CHAPTER IV

ROCK TYPES

In this chapter, an account of the petrographic characteristics, geochemistry and the nature of the original sediments of the various rock types occurring in the study area, have been discussed. The dolomites have been described in a separate chapter (Chapter VII). Similarly, basic volcanics (spilites) that are occurring in Kusma Unit have been dealt with separately in detail in one of the chapters to be followed (Chapter VIII).

KUSMA UNIT

The rocks of Kusma Unit have been found to comprise following main lithological types :

1. Quartzites (Kusma Quarzite)
2. Gritty quartzose phyllites ⎫ Balewa
3. Quartz - sericite phyllites ⎭ Formation.

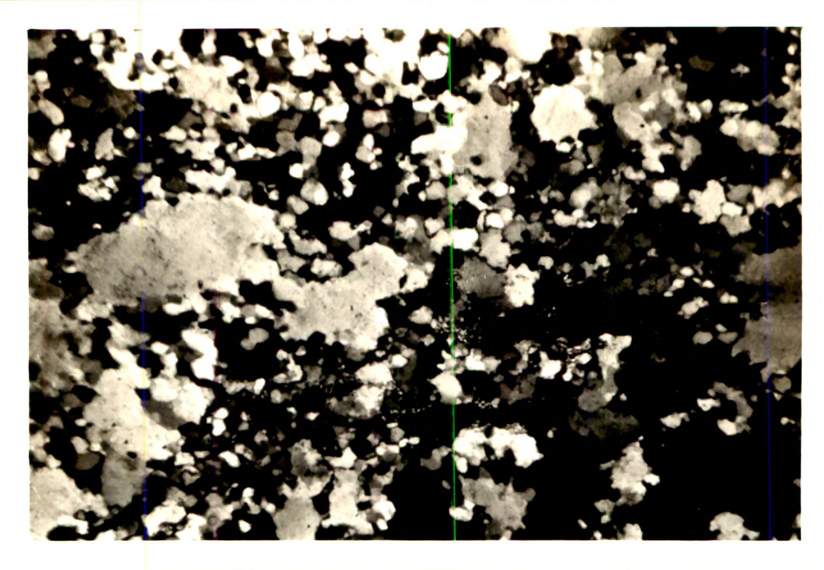
Quartzites

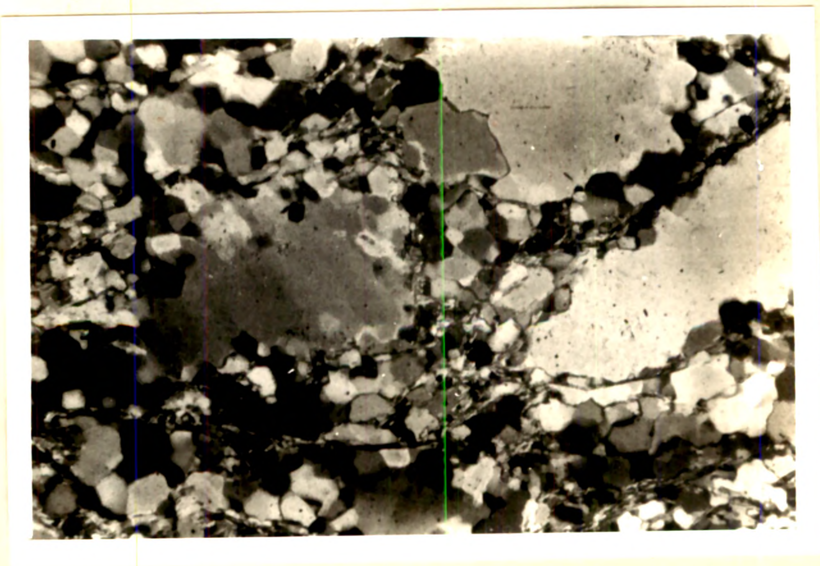
These are highly siliceous rocks, almost entirely made up of quartz, and occur in the field as massive, thickly bedded, hard compact rocks, interspersed with layers of micaceous flaggy quartzites. In thin sections, they have been found to comprise three varieties :

1. Exclusively quartzose, showing an interlocking mosaic of quartz grains that show a considerable variation in the grain size. These rocks give an overall impression of recrystallized cherts with lenses and patches of coarser grains of quartz (Plate IV.1A). Some of the thin sections contain irregular streaks of chloritic material. These streaks show a roughly parallel orientation and might represent some basic volcanogenic material.

Plate IV.1A Photomicrograph of quartzite (Kusma Quartzite) showing interlocking mosaic of quartz (crossed nicols, x 50).

Plate IV.1B Photomicrograph of quartzite (Kusma Quartzite) showing gritty nature (crossed nicols, x 50).



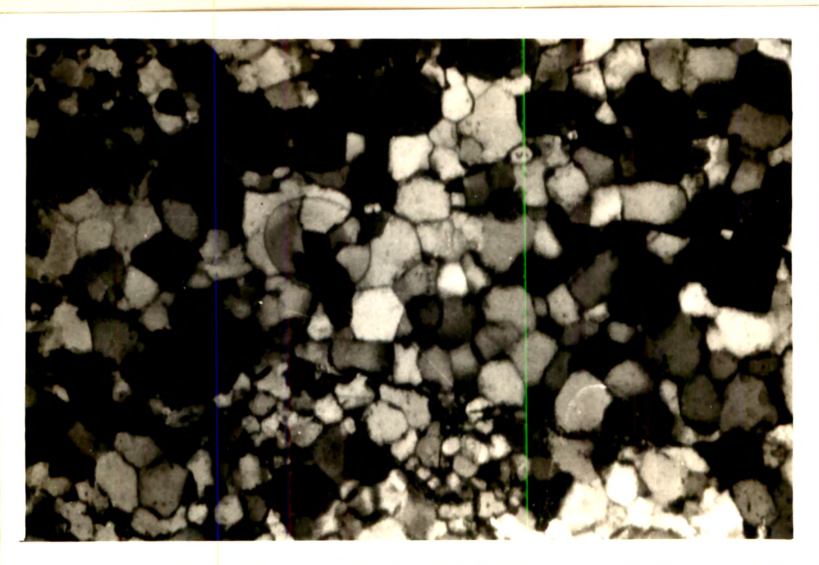


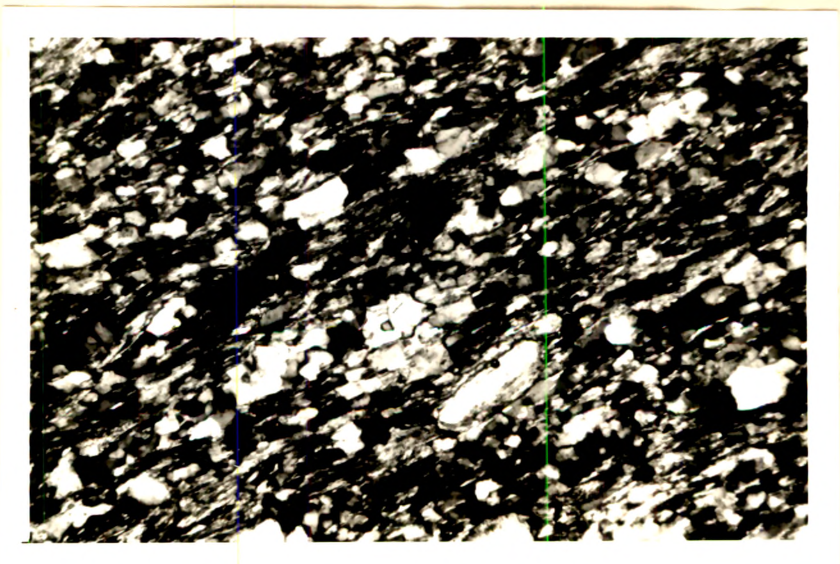
2. Exclusively quartzose but showing a fine to medium grained equigranular aggregate of quartz in which occasionally bigger quartz grains are embedded. These appear to have derived from sandstones which could be considered as quartz arenite, consisting of almost exclusively quartz grains (Plate IV.1B). Occasionally, coarser grains are dominant and reveal their original gritty nature.

3. Containing variable proportion of argillaceous matter in the matrix. Thin sections show equigranular aggregates of quartz with intervening spaces filled by recrystallized argillaceous material, which is now seen as thin flakes of chlorite and sericite. Sporadic development of muscovite is also observed. The micaceous and chloritic flakes show a faint parallelism. The quartz grains show lack of suturing and exhibit sharp boundaries with triple junctions (Plate IV. 2A). With increasing argillaceous content the chlorite and sericite form well defined streaks and the rocks tend to be distinctly foliated (Plate IV.2B).

Plate IV.2A Photomicrograph of quartzite (Kusma quartzite) showing equigranular aggregate of quartz with triple junctions (crossed nicols, x 75).

Plate IV.2B Photomicrograph of well foliated micaceous quartzite (Kusma Quartzite) (crossed nicols, x 50).





