CHAPTER IV

P E T R O G R A P H Y

In this chapter, the author has attempted to describe fully the various structural, textural and mineralogical characters of the rock types - distinguishing and classifying the sedimentary and metamorphic features.

The petrographic account has been prepared, keeping in mind the following three important points:-

(1) The Champaner Series, though affected by folding, regional metamorphism and contact metamorphism due to the invading granites,

has preserved its sedimentary characters at most places. The lithology, depositional structures and textures ideally reveal the successive events and environment of deposition.

(2) The orogenic upheaval has impressed upon the rocks of this Series, quite distinct deformational and metamorphic features. These secondary characters are quite important in deciphering the deformation and regional metamorphism of the rocks.

(3) The intrusion of granite has considerably modified the nature of the rocks in the contact zone and the superimposition of contact metamorphism over regionally metamorphosed rocks, has added further to the petrographic diversity.

It will be evident from the following account that while in some formations, sedimentary characters are partly preserved, in others, the impress of metamorphism has obliterated them fully. On account of metamorphism and deformation, the sedimentary nature, though partly preserved, was found unsuitable for routine sedimentological investigations like shape and size analyses, etc. However, in case of Narukot Quartzites, an attempt was made to conduct 'Thin Section Mechanical Analysis' and the results were quite useful.

BASEMENT GNEISSES

The description is based on a study of the specimens collected from below the 'Basal Conglomeratic Quartzites', and of the pebbles occurring in the Jaban Conglomeratic Graywackes, which are undoubtedly derived from the basement.

These are fine to medium grained gray rocks with distinct streakiness. Under the microscope, the rock is seen to show a granoblastic texture; the foliation is characterised by parallel orientation of biotite flakes scattered uniformly throughout the mass. The minerals are quartz, microcline, plagioclase, (An_{20-25}) and biotite. Plagioclase generally dominates over potash-felspar and frequently shows development of myrmekites. Some of these gneissic samples exhibit a porphyroblastic texture with porphyroblasts of microcline.

BASAL CONGLOMERATIC QUARTZITES

These are typical basal formation comprising a sandy rock containing numerous pebbles. The pebbles are of vein-quartz, quartzite and jasper, and show fairly rounded outlines. While the quartz and quartzite pebbles are light gray or white in colour, those of jasper are red, brown and black. Their diameters range between less than a mm to 5 cm.

The matrix in which these pebbles are embedded, consists of quartz grains, and originally must be made up of almost pure quartz sand. Occasionally, the matrix contains some grains of felspars (microcline). The cementing material is mostly siliceous and its amount is quite variable. Those varieties which contain less cement, show closely welded recrystallised quartz grains (Plate XX A), while those containing the cement has binding material in the form of cryptocrystalline silica. The metamorphic recrystallisation of the cementing material has resulted into a secondary outgrowth of quartz around clastic grains, a phenomenon which has been described to occur also in low grade metamorphosed sandstones (Moorehouse, 1964, p. 441).

CHHOTA UDEPUR DOLOMITES

This formation, as already stated consists dominantly of crystalline dolomite with numerous interbedded layers of quartzites. Only these two main rock types comprise the formation.

Dolomites

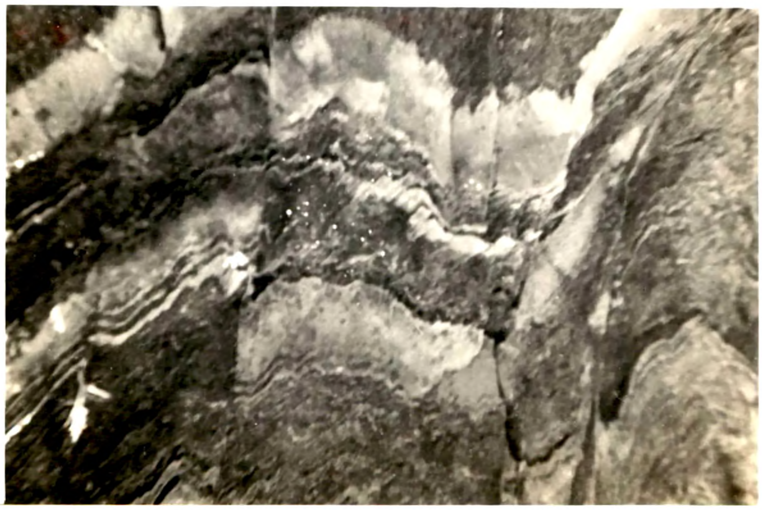
This rock is generally milky white in colour and is both coarse and fine-grained. The coarser variety shows a saccharoidal texture, while the finegrained variety is massive. Staining by alizarin red S, has indicated the carbonate to be dolomite. Under the microscope, the coarse-grained rock is seen to consist of an equigranular mass of dolomite crystals (Plate XX B). The mineral shows characteristic polysynthetic twinning parallel to the short diagonal of the rhomb-shaped grains. In fine-grained variety, individual crystals cannot be distinguished.

