	10	12	6	2
TLQ 28	76	2	0	1	10	11	2
TLQ 25	68	2	1	5	12	8	3
TLQ 24	18	8	0	17	50	5	3
TLQ 23	57	15	1	3	20	5	T
TLQ 22	60	3	1	7	10	13	1
TLQ 21	48	6	1	5	20	12	T
TLQ 20	25	2	0	15	40	5	3
TLQ 19	79	2	1	1	11	6	T
TLQ 17	15	5	0	35	20	8	7
TLQ 13	45	12	0	15	9	11	1
TLQ 12	79	3	1	2	5	9	2
TLQ 11	55	15	1	4	13	4	1
TLQ 10	65	5	0	2	11	6	2
TLQ 7	20	40	0	9	14	7	2
TLQ 3	25	10	1	3	51	5	1
TLQ 2	52	30	1	5	1	5	1

GEOCHEMICAL ANALYSIS

After detailed petrography, six samples with maximum quartz percentage were selected for whole rock geochemistry to determine their elemental concentration. The Atomic Absorption Spectroscopy (AAS) was used for geochemical analysis. The details of the methodology are as under:

Methodology:

For elemental analysis of samples, a homogenous solution of the rock samples was made to get a uniform concentration of the elements present throughout the whole sample. In order to form the solution, the rock sample having maximum percentage of quartz were selected on the basis of petrographic results. A 400g — 500g sample was ground through a crushing machine to convert the rock into smaller fragments. It was then further pulverized into very fine particles. 0.5 gram of the fine rock particles was taken in a Teflon beaker. The Teflon beaker was used because it has the ability to withstand a huge thermal shock and is inert to the rock samples. 10ml of hydrofluoric acid (HF) and 4ml of per chloric acid (HC104) was mixed with the powdered sample. The mixture was heated for an hour. 2ml of per chloric acid was added again and heated till a paste is formed. 4m1 per chloric acid was added and heated for 20 minutes so that 10ml volume remained. Cooled and filtered into a 250ml flask and distilled water was added to it to make the solution ready for the analysis. This solution was then analyzed to determine the concentration of major elements (Fe, Na, K, Mg, and Ca) in the Geochemistry Laboratory, Centre of Excellence in Geology, University of Peshawar while Si was analyzed in the Mineral Testing Laboratory, Hayatabad Peshawar.

Results and Discussion

The results of chemical analysis of six samples is given in Table 4. Details of the analyzed chemical constituents are given below:

Silica (SiO_2):

Glass sand requires a high silica content, ideally 99 to 100 percent silica. Any deviation from purity will make more effort for the glass industry. It will also be more expensive and trouble causing for glass makers. The three samples (TLQ 12, 25 and 28) having silica concentration of 94.34, 93.26 and 97.14 respectively (Table 4), which is well within the range of “soda-lime silica glass” and “glass fiber insulation” quality According to standards given by American Ceramic Society and National Bureau of Standards (Table 5), these three samples can also be used for the preparation of the 3rd quality (Flint glass), 4th quality (sheet rolled and polished glass), 5th quality, 7th quality (green glass) and 9th quality (Amber glass)

Sodium Oxide (Na_2O):

The studied samples contain sodium oxide in the concentration of 1.96, 1.68, 3.88, 2.21, 2.92, and 1.88 percent (Table 5). American Ceramic Society and National Bureau of Standards (Table 2) has not mentioned the minimum amount of sodium oxide required for glass manufacturing.

Magnesia (MgO):

The magnesium oxide concentration is 0.051, 0.066, 0.117, 0.026, 0.033, and 0.022 percent in the samples TLQ 2, 10, 12, 23, 25 and 28 respectively (Table 1). The four samples (TLQ 02, 23, 25, and 28) have the magnesia concentration suitable for each of the glass categories mentioned in American Ceramic Society and National Bureau of Standards (Table2). Otherwise the minimum required amount for other glass categories is not mentioned in this table.

Potassium Oxide (K_20):

According to the Manufacturing Foundation of London the maximum limit for the
potassium oxide concentration is 0.2 9,0 for “Soda-Lime silica glass” quality.

Table 4. Displaying the concentration (wt%). of major oxides present in the analyzed samples

Sample No.	SiO_2 %	MgO %	Na_2O %	K_2O %
TLQ 02	88.32	0.05	1.96	1.92
TLQ 23	0	0.03	2.21	2.14
TLQ 10	0	0.07	1.68	1.77
TLQ 25	193.26	0.03	2.92	0.53
TLQ 12	0	0.12	3.88	0.4

Table 5 : Showing silica sand classification recommended by American Ceramic Society and National Bureau of Standards

Quality	1	2	3	4	5	6	7	8	9
chemical composition	First quality optical glass	optical flint glass container	flint glass	Sheet rolled and Polished glass	5th quality	screen windows	Green glass	8th quality amber glass	9th quality amber glass
SiO_2	99.8	98.5	95	89.5	95	98	95	98	95

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TiO_2	0	0	0	0	0	0	0	0	0
Al_2O_3	0.1	0.5	4	0.5	4	0.5	4	0.5	4
Fe_2O_3	0.02	0.035	0.035	0.06	0.06	0.3	0.39	1	1
MgO	0.05	0.1	0.25	0.25	0.25	0.25	0.25	0.25	0.25
CaO	0.05	0.1	0.25	0.25	0.25	0.25	0.25	0.25	0.25

CONCLUSION :

The various details including field observations, petrographic data and geochemical analysis of Tanawal Formation exposed in Topi area, Swabi are discussed. These discussions leads to the following conclusions:

1. The quartzose rocks of Tanawal Formation are broadly divided in to two categories:

i) Blasto-Psammites : These rocks are fme-medium grained, massive, hard and compact, thin-thick bedded containing predominantly quartz (93-94%), with minor amounts of feldspars, micas, tourmaline, zircon and hematite as framework grains. On Quartz-FeldsparsLithics ternary diagram, they fall in the fields of quartz arenites, sub-arkoses and arkoses.

ii) Blasto-Pelites : These are soft rock with well-developed foliations. Micas are exceedingly abundant (93-94%) , it essentially contains fine-grained quartz and long flakes of micas as framework constituents.

2. Geochemical analysis suggest that, rocks of Tanawal Formation are not suitable for good quality glass manufacturing, however two samples lie within the range of low quality glass specifications i.e containing high percent of SiO_2 (93.4 % and 94.34%) . Samples analyzed are good for manufacture of low quality glass and glass products i.e. flint glass, amber glass, green glass, soda-lime glass and glass fiber insulation.

3. These rocks can be used in various other industries as well, which require silica as raw material for the manufacturing of products like laboratory ware, abrasives, construction, refractory etc.

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