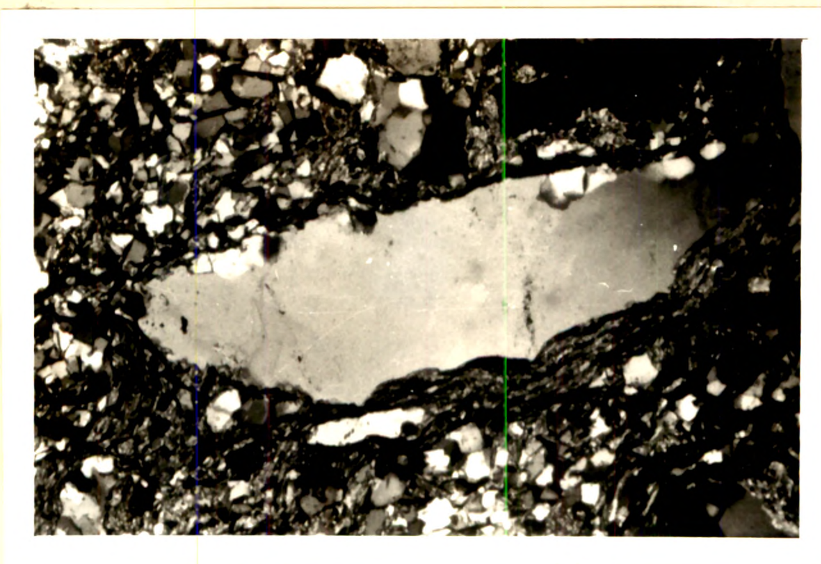
Gritty Quartzose Phyllites

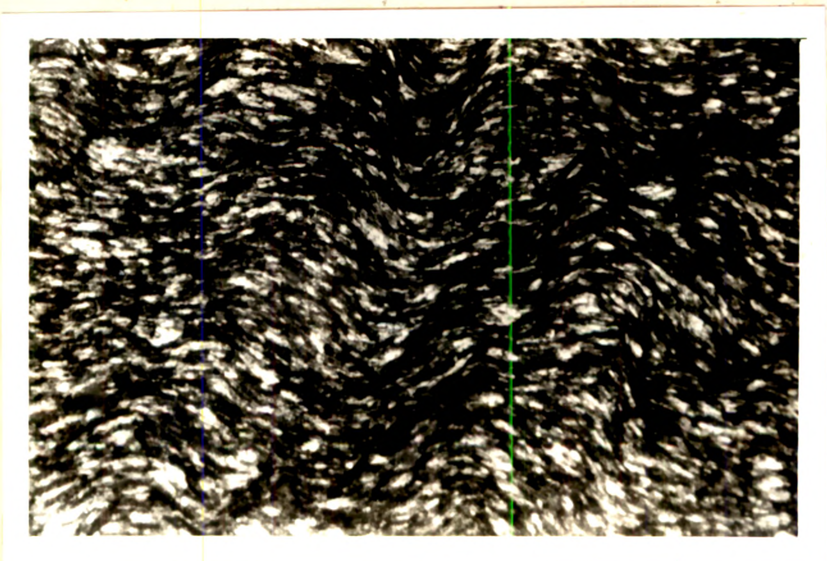
These are yellowish-green to light bluish-green rocks showing a well defined foliation. The overall greenish colour is due to chloritic content. The gritty nature is seen both in hand specimen as well as under the microscope. Thin sections reveal a characteristically foliated mass comprising streaks and thin tufts of muscovite and chloritic-biotite with small quartz grains, associated intimately. Within this foliated mass are interspersed bigger grains of quartz and sometimes felspars (both K-felspar and plagioclase) (Plate IV.3A). These bigger grains obviously represent the original clastic fragments embedded in a matrix which consisted of argillaceous and siliceous material. The original rocks must have been wackes. The foliation is marked by micaceous minerals, and also some of the bigger quartz grains show some elongation in the foliation direction.

Quartz is bimodal, and occurs both as large clastic grains, subangular, sometimes flattened, and in the matrix as small grains. The latter variety is intimately mixed with the micaceous minerals forming streaks parallel to foliation. The micas are sericite-muscovitee and biotite - the former generally predominating. Sericite forms elongate streaks of fine flakes while biotite, which is generally subordinate, is seen as tiny flakes, pleochroic from light yellowish-brown to dark

Plate IV.3A Photomicrograph of gritty quartzose phyllite (Balewa Formation) showing large grain of quartz embedded in a fine matrix of quartz, sericite and chlorite. (crossed nicols, x 75).

Plate IV.3B Photomicrograph of quartz-sericite phyllite (Balewa Formation) with well developed puckering. (crossed nicols, x 75).





greenish-brown. At places, small flakes and patches of green chlorite are seen associated with biotite. Felspars mostly form the bigger grains and comprise both-a plagioclase showing distinct lamellar twinning, and a potash felspar which may show cross-hatching. The matrix also contains sporadically small grains of tourmaline and sphene.

Quartz-sericite Phyllites

This is the most prevalent rock type and occurs in close association with the gritty quartzose phyllite. It forms distinct and widespread intercalations with the above variety, and mainly differs in respect of the near total absence of large quartz and felspar grains. Also the quartz content of the fine grained mass is less as compared to that of the previous variety.

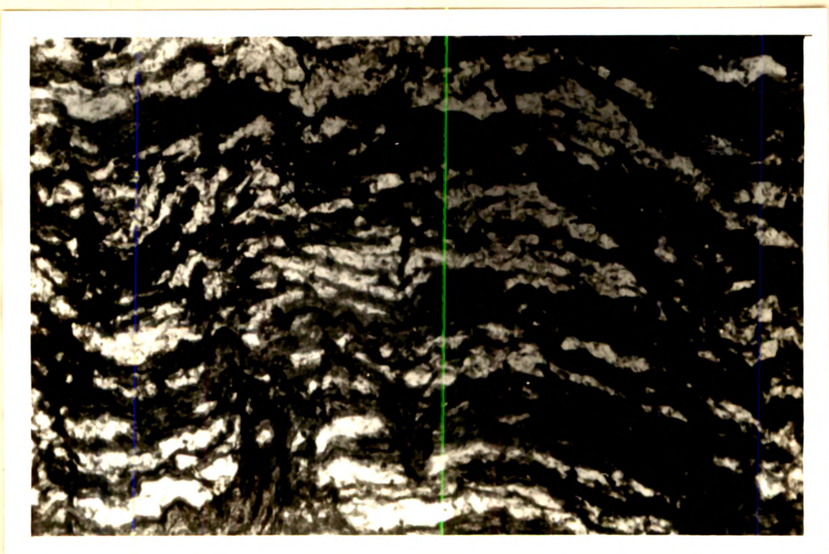
These are essentially low grade metamorphic rocks equivalent to the argillaceous rocks rich in quartz and show distinct phyllitic nature, a foliated and puckered aggregate of quartz, sericite and chlorite (Plate IV.3B). Occasionally, flakes of muscovite are also present. While in most cases, the sericite is dominant over chlorite, a few samples are found to be highly chloritic. Quartz is unimodal and occurs as finely disseminated grains or as well defined streaks. In some cases an alternate layering of quartz-rich and sericite-chlorite rich portions are observed (Plate IV.4). All gradations exist between the above stated varieties and also between the gritty-quartzose phyllites at one end with the chlorite-sericite phyllite at the other end.

Nature of Original Sediments

The depositional features and lithology of the rocks of Kusma Unit, point to a sequence from arenaceous to argillaceous, with all gradations in between. The lowermost beds (Kusma Quartzite) are dominantly quartzose-thick quartzitic layers with occasional thin argillaceous layers. The quartzitic layers represent : (i) Recrystallized cherty rocks, which have been described as colloidal silica by Stocklin & Bhattarai (1977). Perhaps these could represent original cherts that are of common association with spilites (ii) The typical arenites which are now represented by a coarser grained quartzite clearly indicate their clastic origin and exhibit all the textural and depositional features, including ripple marks, cross-bedding etc. In flaggy quartzites, the sericite and muscovite represent the original argillaceous matrix of the arenites.

Upward, in the Balewa Formation, a progressive increase in the micaceous and chloritic minerals (derived from the original argillaceous component) is observed. It appears

Plate IV.4 Photomicrograph of phyllite (Balewa Formation) showing alternate layering of quartz-rich and sericite-chlorite-rich bands (crossed nicols, x 75).



that while the gritty quartzose phyllites have been derived from a coarser sediments, the quartz-sericite phyllites represent comparatively finer sediments. The exclusively argillaceous layers which are now represented by very fine-grained phyllites must have developed from the shaly intercalations in the original sandstones.

The chemical analyses of the gritty quartzose phyllites (Table IV.1) are comparable with the mean composition of graywackes (Pettijohn, 1975, P.228) and arkose (Pettijohn, 1975, P. 210). On the basis of the petrographic studies, it is obvious that these gritty quartzose phyllites are undoubtedly derived from an originally wacke type of rocks. The chemical analyses also point to the similar conclusion. However, the true nature of these original sediments is very difficult to infer as they have been considerably modified due to the effects of the metamorphism. Moreover, there could be more than one variety of these wacke rocks. But, to some extent, on the basis of the chemical analyses of the two representative samples and also considering the nature of the clastic fragments (quartz, felspars) and the matrix in which they are embedded, it has been possible to deduce that the original rocks must have been a felspathic wacke and more closer in composition to an arkosic wacke (Pettijohn, 1975, P. 214). This fact is indicated by the higher percentage of K_2O content than that in the average graywackes. However, it may be pointed out that, though the

Table IV.1 Chemical composition of gritty quartzose phyllite compared with the average Graywacke and Arkose.

