GEOLOGY OF THE TANAWALS IN THE SOUTHWEST TANAWAL AND GANDGHAR RANGE, HAZARA, PAKISTAN.

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ABSTRACT

In the Hazara Palaeozoic sequence, the Tanawal Formation overlies the Hazara Slates and underlies the Abbottabad Formation. The contact between the Hazara Slates and the Tanawals is marked by a pebbly bed which is not persistant, but elsewhere in Kashmir and the Central Himalayan sections gradational contact has been reported by the earlier workers.

The Tanawals comprise dominantly of arenaceous rocks which constitute quartzite, quartzitic schist and quartzitic sandstone with interbedded arenaceous slaty shales, slates, phyllitic slates and conglomerate which are intrudded by the igneous rocks. Among the quartzose rocks, arkosic wacke, subarkose, arenites and quartz arenites are differentiated. Amphibolite, epidiorite, porphyritic micro-tonalite, dacite, rhyo-dacite, pegmatite and quartz veins are the igneous rocks which occur in the Tanawals as sills, dykes and veins.

The Tanawals are unfossiliferous. Their sympathetic stratigraphic relationship with the fossiliferous Palaeozoic rocks in Kashmir, Central Himalaya and Swabi - Lower Swat areas, suggest for them a Devonian - Lower Carboniferous age. The discovery of Hyolothids of Cambrian age near the contact of overlying - Abbottabad Formation and Hazira shales will depress the age of the Tanawals to Precambrian. However, this fossil find is very localized and appears to have been derived from the older horizon and incorporated in these rocks.

INTRODUCTION

In the Palaeozoic sequence of Hazara, the Tanawal Formation occupies a significant place because of its vast spatial distribution, unique stratigraphic position and typical lithological characteristics. Wynne (1879) first brought them within the fold of geological observations in the Tanawal area of Hazara district (now division), thus named after this area as "Tanawal Group".

Subsequent researches on the Palaeozoics of the subcontinent during pre-and post-independence periods, brought to light many new unfossiliferous arenaceous horizons which were correlated with the Tanawals. Thus the Tanawals have held pivotal position for correlation and assigning ages to several formations having similar lithology located at far off places from the Tanawal area.

The Tanawals are unfossiliferous and all the attempted correlations by the past researchers were based either on the lithology of the rocks comprising the Tanawals or the stratigraphic position they held.

The Tanawals have been described and discussed by many authors yet an authentic base is lacking to properly spell out the geology for distinguishing and deciphering the thick metamorphosed arenaceous and pelitic sediments alongwith numerous igneous intrusions which are quite widespread and were left unnoticed by most of the previous workers.

THE TYPE AREA AND PREVIOUS WORK

The past researches on the Tanawals were concentrated in two main areas; in the Gandghar Range, which extends south of Tarbela along the eastern bank of the Indus and in the terrain stretching north of Haripur through Sherwan to Mansehra and Darband which actually forms the Tanawal Territory of Hazara. The Tanawals of the Gandghar Range are the continuation of the latter. Most of the past results on the Tanawals published by the previous workers were obtained from the sections located in these areas.

During this study, besides the Tanawals of Gandghar Range and Gadun area in Swabi, the other sections examined by the authors are located in the vicinity of Alluli, Darwaza, and Kacchi villages, which constitute an area of about 30 square kilometers and comprise the southern extension of the Tanawals, north of Haripur. The authors recommend this area to be considered for the location of the type section of the Tanawals because of the following reasons:

(i) Here the development of the Tanawals is thick, yielding a complete uncontaminated record on the lithology of the rocks and their stratigraphic order,

(ii) Structurally the area is not as disturbed as in the north where severe folding and faulting have dislocated the Tanawals into isolated pockets and merged them into the old metamorphosed sediments, and

(iii) This area does not expose any major igneous body in the close vicinity, thus the usual character of the Tanawals is not altered or obliterated.

The past contributors on the Tanawals are many but a few of them will be quoted here who worked in the Tanawal area or Gandghar Range in Hazara and provided a base for the understanding of the Tanawals.

Wynne (1879) was the first geologist who described the Tanawals and his observation about them was, "Tanawals consist of quartzose rocks, some of them almost unchanged sandstones in rapid alteration with dark earthy bands, flaggy, shaly or slightly schistose with occasional conglomeratic slates containing pebbles of quartz and quartzite ranging upto the size of a goose's egg". He suggested a thickness of 20,000 feet for the Tanawals.

Middlemiss (1896), while investigating the central and western parts of Hazara, mapped these rocks as "Tanol Quartzites", and described them as "feldspathic schistose quartzites". He considered them to form the lower part of the Infra-Triassic of Hazara, but had to change his opinion while experiencing difficulties in constructing a geological section. He also speaks of the Tanols as varying little in character.

According to Wadia (1931), the Tanawals in the Gandghar Range, south of Tarbela comprise of a well stratified sequence of purple, grey and white quartzite with quartz schists and phyllites associated with some massive quartzitic beds having peculiarly scoured and grooved surfaces and containing veins, layers and patches of coarsely crystalline dolomite.

Ali (1962) has worked in the vicinity of Tarbela, Darwaza and Kacchi and described them as well - bedded to flaggy, light grey to yellowish and sometime faintly reddish quartzite with excellent development of cross - beddings and ripple marks. He mentions a thickness of 5000 feet for the Tanawals.