Quartzites

These are fine to medium grained greyish-white siliceous rocks, consisting almost entirely of quartz. In thin section, the rock is seen to consist of an aggregate of equigranular, polygonal quartz grains with smooth outlines. Samples from those areas, where these

PLATE XVII

A. 'S' shaped fold in Bamankua Limestone.



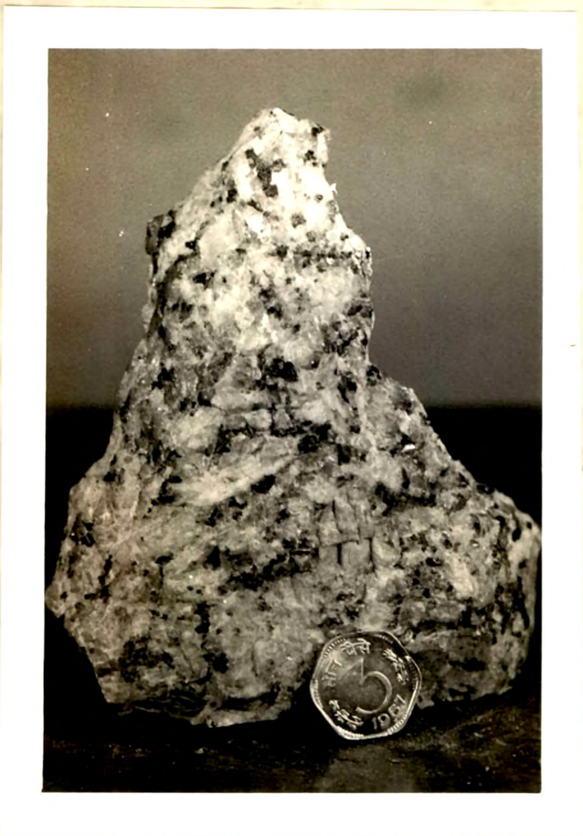
B. Bamankua Limestone showing slipping of beds along axial planes.