Constituents	Gritty quartzose phyllite (study area)		Graywacke (Pettijohn, 1975, p.228)			Arkose (Pettijohn, 1975, p.210)
	3.96	1197	A	B	C	
SiO_2	79.47	76.00	76.84	74.43	71.10	77.1
TiO_2	0.00	0.84	-	0.83	0.50	0.3
Al_2O_3	11.81	10.92	11.76	11.32	13.90	8.7
Fe_2O_3	1.48	3.30	0.55	0.81	trace	1.5
FeO	0.37	0.39	2.88	3.88	2.70	0.7
MnO	-	-	trace	0.04	0.05	0.2
MgO	1.10	1.56	1.39	1.30	1.30	0.5
CaO	0.36	0.15	0.70	1.17	1.80	2.7
Na_2O	0.28	0.85	2.57	1.63	3.70	1.5
K_2O	3.28	3.21	1.62	1.74	2.30	2.8
H_2O^+	-	-	1.87	2.15	1.90	0.9
H_2O^-	-	-	-	0.20	0.26	-
P_2O_5	-	-	-	0.18	0.10	0.1
CO_2	1.74*	2.28*	-	0.48	0.12	3.0
S	-	-	-	0.12	trace	-
C	-	-	-	0.17	0.09	-
Total	99.89	99.50	100.18	100.45	99.82	100.0

* Loss on ignition. Analyst : B. N. Upreti.

chemical composition points the original rock to be felspathic wacke, the rock at this stage does not contain any appreciable amount of felspars that are typically found in a felspathic wacke. This could be conveniently explained by the possible breakdown of the felspars to sericite, except for the larger clastic grains that have survived.

It is interesting to observe that this shallow water sequence is associated with well defined spilitic volcanism.

SIRKANG UNIT

As already stated, this unit to the south of Phalebas Thrust, comprises a very feebly metamorphosed sequence, consisting of carbonaceous slates, bluish-gray stromatolitic dolomite, sandstones, purple slates and phyllites with intercalated thin layers of pink dolomite. The stromatolitic dolomites have been described in detail in Chapter VII, and here a brief petrological account of the remaining rock types has been given.

Carbonaceous Slates

These are dark gray, fine grained rocks with a well defined slaty cleavage that marks the axial plane of the isoclinal folds shown by these rocks. Occasional bands of light coloured material typically reveals the sedimentary layering. In thin sections, the carbonaceous layers do not reveal anything, while the light coloured slates show a very fine faintly foliated aggregate. The stromatolitic dolomites, also reveal very little information in thin sections.

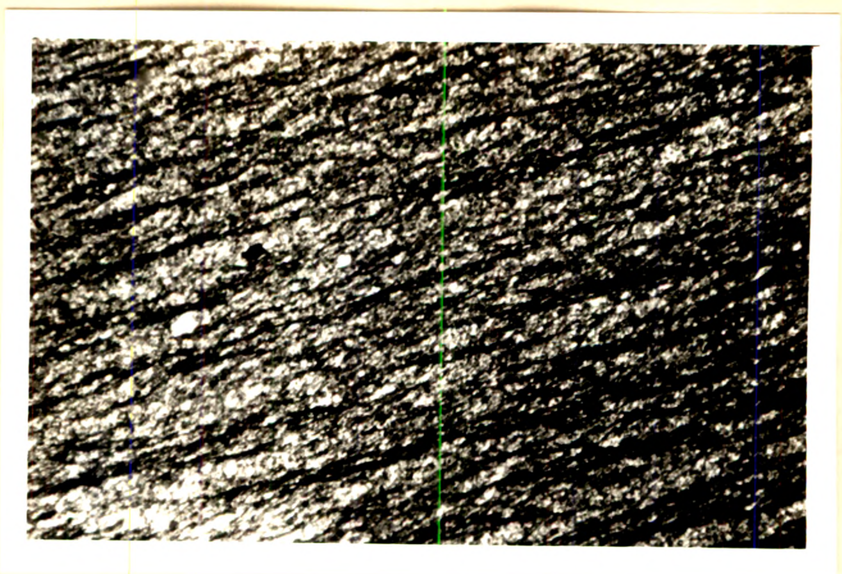
Metapelites

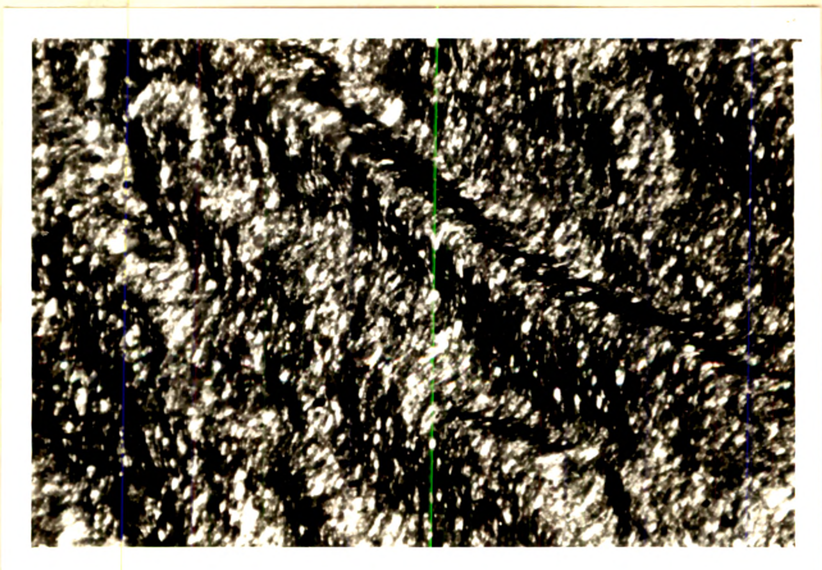
The slates and phyllites of Sumsa Formation, are invariably interbedded with the thin bands of pink dolomite and sandstones. In general, these metapelites are fine-grained and show well developed cleavage planes, due to the abundance of phyllosilicates (phengites + chlorites). Biotite is entirely missing. However, in some varieties which are better recrystallised, tiny flakes of muscovite have been noticed. On the basis of the megascopic as well as microscopic characters the metapelites could be grouped into (a) slates (b) phyllites.

The slates are distinguished from phyllites mainly on the basis of their crystallanity and physical appearance in hand specimen. They are dull and very fine-grained and lack the silky lustre of phyllites. Under microscope, the slates show incipient recrystallisation. The individual phyllosilicate minerals are indistinguishable and they form a uniform groundmass (Plate IV.5A). Quartz grains and phyllosilicates are not easily separable and are indistinct. But nevertheless, the phyllosilicates show a prominent orientation. Under crossed

Plate IV.5A A photomicrograph of slaty rock (Sumsa Formation). Cleavages are conspicuous. (crossed nicols, x 50).

Plate IV.5B A photomicrograph of phyllite of Sumsa Formation. (crossed nicols, x 50).





nicols, and on rotating the stage to positions showing high interference colours of the phyllosilicates, the orientation of the minerals could be noticed. One of the characteristic features of the slates is the strong development of slaty cleavage, due to which the rock splits into very thin slabs. The colour of these slates ranges from light gray to dark gray and purplish. The purple colour may be due to some ferruginous content.

Phyllites, on the other hand, are well cleaved with a characteristic silky lustre. Under the microscope, these rocks are seen to be better crystalline than the slates, and in which the individual micaceous minerals could be easily distinguished (Plate IV.5B). Quartz grains are distinct and recrystallisation is widespread showing sutured outlines. The phyllosilicates show strong parallalism. Many a times quartz also shows streaky nature conformable with the general alignment of the other minerals. In these phyllites, the phengites and chlorites have been formed at the expense of the original clay minerals due to metamorphism, whereas, some of the larger quartz grains still show their detrital nature. Chlorites occur as linear patches and show a preferred orientation. They show the pleochroism from pale yellowish-green to green. A few small rounded grains of tourmaline are also seen.