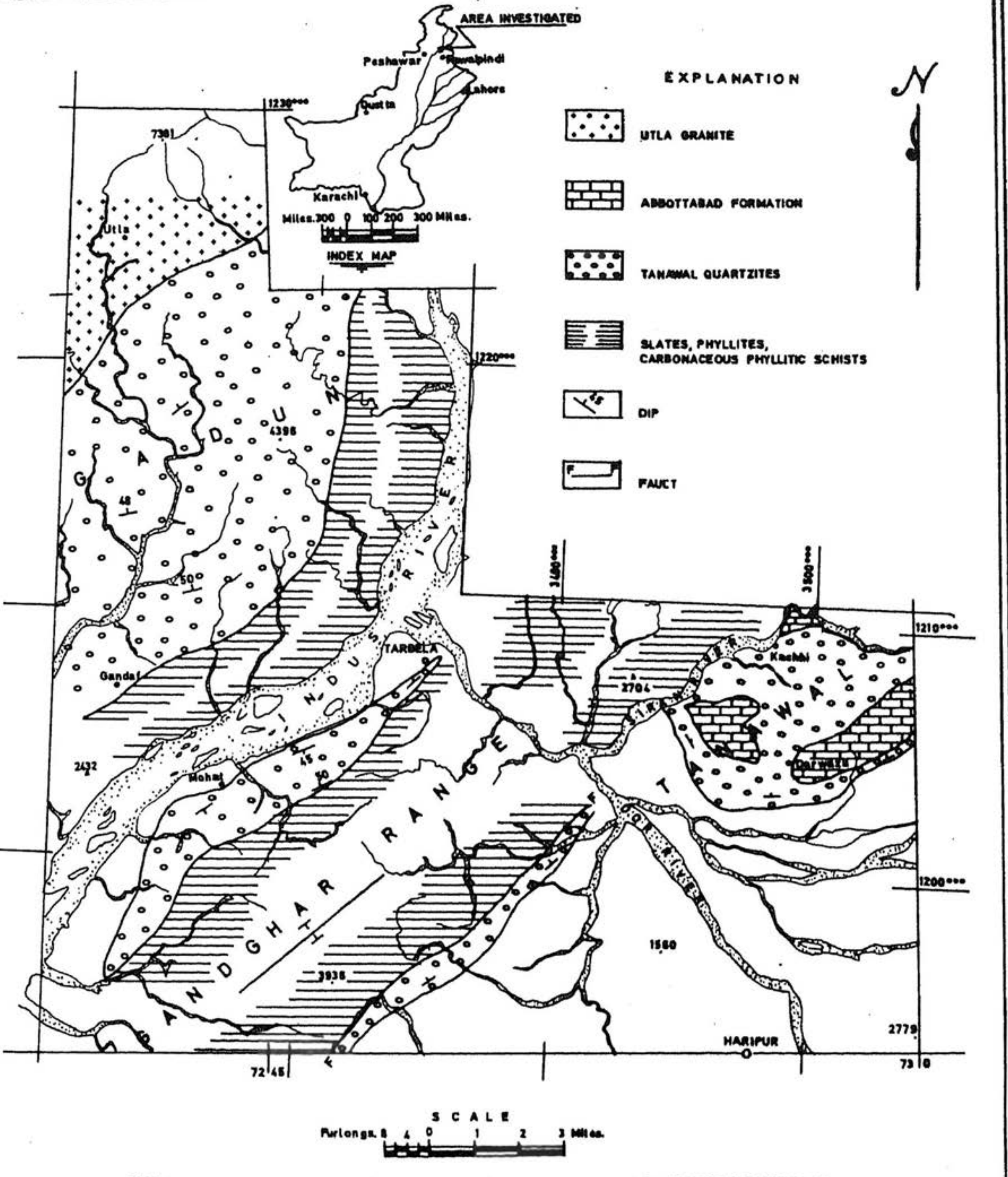
The first attempt to divide the Tanawals into four differentiable lithological units was made by Calkins *et al.* (1975). Their field observations were based on the Tanawal outcrops exposed in the Gandghar Range, south of Tarbela. Their four divisible units are, from bottom to top: Conglomerate, Lower quartzite, Quartz schists and Upper quartzite. How much this division could be made effective depends upon the observations of the future workers in other areas where the Tanawals show extensive distribution?

STRATIGRAPHY

In Hazara, the Tanawals usually border the Hazara Slates along its north-western boundary and due to intricate folding and faulting, they are reduced to isolated pockets. In the northern Hazara a belt of quartzose rocks alongwith schistose sediments has been recorded beyond Tanawal area, extending to north-east of Mansehra into Kaghan valley and Azad Kashmir where Wadia has reported their contact with the Dogra Slates. Wherever the Tanawals are exposed, they present anomalous stratigraphic relationship to the surrounding rocks, overlying the Slates; Hazara, Dogra, Simla or Chitral; and underlying the dolomite bed - which at places are missing.

The contact of the Tanawals with the underlying slates is marked by a well known conglomerate bed. In Kashmir, west of the Hazara syntaxis, Wadia has reported about 200 feet thick conglomerate bed south-west of Pir Panjal. According to him the pebbles are of white and pink quartz, some of them drawn into augen and binded with shaly matrix.