PLATE XVIII

A. Cross-bedding in Rajgad Slates.

B. Rajgad Slates showing penecontemporaneous folding.

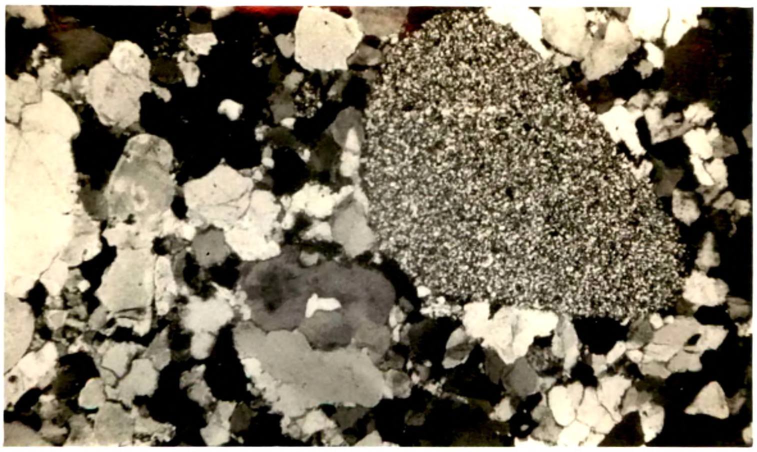
PLATE XIX



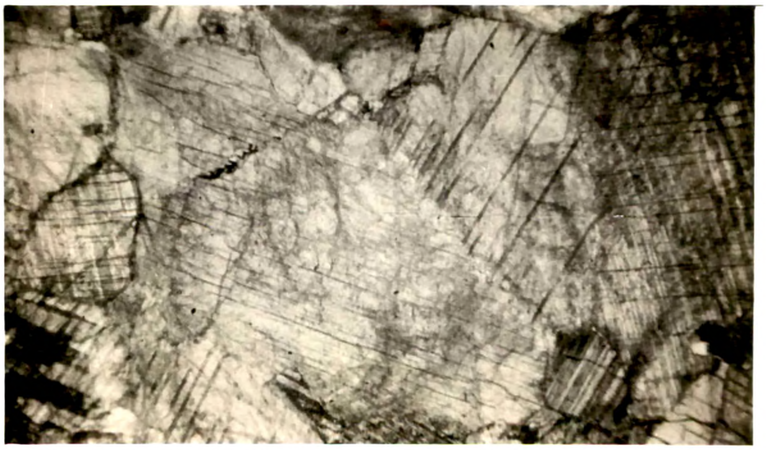
A. Massive granite.

B. Tourmaline pegmatite in granites.

PLATE XX

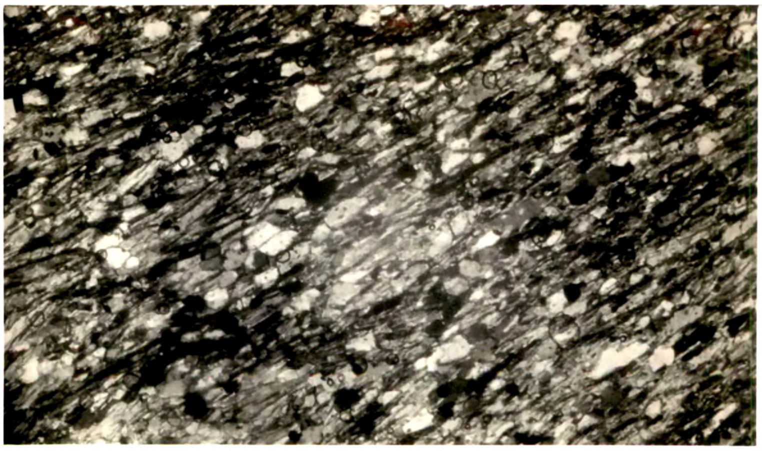


A. Photomicrograph of Basal Conglomeratic Quartzite showing closely welded quartz grains (X30).

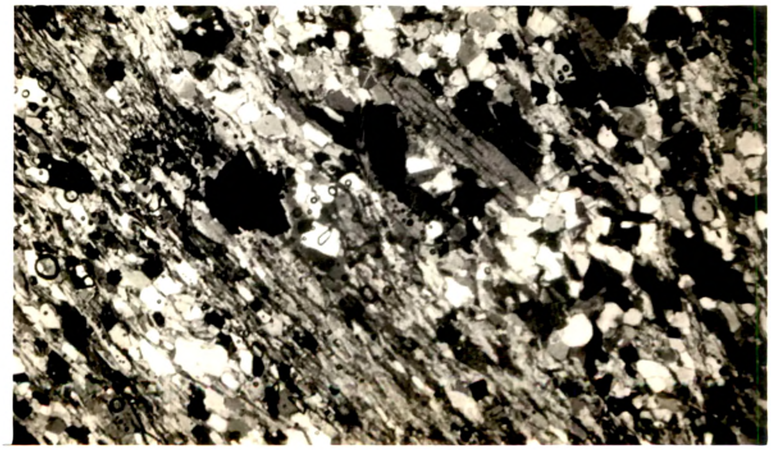


B. Photomicrograph showing texture of Chhota Udepur Dolomites (X30).

PLATE XXI



A. Photomicrograph showing textural characters of phyllites (X30).



B. Photomicrograph showing textural characters of mica schists of Gandhra Pelitic Group (X30).

quartzites have been affected by granites, indicate recrystallisation giving rise to an interlocking mosaic.

GANDHRA PELITIC GROUP

Lower Schists, etc.

These rocks, forming the lower portions of the formation, consist of phyllites, chlorite-muscovite schists, hornfelses and migmatitic gneisses.