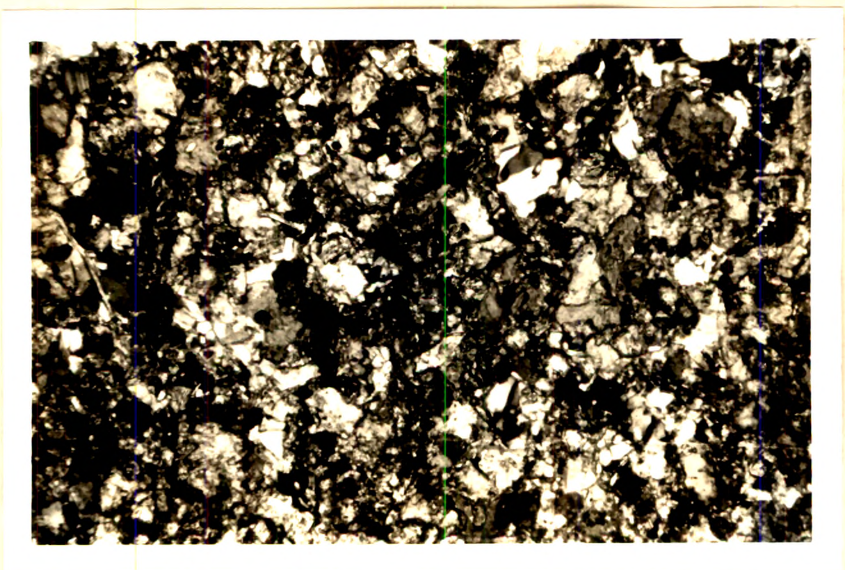
As these rocks are affected by various generations of folds, small isoclinal folds and superimposed micropuckers are very well preserved. Under the microscope, the micro-puckers and crenulation cleavages are clearly visible. Sometimes along these cleavages, which are developed along the crests of the micropuckers, alignment of new set of minerals are observed. They are mostly occupied by iron oxides.

The phyllites can be further subdivided into (a) quartz phyllites and (b) dolomitic phyllites. In case of the quartz phyllites, the proportion of quartz exceeds the phyllosilicates but still the phyllitic nature is well exhibited. In case of dolomitic phyllites, the rock consists of phyllosilicates and quartz along with fine grained carbonate minerals (mostly dolomite). Even these carbonate minerals show strongly preferred orientation. The phyllitic rocks sometimes show banded nature where very thin microscopic bands of predominantly siliceous layers and phyllosilicate layers are observed (Plate IV.6A). In such cases the foldings are more conspicuous. The crenulation cleavages are, however, visible only in the phyllosilicate layers. The siliceous layers show mosaic texture of quartz. In the upper section of the Sumsa Formation, the phyllites are dark gray to gray in colour.

The chemical composition of metapelites of study area and the average composition of the slates and phyllites as given by different

Plate IV.6A Photomicrograph of phyllite (Sumsa Formation) showing distinct differe-ntiated bands of siliceous layers and phyllosilicate layers (crossed nicols, x 50).

Plate IV.6B Photomicrograph of siliceous dolomite (Sumsa Formation) showing fine grained aggregate of dolomite and quartz (crossed nicols, x 50).



authors are shown in table IV.2. The chemical analyses of the slates and phyllites of the Sumsa Formation, when compared with the average chemical composition of similar rocks from elsewhere show that the former are more or less comparable with the latter. But a distinct difference is observed in the case of potash content of the metapelites of the study area. Most of them show over 6 % K_2O content. Therefore, they may be considered as the metamorphic equivalent of the slightly potassic shale of Pettijohn (1975, P. 287). In case of sample No.24 (purple slate), Fe_2O_3 is high due to its slightly ferruginous nature. Alumina is more or less similar to the average values. The relation between the weight percent of Na_2O and K_2O is shown in Fig. IV.1. The compositions of these rocks also do not vary much from that of the composition of average shale, indicating that no significant readjustment of chemical components occurred during their regional metamorphism.

Siliceous dolomite

These purple rocks (in hand specimen) intimately alternating with purple and gray slates, under microscope show a finegrained aggregate of dolomite and quartz (Plate IV.6B). The proportion of quartz varies considerably and is found to be of two types - detrital and authigenic. The detrital quartz grains are of silt size and finer.

Table IV.2 Chemical composition cf metapelites of the study area compared with the average slates and phyllites

Constituents	Study area							
	8B	24	184	1163	A*	B*	C*	D**
SiO_2	65.05	60.13	64.80	64.80	64.9	60.4	64.0	58.10
TiO_2	0.00	0.00	0.83	0.83	0.9	0.8	-	0.65
Al_2O_3	18.90	17.32	16.68	14.33	17.3	18.5	20.2	15.40
Fe_2O_3	2.27	8.56	4.11	4.85	2.9	4.1	-	4.02
FeO	0.08	0.12	1.88	1.24	3.8	6.7	7.0	2.45
MnO	-	-	-	-	-	0.1	-	-
MgO	3.44	3.27	3.35	3.71	3.1	2.7	2.2	2.44
CaO	0.35	0.63	0.77	0.98	1.1	1.1	0.4	3.11
Na_2O	0.34	0.23	0.21	1.14	2.7	1.3	1.5	1.30
K_2O	6.20	6.73	4.53	5.28	3.3	4.1	4.7	3.24
P_2O_5	-	-	-	-	-	0.2	-	0.17
H_2O^+	-	-	-	-	-	-	-	5.00
H_2O^-	-	-	-	-	-	-	-	
CO_2	-	-	-	-	-	-	-	2.63
SO_3	-	-	-	-	-	-	-	0.64
Organic	-	-	-	-	-	-	-	0.80
Loss on ignition	2.72	2.68	3.28	1.96	-	-	-	-
Total	99.35	99.67	100.44	100.12	100.00	100.0	100.0	99.95

Analyst : B.N.Upreti

* Average chemical composition of slates and phyllites (cf. Huang, 1962, P.397).

** Average chemical composition of shale (cf.Pettijohn, 1975, P.286).

The development of authigenic quartz is seen to be due to the replacement of dolomite. It shows a typical replacement texture (Plate IV.7). Many a time, lenses of finely recrystallised argillaceous material are found to occur within these siliceous dolomites. Sometimes, graded beddings are also observed in the thin sections.

SANDSTONES

The sandstones of the Sirkang Unit are interbedded with argillaceous rocks like slates and slaty phyllites. These are confined to the Sumsa Formation which lies above the Phoksing Dolomite. The thickness of the individual bands of sandstones is quite variable ranging from a few centimeters to as much as few meters and sometimes upto 100 m. The thinner bands of sandstones are finely intercalated with slates and slaty phyllites. The dolomitic sandstones and siliceous dolomites are mostly found intercalated with purple slates. These sandstones and slates are sometimes very thinly interbedded and occasionally form lenses within each other. The dolomitic sandstones and siliceous dolomites are purplish in colour and readily give effervescence with dilute hydrochloric acid.

On the basis of modal analyses (Table IV.3) and the classification of Pettijohn et al. (1973), the following

Plate IV.7 Siliceous dolomite (Sumsa Formation) showing replacement of dolomite by quartz (crossed nicols, x 50).

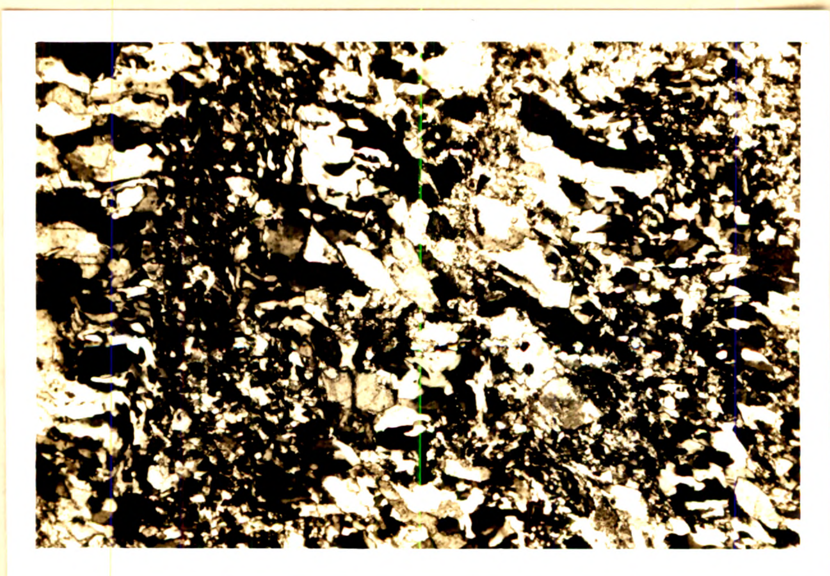


Table IV.3 Modal analyses of sandstones

Sample No.	Quartz	Felspars	Rock fragments	Matrix +cement	Name
28	42.91	4.29	00.48	52.32	Felspathic graywacke
32	75.48	6.29	8.09	10.14	Sublitharenite
34	58.35	1.27	3.81	36.57	Lithic graywacke
149G	93.10	0.98	3.92	2.00	Quartz arenite
201A	51.35	6.19	4.33	38.13	Felspathic graywacke
239A	30.42	5.82	8.50	55.26	Lithic graywacke
263	36.72	5.58	4.18	53.52	Felspathic graywacke
316	25.20	2.10	7.70	65.00	Lithic graywacke
756D	47.38	2.76	4.96	44.90	Lithic graywacke
826	64.88	10.97	15.54	8.61	Sublitharenite

QFR Diagram

	28	32	34	149G	201A	239A	263	316	7560	826
Q	90	84	92	95	83	68	79	72	86	71
F	9	7	2	1	10	13	12	6	5	12
R	1	9	6	4	7	19	9	22	9	17

Q - Quartz F - Felspars R - Rock fragments.

varieties of sandstones have been recorded (Fig. IV.2 , IV.3) :

1. Quartz arenites,
2. Sublitharenites,
3. Felspathic graywackes,
4. Lithic graywackes and
5. Dolomitic sandstones.

Their equivalent names according to Folk et al.'s classification (1970) are shown in Fig. IV.4.