The conglomerate bed has also been recorded in many other sections, some of them are; Soban Gali on Abbottabad - Sherwan road, near Darwaza, Kacchi, and Alluli located on the southern tip of Tanawal area and near Tarpakhi, in Dal Darra and east of Sirikot in the Gandghar Range. Near Darwaza the conglomerate bed is exposed close to the pass and is about 30 meters thick.



TANAWAL OUTCROPS IN GANDGHAR RANGE AND SOUTHERN TANAWAL, HAZARA, AND GADUN AREA IN SWABI, N.W.F.P., PAKISTAN

(FAZAL AHMAD)

The pebbles are of white quartz and pink or grey quartzite which are rounded and are embedded in dark grey, very fine shaly matrix. Pieces of arenaceous slate are also found incorporated in the conglomerate. The lithology of conglomerate is more or less similar in all the sections mentioned above except Soban Gali where, besides quartz, silty slate pebbles abound in the matrix. As evidenced in some sections and also reported by the previous researchers, the pebbles in the conglomerate are deformed and flattened which manifestly reflect the effect of dynamic metamorphism subsequent to their deposition.

Conglomerate bed has also been reported by Wadia (1928) from Simla, Garhwal and Kumaon areas at the base of the dominantly arenaceous bed which they considered homotaxial with the Tanawals. The conglomerate bed is not persistant in development, and occurs as isolated pockets. This dislocation is attributed to tectonism.

Overlying the Tanawals are dominantly calcareous rocks with subordinate quartzite, slaty shale and conglomerate, which were first named by Middlemiss (1896) as "Infra - Triassic." Later on, this name was replaced as "Abbottabad Formation" by Marks and Ali (1962), and then to "Abbottabad Group" with the addition of some new formations by Butt (1968). Still these names are to be formalized by the National Stratigraphic Committee, thus the authors for their usage would adhere to "Abbottabad Formation," to name the rocks overlying the Tanawals. Here again the Tanawals are separated from the overlying "Abbottabad Formation" by a conglomerate bed which the previous workers placed at the base of this formation and differentiated it as a "Basal Conglomerate Member," (Ali, 1962). This conglomerate bed directly overlies the Tanawals and consists of badly sorted pebbles composed of quartzite, similar to the Tanawals alongwith phyllite and schists derived from the older Hazara Slates. The arrangement of the pebbles with respect to stratification suggests a rotation of this bed as a result of tectonism. This conglomerate is exposed in the vicinity of Darwaza, Pind Khan Khel and Kacchi villages in southern Tanawal. The conglomerate bed does not show persistant development and a maximum length observed west of Darwaza is about 1½ kilometer exposing a thickness of about 60 meters.

Arenaceous rocks equivalent to the Tanawals are also developed on the western bank of the Indus in the Gadun area of Swabi, district Mardan, which represent the extension of the Gandghar Range outcrop through an anticlinal fold with its axis running in a north-south direction and approximately coinciding with the present Indus bed. The Gadun outcrop represents the western limb of the fold. The authors would like to name the Tanawals developed on the western bank of the Indus as "Gadun Quartzites" which ultimately appear again near Swabi and Chamla (Lower Swat) and named by Martin *et al.*(1962) as "Swabi Quartzites" and "Chamla Quartzites" respectively.

The Gadun Quartzites lithologically are very similar to the Gandghar Tanawals and show quite widespread distribution in this area. In the south, in the vicinity of Akhtarabad near Gandab, the quartzose rocks overlie the slates, equivalent to Hazara Slates and the Manki Slates developed in the Attock - Cherat Range (Tahirkheli, 1970). Near the contact, a pebbly bed is developed in the slates with abundant quartz pebbles in slaty matrix. The top of the quartzose rocks in the north along Topi - Utla road, show from 50 to 80 meters thick arenaceous slate and phyllite which apparently appear to be the part of the Tanawals and have got intrusive contact with the Ulta porphyritic granite. Thus in Gadun area the rocks equivalent to Abbottabad Formation, which overlie the Tanawals are missing.

On the basis of these field observations in northren Tanawal and Gandgher Range it is confirmed that the Tanawals overlie the Hazara Slates with an unconformity and in turn is overlain by the Abbottabod Formation, again with a well marked unconformity.

The thickness of the Tanawals has been discussed by some of the earlier workers. A minimum thickness of 20,000 feet has been suggested by Wynne whereas Ali considered them to be 5000 feet thick. Actually the repetition of the beds as a result of folding has exaggerated the apparent thickness of the Tanawals. The authors on the basis of their works in the southern part of Tanawal and in the Gandghar Range, consider the maximum thickness of the Tanawals to be around 1000 meters.

Lithological Characteristics

The Tanawals, in general, are composed of three types of rocks, quartzitic sandstone, quartzitic schists, slaty-shales,slate,phyllitic slate and conglomerate. The quartzitic sandstone and quartzite are the dominant rocks and constitute nearly 85 percent of the rocks in the Tanawals, remaining 10 percent being arenaceous slate and phyllitic slate and 5 percent conglomerate and others. Variation in metamorphism of the Tanawals is great and varies from epi- to mesograde ranging from slaty shales to phyllite and sandstone to schistose quartzite.