Phyllites: These represent the regionally metamorphosed derivatives of original pelitic rocks, and are finegrained, cleaved, greenish-grey rocks. Under the microscope, these show a strongly foliated mass consisting of chlorite, sericite, quartz, and magnetite. Quartz forms tiny granules and occurs as thin streaky aggregate along the foliation. Chlorite and sericite, as tiny flakes, occur in close association, the former is distinguished by its pale green colour, pleochroism and low birefringence. Magnetite grains of euhedral shape are seen scattered throughout the mass (Plate XXI A).

Chlorite-Muscovite Schists: These are slightly more micaceous than the phyllites and perhaps indicate a higher metamorphic grade. The rocks show a light green colour and are mediumgrained. Under the microscope, they show usual foliated structure and are seen to be made up of chlorite and muscovite with some quartz. Some samples contain, in addition, andalusite and biotite (Plate XXI B).

The whole mass shows clear evidence of intense shearing and crushing. Chlorite and muscovite form elongated streaks and the intervening spaces are filled with the granular quartz. The entire foliated mass is interspersed with eyeshaped aggregates of quartz, which obviously represent bigger quartz grains crushed and recrystallized during the deformation.

Some samples of these schists, contain in addition occasional crystals of andalusite and biotite. The appearance of these two minerals indicates the early effects of the contact metamorphism which ultimately transformed the phyllites and schists into hornfelses. The crystals of andalusite have idiomorphic outlines and invariably show concentric replacement rims of muscovite followed outward by chlorite and also contain numerous inclusions of quartz, chlorite, sericite and biotite (Plate XXII A).

Hornfelses: Hornfelsic rocks, derived by the contact metamorphism of the schists and phyllites, are confined to the aureole of the granite mass. These are usually dark coloured, greyish-brown rocks and under microscope show a medium to coarse hornfelsic or granoblastic texture (Plate XXII B). Generally, these lack a well defined foliation, though a coarse parallelism of minerals is observed in transitional varieties (Plate XXIIIA). Hornfelses farther from the granite contact are seen to consist of biotite, muscovite, quartz and andalusite. Generally, andalusite occurs as scattered porphyroblasts but occasionally it forms big aggregates and clusters of numerous crystals. On the otherhand, the rock nearer the contact, is characterised by the presence of cordierite instead of andalusite. Thus the minerals present are biotite, muscovite, quartz, and cordierite. Generally, cordierite and andalusite do not occur in the same rock, except in few cases where the rock in the immediate vicinity of gneisses is seen to consist entirely of biotite, cordierite and andalusite.

Quartz occurs as scattered grains of fine to medium size in the main mass of the rock. It also forms small lenticles of sutured aggregates and inclusions within andalusite and cordierite. These quartz inclusions quite often show parallelism with the schistosity outside (especially in transitional or foliated hornfels). This significantly indicates static growth of andalusite and cordierite.

Of the two micas, biotite is dominant and is always present. It occurs as tiny flakes in ground-mass and as inclusions in cordierite and andalusite. It also forms big porphyroblastic flakes (Plate XXIII B). Biotite flakes tend to increase in size and proportion towards the granite contact. A rough parallelism of biotite flakes produces a sort of schistosity in some hornfelses. With the increase in size and number of biotite porphyroblasts, the traces of the original foliation are completely obliterated. In the innermost zone, biotite flakes form clusters and mass showing a decussate texture. The biotite in outer zone of the contact aureole, is pleschroic from light yellow to brown or rarely to green (with scheme $X \angle Y < Z$). In the inner zone, the pleochroism is much stronger from yellow to dark reddish-brown (and scheme $X \angle Y < Z$). The pleochroic halos around included apatite and zircon are quite conspicuous.

Muscovite is found in subordinate proportion and generally forms small shreds occurring in close association with biotite in the groundmass. It tends to form porphyroblastic flakes with increasing contact effect. The other mode of occurrence is as tiny inclusions in andalusite and cordierite. Secondary muscovite (sericitic) developed due to hydrothermal alteration of andalusite and cordierite, is seen as patches and rims around the above minerals.

Andalusite is common in the outer contact zone where it forms big, spongy, porphyroblasts studded with the inclusions of quartz, biotite, muscovite, chlorite and iron oxides (Plate XXIV A). In most cases, it is found altering to sericite along borders and fractures. Its content dwindles in rocks nearer to the granite contact. Inclusions are almost absent from the andalusites occurring in the rocks of inner contact zone. Inclusions in andalusite show a rough parallelism which coincides with the schistosity of the matrix if preserved. This parallelism is seen as trains of small grains or as elongated aggregates. It is interesting to note that this parallelism of inclusions is distinctly preserved even in such hornfelsic rocks in which schistosity is fully obliterated.