Quartz Arenites

This variety is almost exclusively made up of detrital quartz. Earlier, some workers called such a rock as ortho-quartzite (Tieje, 1921) to distinguish it from the metamorphic quartzite. Krynine (1945) applied this term to sands made up of entirely quartz grains cemented by silica. The term ortho-quartzite was essentially used to distinguish the sedimentary quartzite from that of the metamorphic quartzite. However, since the term was later used loosely and did not truly reflect the original concept of the rock as very hard, highly durable and nonfriable, it has been slowly replaced by a new term quartz arenite suggested by Williams et al. (1954) or quartz-arenite by McBride (1963).

CLASSIFICATION OF SANDSTONES
(PETTIJOHN ET AL., 1973)

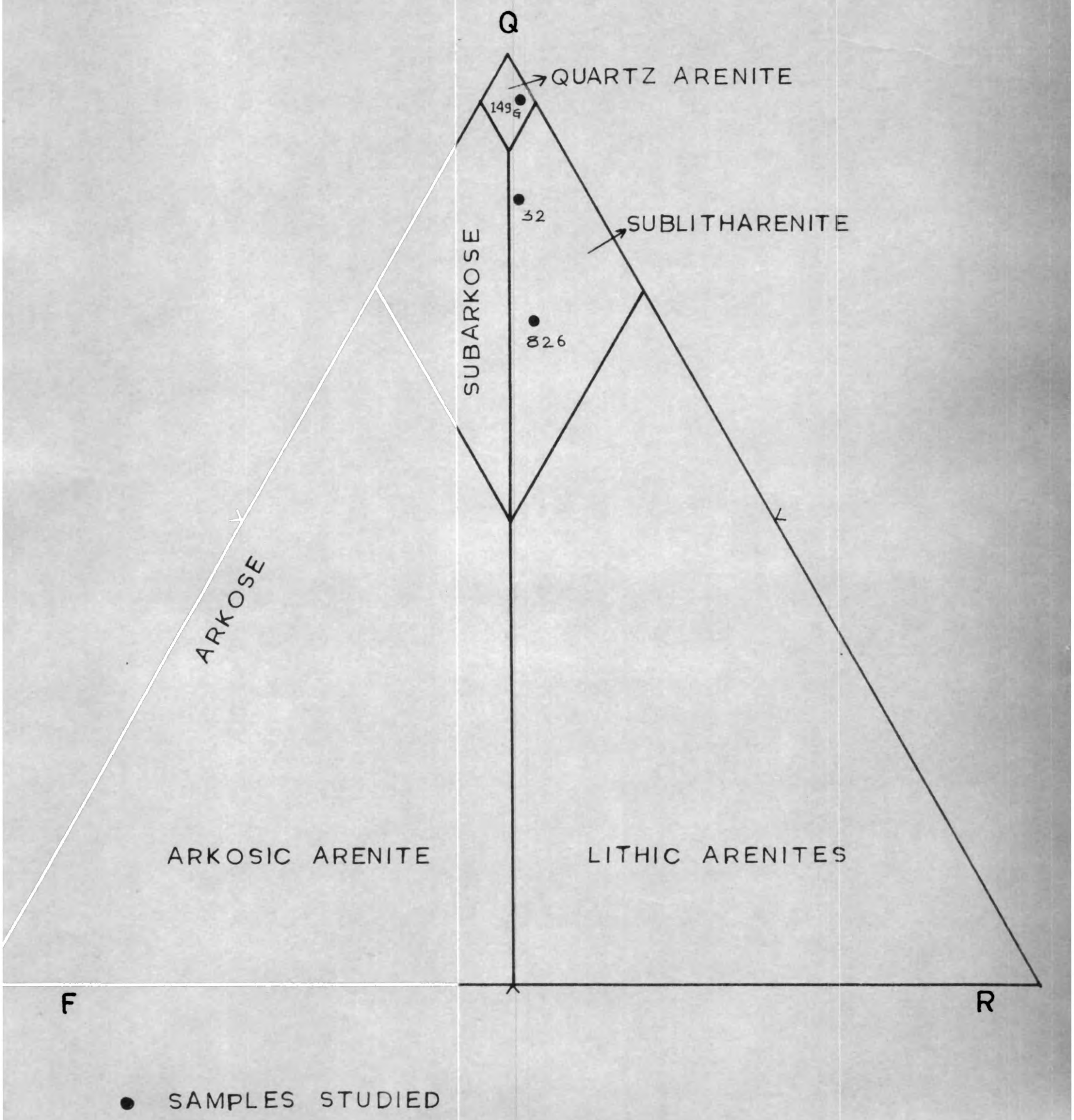
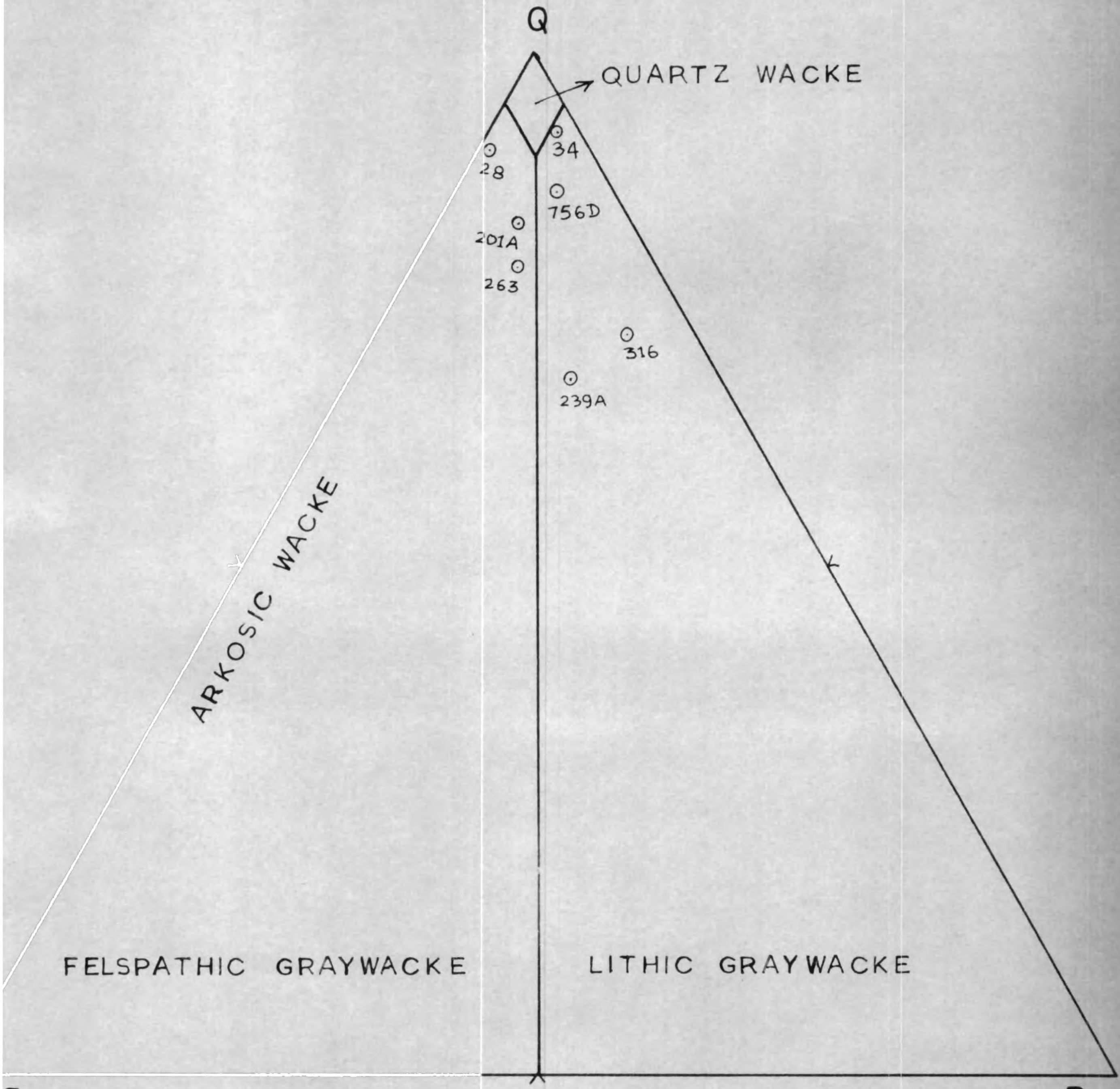