The quartzitic sandstones and quartzite are thin to thick bedded but occasionally massive beds are also encountered. Grey, greenish-grey, yellowish-brown, Pinkish-brown and white to cream colours are quite conspicuous. These are usually medium to coarse textured but pebbly, gritty and schistose quartzitic beds are not uncommon.

Thin wavy manganese dendrites are observed on the weathered faces. Thin quartz veinlets, parallel and across the bedding plane are also noticed in the white and light brown varieties of quartzitic sandstone, the former appears to be the result of metamorphism and the latter represents the last phase of igneous activities. The cementing materials are siliceous, clayey or ferruginous. On the basis of petrological examination, among the arenaceous rocks the following varieties have been differentiated: arkosic wacke, subarkose, arenites and quartz arenites, which will be described in the subsequent pages. Ripple marks and cross beddings are marked in the quartzose rocks which are well preserved.

Slaty shales, slate and phyllitic slate form thin to thick band and at places are squeezed and interfingered with the quartzitic sandstone. These rocks are thin bedded, not well cleaved and range in colours from light grey to greenish-grey; where carbonaceous matter is present these become dark grey to black. Arenaceous and pelitic bandings in these rocks are conspicuous. Yellowish - brown coloured ferruginous impressions are quite frequently seen and at places the shales and slaty shale become talcose too. Proportion of silt and sand is relatively higher in these rocks which is quite significant to help in differentiating them from the underlying Hazara Slates.

Conglomerate, as said before, is not consistant in distribution in the Tanawals. The coarser material in the conglomerate ranges in size from pebble to grit and consists of quartz, quartzitic sandstone, quartzite, and arenaceous phyllitic slate; quartzose rocks of white, brown, yellowish - brown and light grey colours, typical of the Tanawal rocks, have abundant distribution. The matrix is light to dark grey, fine to very fine textured pelitic material.

The Tanawals are intruded by the igneous rocks and five igneous episodes based on the rock types have deen differentiated, which from early to late are enumerated as i. metamorphosed basic igneous rocks; garnet amphibolite and amphibolite, ii. micro - gabbro, epidiorite, iii. porphyritic micro - tonalite, iv. dacite, rhyo-dacite, and v. acid igneous intrusions in the form of thin pegmatite, and quartz alongwith the mineralized veins enriched in baryte, lead and copper; the later two are not very common whereas the former occurs in commercially exploitable deposits.

Dolomite association in the Tanawals is marked in the outcrop exposed on the eastern bank of the Indus near Tarbela Dam, which was first reported by Middlemiss (1896). The interfingering of dolomite is also observed in the Swabi - Chamla Quartzites which are equivalent to the Tanawals. Wynne (1879), Wadia (1931) and Fuche (1975) have also reported occurrence of dolomite bed in the Tanawals in Kashmir. But in the southern Tanawals in the vicinity of Darwaza, and Kacchi where the Tanawals attain enormous thickness, the dolomite association in not observed. In some sections in this area, tectonic dolomite intercalations are observed which appear to be the ripped-apart part of the overlying Abbottabad Formation.

AGE AND CORRELATION

As mentioned elsewhere, the Tanawals are totally barren of fossils and while assigning age the previous workers kept in view their lithological characteristics, stratigraphical position and their intertonguing with the Agglomeratic Slate of Pir Panjal and other fossiliferous horizons in Kashmir, Central Himalayas and Swabi - lower Swat regions.

Wadia (1928) has pointed out to an apparent conformable passage of the Tanawals into Agglomeratic Slate at Jured, which according to him favour an age a little older than that of the Pir Panjal volcanics, of which the Agglomeratic Slate forms a part. This would bring the Tanawals partially equivalent to the Muth Quartzites, with an age range from Devonian to Early Carboniferous. He again indicates another section in Chor-Panjal Pass where the upper boundary of the Tanawals comes into apparently normal and conformable contact with the Agglomeratic slate with its Gondwana flora of Gangamopteris, Aleploteris, Cordiates and other plants. Many other workers who mapped these rocks in Kashmir and elswhere have affirmed the view held by Wadia.

Among the recent workers, Fuchs (1975) had described a section northwest of Sach Pass where the Tanawals interfinger with the Syringothyris Limestone. In another section between Sach Pass and Dalhousie, the sample collected by Gupta (Fuchs & Gupta, 1971) from the lower part of psammitic bed, considered equivalent to the Tanawals were examined by him, which yielded lower Devonian conodonts in the basal part of sequence. Martin *et al.* (1962) while working in Swabi and lower Swat encountered dominantly psammitic rocks called Sawabi Quartzites and Chamla Quartzites representing the Tanawals, which interfinger with the fossiliferous dolomites of Siluro- Devonian age.

The Baraghat section in Tirah, Khyber Agency (Tahirkheli *et al.*, 1975) exposes a sequence similar to Hazara where the Tanawals are represented. This sequence in ascending order reveals; i. Thin bedded argillaceous limestone, ii. Landikotal slate, iii. Quartzite with intercalated arenaceous phyllitic slates and iv. Dolomites In Hazara Palaeozoic section this sequence corresponds to ii. Hazara Slates, iii Tanawal Formation, iv. Abbottabad Fromation; Argillaceous limestone (i) has been correlated with the Shahkotbala Limestone of the Attock - Cherat Range. Both iii. and iv. are fossiliferous and have yielded Devonian-Permocarboniferous fossils.

In the Attock-Cherat range (Tahirkheli, 1970), the Shahkotbala Formation which is the oldest unit, has yielded fossils of Medial to Late Palaeozoic age. The Manki Slates are equivalent to the Hazara slates-which on the basis of these fossils, is placed in the Silurian. The Tanawals overlie the Hazara Slates and thus their age is very much agreeable to Devonian - Lower Carboniferous.

The discovery of Hyolothids, (Latif, 1972 and Rushton, 1973) at the base of the "Abbottabad Formation" near its contact with the "Hazira Shales" would shift the stratigraphy of the Tanawals from Devonian-Early Carbonifeours to Precambrian. This discovery has got good argument yet there are a few controversial points too, beside numerous pro-Devonian Early Carboniferous field evidences gathered by many researchers, and some of them have already been listed earlier.

This fossiliferous horzion is 3-4 meters long along the strike, 1½ to 2 meters wide and 2-3 meters deep, and the fossiliferous rock is argillaceous dolomitic limestone. This few square meters of fossiliferous horizon in the rocks which have spatial coverage of hundreds of square kilometers not only in Hazara but outside also, weakens this argument for its in situ origin. The authors concur with the very well explained views of Fuschs that it is easy to explain the reworking of fossils from the older formation to their re-incorporation in the younger horizon than to suppress the logical field evidences which still hold solid ground for assigning Devonian—Early Carboniferous age to the Tanawals and their equivalents.

The correlation of the Tanawals and their equivalents in the Indo-Pakistan subcontinent, based on the past and present researches is as shown below:-

1	2	3	4	5
Hazara	Kashmir	Simla	Garhwal	Spiti
Tanawal Quartzites	Muth Quartzits	Bawar Qtz. Jaunsar Bed	Naghat series	Muth Qtz.
6	**7**	**8**	**9**	**10**
Swabi	Buner	Khyber	Chitral	Nepal
Swabi Qtz.	Chamla Qtz.	Qtz. of Baraghat section (Tirah) spinragh Qtz. of Jamrud	Charun Qtz.	Qtz. in Chails in Thulo Bheri valley

DEPOSITIONAL AND TECTONIC ENVIRONMENT

The Tanawals comprise part of the Lesser Himalayan sequence in Hazara. They represent the Tethyan facies which were deposited after the shrinkage of the geosyncline in which the great slates series; Hazara Slates Dogra Slates, Manki Slates, Simla Slates and Landikotal Slates were deposited. Before the commencement of deposition of the Tanawals, a ridge called "Himalayan Ridge," (Fuchs,1975) was created in the Central Himalayas which extended to northwest and coincided with the Tanawal Zone. North of this ridge was Tethyan basin where the Tanawal sedimentation was taking place, whereas on the south this ridge bordered Indian Subcontinent as evidenced by the occurrence of Gondwana Flora in the Agglomeratic slate, with which the Tanawal have kinship and existence of Upper Palaeozoic glacial boulder bed. Whatever may be the causes of the shallowing of the Tethyan Basin, the character of the Tanawals shed ample light on the rapid fluctuations during the deposition of the Tanawals, which have affected the grain size. Thus in the Tanawals, beside pelitic interfingerings which is frequent in the northwest, the quartz grains also show great variations in size, ranging from fine to grit.

From the mineral assemblage in the Tanawal Quartzites, such as quartz, feldspar, biotite, tourmaline, sphene and ores, it is apparent that the source area was underlain by the igneous rocks where acidic igneous suite predominated. The mineral grains are rounded to well rounded which point out to the long distances they travelled and a long abrasional history.

In the Tanawal sequence, in the southwestern Tanawal, the top and bottom are eomparativcly more sandy and gritty, whereas the finer pelitic bands frequent in the middle part. Thus during early and late periods cf deposition of the Tanawals, shallow and agitated conditions prevailed, whereas during the middle period the deposition was comparatively in deeper water which remained oscillatory.

After the culmination of deposition of the Hazara Slates, which underlie the Tanawals, there was a period of non-deposition when erosion was rampant. This is evident by the occurrence of rounded to subrounded heterogenous material ranging in size from very fine to pebble, the maximum size range of the quartz pebbles measurcd 5 cm in diameter. The contact of the conglomerate and underlying Hazara Slates is unconformable though some workers reported gradational contacts in Kashmir and elsewhere. No tectonic deformation has been observed in the Hazara Slates before the deposition of the Tanawals.

Some previous workers have mentioned about stretching and flattening of the pebbles in the conglomerate bed which was noticed by the present authors too. This phenomenon is attributed to differential movement between the competent and incompetent strata as a result of local deformation.

The Tanawal Quartzites are again succeeded by conglomerate bed in the Gandghar Range near Darwaza in the southern Tanawal, which underlie the Abbottabad Formation and are considered here equivalent to the Tanakki Boulder Bed and Tobra Formation of the Salt Range. Two views are held for their origin; deposition as a result of glaciation or by fluvio-glacial agency. In case of the conglomerate bed of the new sections, the authors hold the latter view because, firstly the locally derived material is abundant and secondly scouring, as has been witnessed in Tobra Formatlion, is observed.