FIG. IV. 3

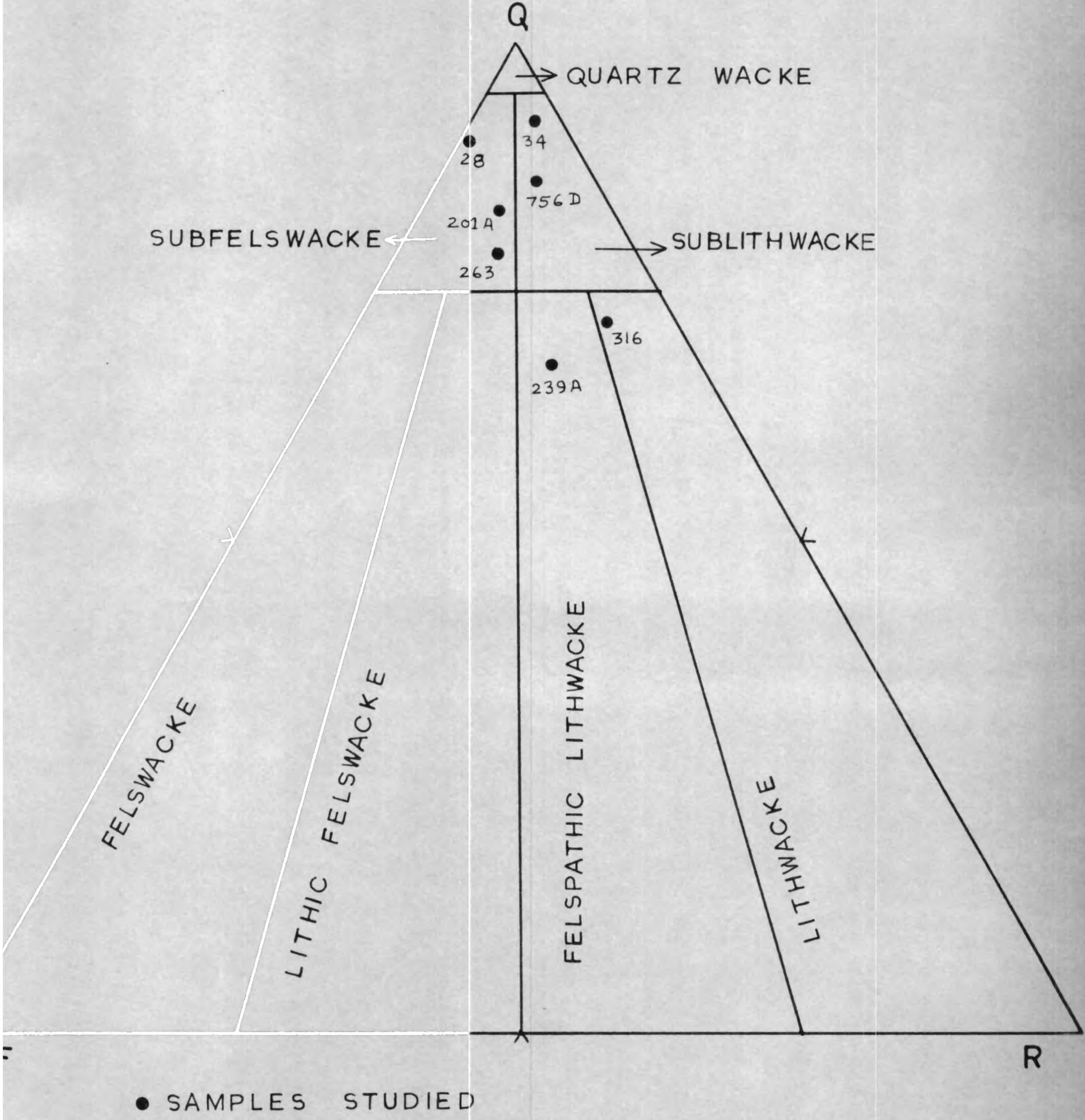
CLASSIFICATION OF SANDSTONES
(PETTIJOHN ET AL., 1973)



⊙ SAMPLES STUDIED

FIG. IV.4

CLASSIFICATION OF SANDSTONES
(FOLK ET AL. 1970)

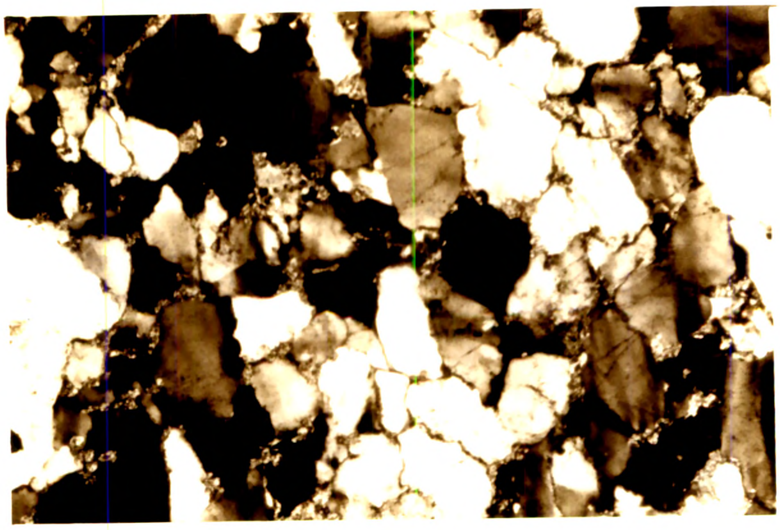


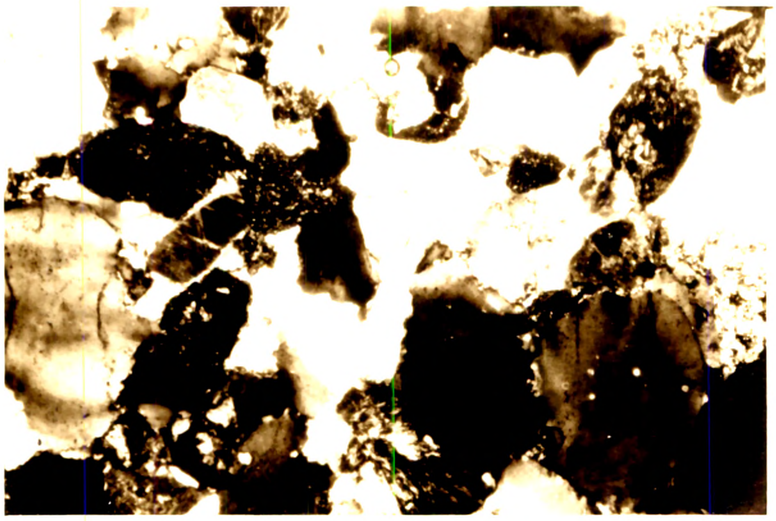
Quartz arenite, as such is not much abundant in the study area and only at a few places its layers are found to occur. One of the good occurrences of these sedimentary rocks are exposed in Purtighat area, on the left bank of the Kali Gandaki river. The rock here is coarse to medium grained and is associated with red shale.

Under the microscope, the rock shows a well sorted nature with negligible amount of matrix. The gains of quartz are subangular to subrounded (Plate IV.8A). Strikingly, the majority of the grains of quartz show undulose extinction. The individual grains are both monocrystalline as well as polycrystalline, though the latter are few in number. The individual quartz crystals of the polycrystalline quartz fragments have sutured contacts with one another. Around quite a few grains of detrital quartz, authigenic development of silica is also observed. This silica constitutes the cementing material, having developed in crystallographic and optical continuity with the detrital grains. Most of such grains, where the enlargement process is due to the authigenic overgrowth of quartz, invariably meet along irregular boundaries and result in the formation of interlocking quartz mosaic. The rounded outline of the detrital grains is still mostly visible due to a thin ring of dust inclusions along the original grain boundary. A few grains of well rounded chert fragments have also been found to occur in this rock type.

Plate IV.8A Photomicrograph of quartz arenite (Sumsa Formation) with sub-rounded grains of quartz (crossed nicols, x 50).

Plate IV.8B Photomicrograph of sublitharenite of Sumsa Formation (crossed nicols, x 50).





The quartz arenites contain approximately 93-94 % of quartz (Table IV.3). Some of the intergranular space is filled by argillaceous material which is converted into fine sericite mica showing streaky alignment. Significantly, no felspar grains are present, and this fact points to a mature nature of the original sediments.

The quartz arenites of the Sirkang Unit though quite subordinate in amount, are important from the point of view of depositional environment. These quartz arenites appear to have been deposited in a shallow marine shelf, where the fine clay matrix was removed easily. This is also supported by the presence of ripple marks in them. The sands were possibly derived from the Indian Shield lying to the south. Valdiya (1970) on the basis of the reconstructions of palaeocurrents came to similar conclusions, in the Kumaon Himalaya.

Sublitharenites

The sandstones which contain a substantial proportion of rock particles and which have little or no matrix material but instead have precipitated minerals (S_iO_2 , Carbonates etc.) have been variously named by different authors. Pettijohn (1949) originally called such rocks as subgraywackes. Later on, he preferred to call them as lithic sandstones (Pettijohn, 1954). The name low-rank graywacke was given by Krynine (1945).

Williams et al. (1954) proposed the term lithic arenite whereas McBride (1963) suggested the name litharenite.