PETROLOGY

On the basis of thin section studies the arenaceous samples have been identified as quartzose sandstones. These consist mostly of quartz, with feldspar not exceeding seven percent. The important accessory minerals are tourmaline, sphene, opaques and muscovite. The pore-filling medium is either a matrix, consisting of a fine grained intergrowth of sericite, chlorite together with some silt-sized quartz and feldspar or silica. A yellowish-brown ferruginous material is also occasionally present as matrix.

Quartz grains are usually rounded to subrounded and are free of inclusions. In one thin section, however, the majority of the grains were recorded with poorly rounded outlines. In all the sections maximum quartz grains are monocrystalline. The ratio of the polycrystalline quartz grains to monocrystalline is lowest as in more mature sand.

Some of the quartz grains show slight elongation which tends to be longer in the direction of crystallographic c-axis. Two views are put forth to explain this phenomenon:

i. Differential abrasion because of the slight difference in hardness of quartz along the c-and a- crystallographic directions(Wayland, 1939), and

ii. An expression of the initial shape of quartz (Ingerson and Ramisher, 1942).

The long axis-short axis ratio (elongation ratio) of the quartz grains has been determined in every section. This ratio has been usefully employed as a criterion of provenance; quartz grains derived from metamorphic rocks have a higher elong.ratio e.g. 1.75 for schist, than those of igneous origin, e.g. 1.43 for granite (Bokmen, 1952 and Pettijhon, 1975). The elongation ratios of the quartz grains in the studied samples have been determined and listed in tables 2 to 6.

The mean elong-ratio of the quartz grains in one specimen is much higher than those of the remaining samples. This clearly discriminates between the standstones with detrital grains derived from a metamorphic assemblage than those which could be correlated to rocks of igneous origin. The division of the Tanawal Quartzose Sandstones into two groups, although based on the long axis-short axis measurments of the elongated quartz grains in thin section, closely corresponds with their classification based on mineralogy and sand to matrix ratio.

CLASSIFICATION OF QUARTZITIC SANDSTONES

According to the scheme of classification proposed by Dott (1964) and modifide by Pettijohn (1975) for terrigeneous sandstone, the rocks have been distinguished as a. wackes and b. arenites. Pettijohn's classification considers relative proportions of quartz, feldspar and rock fragments within the framwork of sand, and ratio of sand to the matrix as defining parameters of various sandstone classes.

A. Wacke (Arkosic Wacke) These are light brownish-grey rock with a pale grey appearance on fresh surface. In thin section the principal mineral is quartz. K-feldspar is the next abundant mineral whereas sphene, tourmaline, opaque and muscovite are present only in accessory amount. The matrix is a microcrystalline aggregate of quartz, chlorite, sericite, clays and patchy carbonate, and constitute up to about 19 percent of the rock. Quartz grains are generally poorly rounded. On the basis of relative proportions of quartz and feldspar the rock has been further distinguished as arkosic wacke.

TABLE—1. Modal Composition of arkosic wacke

Minerals		Proportions
Sand		
Quartz	....	70%
Feldspar	....	7%
Rock fragments	....	1%
Tourmaline Muscovite Sphene Opaques	....	4%
Matrix		
Sericite. Chlorite. Quartz. Carbonate.	....	18%

TABLE-2. Measurments of long and short axis of the slightly elongated quartz grains.

Long axis	Short axis	Elongation ratio
0.54 mm	0.25 mm	2.16
0.34 mm	0.21 mm	1.62
0.25 mm	0.13 mm	1.92
0.41 mm	0.15 mm	2.73
0.32 mm	0.15 mm	2.13
0.25 mm	0.18 mm	1.39
0.41 mm	0.21 mm	1.95
0.28 mm	0.19 mm	1.47
0.22 mm	0.10 mm	2.20
0.35 mm	0.19 mm	1.8[illegible]
		Mean elongation [illegible]

B. Arenites : As are named, the interstitial matrix in these rocks is constantly less than 15 percent. Compared with feldspar and rock fragments, quartz is the most abundant mineral and thus the samples have been further classifide as quartz arenites except one or two samples which are proportionally rich in feldspar and plot in the subarkose field on the Q.F.Rx triangle.

Quartz Arenites : These rocks are coarse grained, white in colour with occasional light pink spots on fresh surfaces. In thin sections these consist mainly of highly rounded to subrounded quartz grains with traces of feldspar. Heavy minerals are scarce. Very well-rounded tourmaline and sphene is, however, present up to 2 percent. The matrix measures from 4 to 12 percent in thin sections. Within the matrix, silica as quartz is characteristic. It has grown in optical continuity with the original detrital quartz. Areas of the original quartz grains are marked in some cases by dusty margins. Besides silica, matrix contains fine grained white mica and carbonate material.

Quartz grains are monocrystalline and contain rarely fluid inclusions and fine dust-like opaque particles. In certain cases the sand grains are highly fractured and show undulatory extinction.

Such rocks were originally described as orthoquartzite (Tieje, 1921 and Krynine, 1945), but in the recent literature these have been named as quartz arenite (Pettijohn, 1975).

Sub Arkose: Coarse grained arenaceous rocks with light grey to cream colour are also present in the samples from Tanawals. At places, it exhibits a pale pinkish appearance due to the presence of a red ferruginous material. In thin section it consists of 85 percent quartz and 7 percent feldspar. Quartz grains are rounded to subrounded and mostly equidimentional. There are, however, grains slightly elongated in one direction. Both kinds of feldspars (alkali and plagioclase) are present. Occasionally quartz grains show secondary growth. Large detrital muscovite and biotite characterize most of the arkoses but these are absent here. Matrix consists of silt-sized quartz and feldspar. A red ferruginous material is also there as an interstitial pore-filling medium.

TABLE—3 Modal Composition of quartz arenite.

Minerals	1	2	3	4
Sand				
Quartz	95%	86%	23%	94%
Felspar	1%	3%	2%	traces
Rock fragments	—	—	—	—
Tourmaline.	—	2 %	3%	—
Sphene	traces	2 %	3%	—
Matrix	4 %	9 %	12%	6%

TABLE—4. Measurments of long and short axis of the slightly elongated quartz grains in quartz arenite.

1			2			3			4		
Long axis	Short axis	elong ratio	long axis	short axis	elong ratio	long axis	short axis	elong ratio	long ratio	short axis	elong axis
1.5 mm	0.85 mm	1.76	0 28 mm	0.13 mm	2.15	1.1 mm	0.45 mm	2.44	1.05 mm	0.87 mm	1.21
1.4 mm	1.1 mm	1.27	0.30 mm	0.12 mm	2.5	0.8 mm	0.45 mm	1.77	0.45 mm	0.43 mm	1.05
1.0 mm	0.85 mm	1.18	0.30 mm	0.26 mm	1.15	0.51 mm	0.30 mm	1.70	0.75 mm	0.42 mm	1.79
1.3 mm	0.54 mm	2.40	0.40 mm	0.30 mm	1.33	0.62 mm	0,35 mm	1.77	0.70 mm	0.49 mm	1.42
1.0 mm	0.81 mm	1.23	0.62 mm	0.5 mm	1.24	0 58 mm	0.49 mm	1.18	1.50 mm	0.64 mm	2·34
1.1 mm	0.65 mm	1.69	0.3 mm	0.09 mm	3.3	0.30 mm	0.15 mm	2.00	0.72 mm	0.42 mm	1.71
2.2 mm	1.2 mm	1.83	0.55 mm	0.18 mm	0.8	0.64 mm	0.41 mm	1.56	0.53 mm	0.34 mm	1.55
1.4 mm	0.93 mm	1.51	0.33 mm	0.15 mm	2.2	0.41 mm	0.28 mm	1.46	0.71 mm	0.53 mm	1.33
1.5 mm	1.15 mm	1.30	1.65 mm	0.55 mm	1.18	0.29 mm	0.19 mm	1.53	0.31 mm	0.21 mm	1.48
1.25 mm	0.90 mm	1.39	0.60 mm	0.31 mm	1.07	0.35 mm	0.32 mm	1.09	0.64 mm	0.33 mm	1.93
Mean elong. ratio.		1.55			1.43			1.65			1.58

TABLE-5. Modal Composition of Sub-Arkose

Quartz	... .	85 %
K-feldspar Plagioclase }	....	7 %
Matrix	....	8 %

TABLE—6. Measurments of long and short axis of the quartz grains in subarkose.

Long axis	Short axis	elongation ratio
1.5 mm	1.0 mm	1.5
0.9 mm	0.6 mm	1.5
0.6 mm	0.5 mm	1.2
1.0 mm	0.45 mm	2.2
0.9 mm	0.5 mm	1.8
0.93 mm	0.7 mm	1.3
0.65 mm	0 63 mm	1 0
0.50 mm	0.28 mm	1.8
0.49 mm	0.30 mm	1.6
1.5 mm	1.50 mm	1.0

Mean elongation ratio 1.49

IGNEOUS ROCKS

Igneous rocks, mostly occurring as dykes and sills within the Tanawal Formation, are distinguished on the basis of mineralogy and texture into the following groups.

A) Dykes of basic igneous rocks:
- i. Metamorphosed to amphibolite,
- ii. Occurring as microgabbro and
- iii. Hydrothermally altered to epidiorite.

B) Dykes of intermediate character:
porphyritic micro-tonalite.

C) Acidic Lavas:
Dacite-rhyodacite.

Amphibolite: These are greenish grey coloured rocks with a spotted appearance and exhibit a yellowish-brown to reddish-brown tinge on weathered surfaces. Hornblende and feldspar are easily distinguisable in the hand specimens. Samples are coarse grained, hard and spotted with reddish-brown and dark-green patches. No banding has been observed in the amphibolites.

Variations in mineral content in these amphibolites further distinguish these into two groups defined respectively on the basis of assemblages:

a) Garnet-cummingtonite-plagioclase-quartz
b) Hornblende-plagioclase-zoisite.

Coexistance of a medium plagioclase (An 30%) with zoisite in the later type is characteristic and the presence of cummingtonite in the former indicates high content of MgO in the parent igneous rock. Rocks with garnet, cummingtonite and plagioclase are described as garnet amphibolite while the later type are defined simply as amphibolite.