These rocks are essentially matrix-poor sandstones. Unlike quartz arenites, which contain less than 5 % of either felspars, rock particles or matrix, these lithic arenites contain 25 % or more of rock fragments, but a smaller proportion of felspars and less than 10 % of matrix, as suggested by Williams et al. (1954). Sublitharenites may be described as a transitional class of lithic arenites where the rock particles are less than those in litharenites. McBride (1963) gives the modal composition of the sublitharenites as 65 - 90 % quartz, 5 - 25 % rock fragments and 0 - 10 % felspars.

In the present study area, sublitharenites are well exposed in the Luwa Khola section, where they attain a thickness of about 100 m. In Dhullu area, the thickness of these rocks are usually 2 - 3 m.

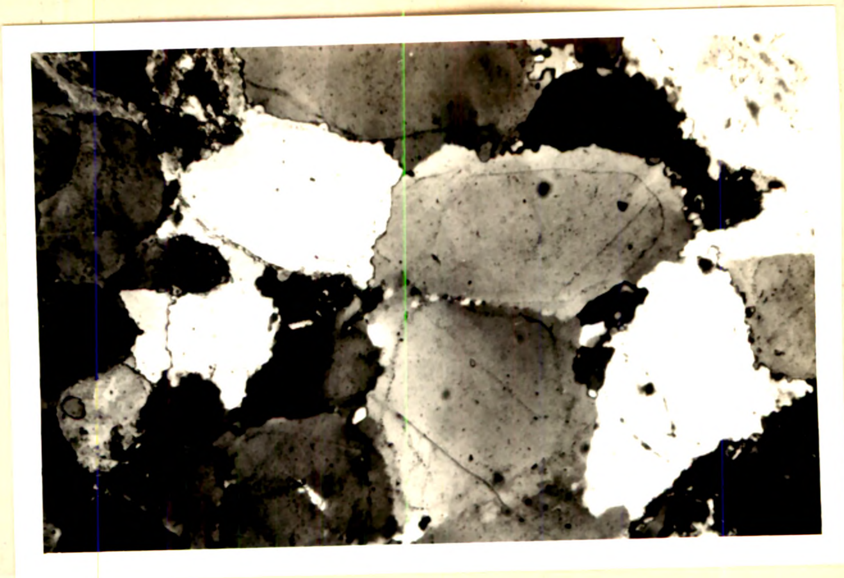
The typical sublitharenite of this area consists of rounded to well rounded grains of quartz, rock fragments and felspars (Plate IV.8 B). They are well sorted and the detrital quartz constitutes 65 - 76 % of the total rock volume (Table IV. 3). The proportion of felspar grains in these rocks is less in comparison to those of rock fragments. The matrix is very poor (8 - 10 %).

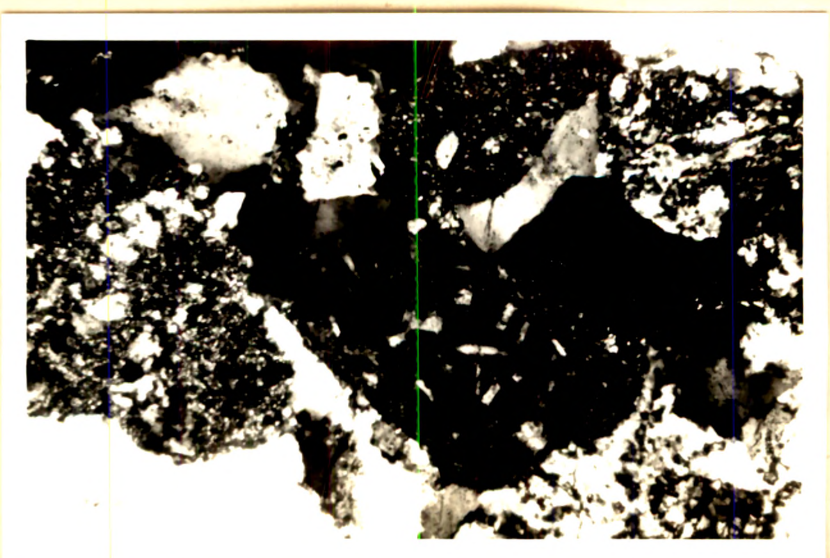
Both monocrystalline as well as polycrystalline quartz grains are present; however, the amount of polycrystalline quartz is less as compared to the monocrystalline variety. The individual quartz grains of the polycrystalline quartz show sutured outline and undulose extinction. The grains of quartz forming the framework, show variety of contacts like long contact, point contact and concavoconvex contact. The detrital grains of quartz and felspar are cemented by secondary quartz overgrowth, where the boundary between the detrital core and overgrowth is very distinct due to presence of dark inclusions along the original smooth outline of the grains. The continuous overgrowth of the secondary quartz around the detrital grains has finally resulted in the formation of interlocking quartz mosaic (Plate IV.9A).

Chert grains are quite common and are subrounded to rounded. These can be easily distinguished under crossed nicols by their microcrystalline nature. The microcrystalline quartz in the chert shows a finely speckled, twinkling appearance. Quite a few grains of chalcedony are also observed and are seen as cryptocrystalline, fibrous or flamboyant silica with the index of refraction lower than that of quartz. In some cases, jasper, a variety of chert, with a brilliant red colour due to the presence of hematite, is also found to occur. Black chert is also not uncommon; this when seen under the polarised light, shows fine inclusions of magnetite.

Plate IV.9A Photomicrograph of sublitharenite (Sumsa Formation) showing overgrowth of secondary quartz in optical continuity with the detrital quartz grain. (crossed nicols, x 50).

Plate IV.9B Photomicrograph of sublitharenite (Sumsa Formation) with basic rock fragments. (crossed nicols, x 50).





It is interesting to observe the detrital orthoclase grains showing occasional authigenic development of felspar (orthoclase ?) rim. Here also, the original rounded grains of felspars are clearly recognised, as the development of secondary overgrowth is not in optical continuity. Among the felspars, orthoclase is most abundant; however, microcline is also occasionally found. These felspars are altered to various degrees ranging from nearly fresh to highly altered grains. They show alteration to kaolinite and sometimes to sericite. Small amount of chlorite has also been developed. Rarely, a few laths of plagioclase are observed.

Rock fragments are another important constituent of the sublitharenites and comprise varieties of rocks. Fragments of slaty and phyllitic rocks are common. They usually show an elongated outline and fine development of sericite mica with a preferred orientation. These are mostly deformed rock fragments and therefore, are spread in the form of pseudomatrix. Some devitrified glass and a few basic rock fragments (? spilites) are also present (Plate IV.93). They were possibly derived from the spilitic lava flows of the Kusma Unit that are older than these sandstones of Sirkang Unit. They are very much altered and it is difficult to find out the original nature of these rock fragments. Some chloritic materials and minute plagioclase grains along with magnetite can be identified in them. These rock fragments are also sometimes squashed,deformed and altered, thus filling up the pore spaces between the more resistant grains of quartz and felspar.

Sublitharenites represent immature sands, requiring conditions favourable for the production and deposition of the relatively unstable minerals. Due to the mechanically weak character of most of the shales, slates, phyllites and basic igneous rocks, they are doubtful tc survive prolonged action of transport. Therefore, they may be indicators of relatively local provenance perhaps even within uplifted parts of the same sedimentary basin (Pettijohn et al. 1973).

WACKES (GRAYWACKES)

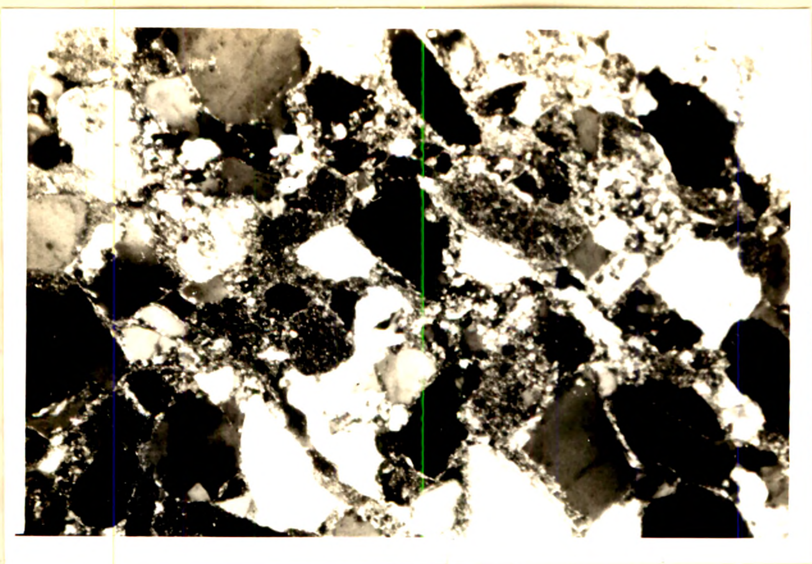
The term graywacke has been variously defined since the inception of this word by Lasius in 1789 who used this term for the dark, tough Palaeozoic Kulm sandstones in the Harz Mountain of Germany (cf. Pettijohn et al., 1975). However, subsequently more precise definitions were proposed by various authors depending upon the quantitative measurements of the proportions of the matrix and the labile components like felspars and rock fragments. Krynine (1945) used the term graywacke to denote a rock with substantial amount (20 % or more) of rock fragments like chert, slate, schist and phyllite. Pettijohn et al. (1973, P.155) redefined the term graywacke, and on the basis of framework grains of quartz, felspars and rock fragments and also taking into account of the matrix, have classified the sandstones into two main groups viz. 'clean' sands or arenites (sands with less than 15 % matrix) and the 'dirty' sands or wackes (those with more than 15 % matrix). The wackes are further subdivided as lithic graywacke, felspathic graywacke, arkosic wacke and quartz wacke.

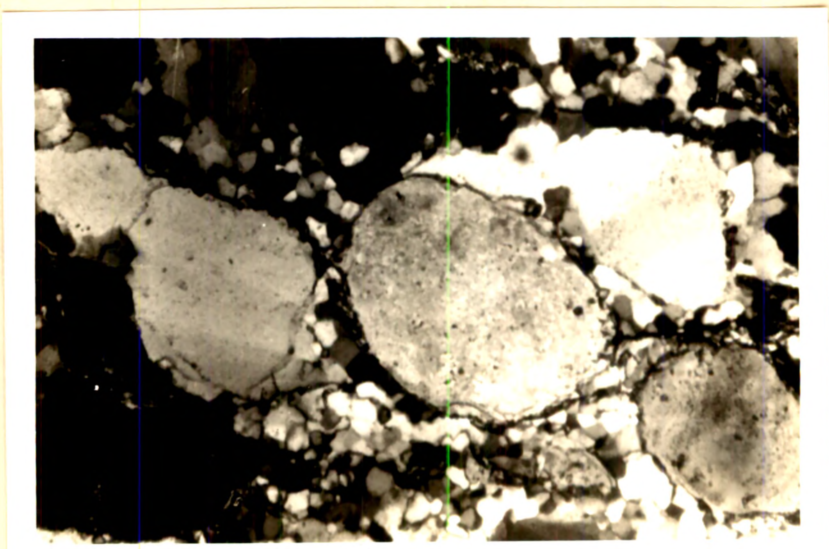
The wackes of the study are have been found to belong to the categories of lithic graywacke (Plate IV.10A) and felspathic graywacke (Plate IV.10B). They have been differentiated on the basis of the relative proportions of lithic fragments and felspars (Fig. IV.3). They constitute different parts of the same formation and sometimes even grade from one to another variety.

The sand fraction in these wackes is rich in quartz, and constitutes 25-58 % of the total rock volume. The proportion of matrix also varies very much ranging from nearly 36 % to as high as 65 % in some cases. But in case of such high percentage of matrix, it is likely that they may not truly represent the matrix percent and part of it might constitute the squashed rock particles. The sizes and shapes of the detrital grains also range within a wide limit. These rocks sometimes look like microbreccia due to the very sharp, angular quartz and felspar grains embedded in the matrix of fine quartz, chlorite and sericite. It is very difficult

Plate IV.10A Photomicrograph of lithic graywacke of Sumsa Formation. (crossed nicols, x 50).

Plate IV.10B Photomicrograph of felspathic graywacke of Sumsa Formation (crossed nicols, x 50).

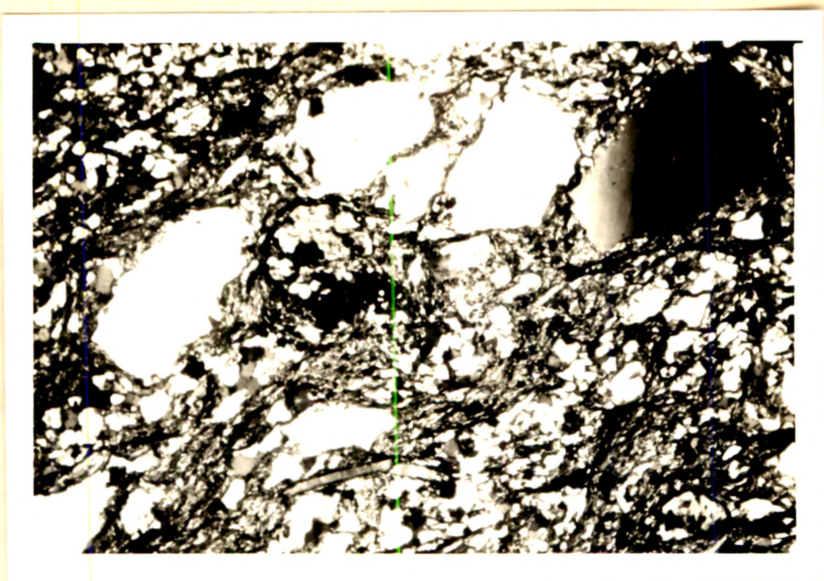




sometimes to distinguish between the deformed and squashed rock particles of pelites and metapelites from the sericitic matrix. The alignment of the folia of sericite and chlorite and somewhat faint relict grain boundary usually help to distinguish between the two. The sorting is very poor, and the sands are held together by a fine grained matrix consisting of an intermix of chlorite, sericite and minute silt-sized particles of quartz and occasionally felspars. It is usually observed that finer the detrital grains, higher is the matrix content.

Quartz The angular to subangular quartz grains embedded in the matrix of sericite, chlorite and fine grained quartz, are the main detrital sands of these wackes. Due to high matrix content, the percentage of grain to grain contact is very poor and therefore, floating grains of quartz and felspars are most common. Perhaps due to the effect of deformation, the micaceous minerals and sometimes quartz grains show a preferred orientation. The sericite mica is found to replace the detrital quartz grains and the original water-worn boundaries of quartz are mostly obliterated, the existing boundary being indistinct (Plate IV.11). This phenomenon has been described as the 'Chevaux - de - Frise' by Krynine (1940). Here, the sericite and sometimes the chlorite crystals project into the clear quartz grains. Similar observations have also been made by

Plate IV.11 Photomicrograph of wacke (Sumsa Formation) showing partial replacement of quartz by sericite (crossed nicols, x 75).



Pettijohn (1975, P.228) and williams et al. (1954, P.298). In contrast to the quartz arenites and sublitharenites, the wackes show very less authigenic development of silica.

Felspars The clastic grains of felspars are another important constituent of the graywacke. The proportion of the felspars to rock fragments increases from the lithic to the felspathic graywacke. Potash felspar is the chief variety of felspar. However, a few grains of plagioclase are sometimes present in these rocks. Invariably, potash felspar shows some clouding, and sometimes a conspicuous alteration to sericite and kaolinite.

Rock fragments Rock fragments are always present in these wacke rocks, and comprise basic igneous rocks, slates and phyllites, etc. The basic rock fragments are highly weathered, and can only be identified due to their dirty black and greenish mass in the polarised light as well as their definite grain boundaries to prove that they are detrital in nature. Slates and phyllites are among the most common rock fragments of these graywackes. They show various sizes and shapes. Though most of the slates and phyllitic rock fragments are deformed and squashed, rendering it difficult to distinguish from matrix, the foliation planes marked by the orientation of sericite mica and their distinct grain outline indicate their clastic origin.

Chert fragments are also found in appreciable amount in these rocks. They are rounded to subrounded and consist of aggregates of microcrystalline silica. Black ferruginous cherts are rather common. In few cases the clastic grains of tourmaline and zircon are observed. They show better roundness than the other detrital grains.

The petrographic study of the wackes of Sirkang Unit is important from the point of view of the reconstruction of environment of deposition. The widespread occurrence of sun-cracks and ripple marks on these graywackes indicate that they were deposited in shallow water conditions. The wide variations in the thickness of the purple slates, dolomitic sandstones, siliceous dolomites and graywackes and their intimate associations and alternations indicate a changing depositional environment, influenced by tectonics geochemistry and source area. The presence of weathering-prone rock fragments like those of basic igneous rocks, is indicative of the nearness of provenance. All these suggest that these rocks were deposited in a shallow water environment and the constituent materials may have been derived from a proximal site.

Dolomitic sandstones

In these rocks, the clastic grains of quartz and felspars are embedded in an aggregate of crystalline dolomite and fine grained quartz (Plate IV.12). Quartz grains are angular to subangular and exhibit highly undulose extinction. Felspars, predominantly potash felspar, show better roundness than quartz, and are invariably altered. Leaching out of carbonate cementing material render them highly friable.

The dolomitic sandstones, in contrast to the other sandstone varieties (Wackes, arenites etc.), contain dolomite as cementing material, and indicate a different environment of deposition. Instead of silica precipitation in the pore-spaces as cementing material, here in this case, carbonate minerals were deposited. The whole sequence of Sumsa Formation where the purple slate-siliceous dolomite-sandstones show intercalations and frequent repetition, indicate an intricate balance mainly controlled by the provenance, pH conditions of sea-water and energy level.

Plate IV.12 Photomicrograph of dolomitic sandstone (Sumsa Formation) showing detrital grains of quartz cemented by dolomite (crossed nicols, x 50).