Garnet amphibolite: The modal composition is given in table 7. Garnet is light pink in colour, mostly polygonal with quartz and rarely alkali feldspar development along the fractures. Cummingtonite is light green in colour, slightly pleochroic with a large axial angle (approx. 70°) and positive sign. Plagioclase is highly cloudy because of the turbidity due to the development of kaoline. Zoisite occassionally encircles the garnet grains.

Amphibolite: A green hornblende, pleochroic from dark-green to light yellowish-green is the most abundant mineral which ranges from 50 to 80 percent in the thin sections. In some hornblende crystals minute quartz grains are embedded. Zoisite usually develops rims around hornblende while distinct thick bladed crystals are not uncommon. The amount of zoisite varies from 8 to 22 percent. It is colourless in thin section with a high relief and normal interference colour (middle first order). Zoisite also occurs as granular aggregate produced by the hydrothermal alteration of plagioclase in these rocks. In such cases it is intimately associated with muscovite and calcite.

Microgabbro: It is a medium to fine grained rock with ophitic texture and consisting of 73 percent plagioclase (labradorite) and 23 percent hornblende. Zoisite, ilmenite and sphene are accessory minerals. Calcite occurs as fracturefills. Plagioclase is slightly zoned and turbide at the more calcic core. Hornblende is mostly fresh but some crystals have been altered to a fibrous and colourless amphibole.

Epidiorite: It is a medium grained rock in which the original constituents have been replaced by colourless to pale green fibrous amphibole, calcite, zoisite and chlorite. There is no doubt to the identity of finely divided zoisite which is produced by the alteration of plagioclase and renders the original plagioclase grains semi-translucent under a low magnification.

In some cases when only the central portion of the plagioclase grains are affected by the hydrothermal alteration (epidotization) the plagioclase is lath-shaped with albite twining, but with more advance alteration these are completely replaced by zoisite and epidote with little sericite. Identification in case of drastic alteration of plagioclase is made only by their shape and not by their substance.

The amphibole is pale green in thin section with faint pleochroism and consists of closely packed fibers and shreds of actinolite associated with calcite. It is seen occassionally as a mere fringe of acicular crystals.

Quartz exists in two distinct forms, firstly as clear distinct crystals and secondly as interstitial material with rod-like aggregates of incipient crystals. Flaky chlorite crystals in interlocking aggregates are common in thin section.

Skeletal crystals of an opaque mineral are frequently seen in the thin section. In the initial stages of alteration it exhibits a whitish alteration margin. Sometimes the crystals are completely replaced by a grey-brown translucent material with high relief and traversed by bars of iron oxide. Such is the behavior of ilmenite in igneous rock.

The occurrence of rock as a dyke, the presence of ilmenite and the hydrothermal alteration of the original constituents into amphibole, less basic plagioclase (oligoclase), zoisite, epidote, calcite and chlorite, suggest that the rock would have been of gobbroic composition which has been transformed into epidiorite.

Porphyritic microtonalite: These rocks are light - grey in colour with a white shade and scattered minute dark spots.

In thin section the rock is strongly porphyritic, phenocrysts of plagioclase and quartz are embedded in a microcrystalline groundmass of plagioclase, quartz and chlorite. Alkali feldspar, sphene and opaque grains are present in accessory amount in the groundmass. The plagioclase as phenocryst is fresh, unzoned, well-shaped and exhibits albite twining. It is andesine with An 42 percent. The quartz phenocrysts have corroded margins and are inclusions free. Some of these give typical hexagonal basal sections. Dark-green coloured chlorite is the only ferromagnesian mineral present in the groundmass. Plagioclase and quartz constitute 70 and 30 percent of the phenocryst phase respectively. Groundmass contains plagioclase and quartz slightly less than the above proportions but in addition it shows approximately 10 percent chlorite, sphene and opaque minerals and 5 percent alkali feldspar. On the basis of proportions of the phenocryst minerals, the rock corresponds to a tonalitic composition and has been named as prophyritic microtonalite.

Acidic Lavas: The rock is reddish-brown in colour with a rough fragmental shape and has inclusion of greyish-white rock fragments. At places it exhibits vesicles with characteristic ragged outlines in thin section. Under microscope the rock exhibits phenocrysts of quartz and plagioclase and very rarely alkali feldspar. The nearly glassy groundmass is studded with brown dust-like particles which impart a brownish colour to the rock in hand specimen. Sphene and tiny opaque grains are also present in the groundmass. On the basis of the presence of both quartz and plagioclase as phenocrysts and the marked predominance of plagioclase over K-feldspar, the rock could be described as dacite or rhyodacite. A chemical check is desireable, however, for the final confirmation.

TABLE 7. Modal composition of the five studied samples of metamorphic and igneous rocks.

Minerals	1	2	3	4	5
Garnet	25	...	...	...	...
Cummingtonite	15	...	...	...	...
Hornblende	...	50	82	23	—
Actinolite	...	...	...	...	25
Plagioclase	50	15	8	73	65
Quartz	6	...	2	...	...
Zoisite	...	22	5)	...	...
Epidote	...	...	...)		
Chlorite	...	...	...)	3	10
Opaque	...	5	3)		
Calcite	...	...	...	1	...
Sphene	...	...	—	...	...
Orthoclase	4	...	...	...	...
Muscovite	...	8	...	...	...

1. Garnet amphibolite.
2. and 3, Amphibolite.
4. Microgabbro.
5. Epidiorite.

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