Andalusite shows straight extinction in prismatic sections, whereas the transverse sections with two sets of cleavages have characteristic symmetrical extinction. The interference colours are first order grey and yellow. The mineral is optically -ve with a 2V of about 82°.

Cordierite appears in hornfelses first as irregular interstitial grains. But progressively, it shows increase in size and content on going towards the granite contact. It is identified by its typical low relief, lack of cleavage and characteristic twinning (polysynthetic and cyclic), alteration and inclusions(Plate XXIV B). It is found to be optically negative and the 2V varies from 45° to 55°. Nearer the granite, it forms large crystals of poikiloblastic habit. Big irregular grains are studded with inclusions of quartz, biotite, muscovite, tourmaline, and zircon. Inclusions of zircon show pleochroic halos around them. Quartz inclusions themselves contain smaller flakes of sericite. This phenomena suggests that the quartz was first to recrystallize probably during regional metamorphism, and during subsequent contact metamorphism the same quartz was entrapped by the growing porphyroblast of cordierite. In almost all instances, the cordierite shows alteration to yellow, isotropic substance (possibly a variety of chlorite).

Chlorite is only occasionally present. Some of it occurs as tiny flakes representing the original constituent while the rest is an alteration product of andalusite, biotite and cordierite. The latter variety forms rims around andalusite. The chlorite is pleochroic in shades of green (X = Y = Green, Z = pale green, and X = Y > Z), and shows very low interference colours. The yellow alteration product of cordierite may also be a variety of chlorite (Moorehouse, 1964, p.422; William, Turner, Gilbert, 1965,p.183; Winchell and Winchell,1968,p.472).

The accessory minerals in the hornfelses are tourmaline, magnetite, and apatite. Of these tourmaline is the most important. It occurs abundantly throughout as prismatic crystals of variable size showing well defined triangular cross-sections, and shows pleochroism from O = sltay-blue to E = faint pinkish yellow and O > E. Typical colour zoning is seen in cross-sections. Well crystallised nature of this tourmaline points it to be a product of metasomatism due to granite.

Gneisses: Gneisses are the migmatised metapelites and occur between schistose rocks, hornfelses and intrusive granites. From their petrographic study, a complete picture of the course of migmatisation is obtained. Taking into account the increasing feldspar content towards the granite contact, these rocks have been classified into following four types which grade into one another:

Feldspathic Schists

Permeation Gneiss

Augen Gneiss

Porphyroblastic Gneiss

Feldspathic Schists are transitional rocks which with increase of feldspar content, grade into permeation gneiss. These rocks show an initial stage of feldspathisation in country rocks, especially metapelites.

Under microscope, these rocks show a coarser grain than mica schists. The foliation is characterised by parallel flakes of mica, the intervening space filled with aggregates of quartz and occasional feldspar.

The rocks are made up of biotite, muscovite, quartz and feldspar. The feldspar is mostly a plagioclase with small amount of microcline.

Quartz is the dominant constituent. It forms the groundmass as well as elongated aggregates of many grains. Most of the quartz in these rocks appears to be the original constituent of the schists. However, some quartz grains which tend to form porphyroblasts may have been introduced by the granitic emanations. Such quartz is seen also to occur intergrown with plagioclase.

Plagioclase (An_{20-24}) forms somewhat smaller grains which are seen occurring scattered in the foliated mass. Bigger crystals contain inclusion of quartz and mica and show considerable alteration to sericite. The mineral shows characteristic polysynthetic twinning, low relief and refractive index higher than balsam.

Microcline is only occasionally present. If present, it is confined to the groundmass and is recognised by its faint cross-hatched twinning.

Muscovite forms slender and tiny flakes and occurs in the form of parallel layers or is uniformly scattered in the mass.

Biotite occurs in aggregate of flakes forming tufts or lenses which are parallel to the schistosity. Individual flakes within each lens may show sub-parallel arrangement. Also smaller biotite flakes are scattered in the mass. It is strongly pleochroic with X = yellow, Y = brown and Z = dark brown or greenish brown ($X < Y < Z$). The mineral quite often shows pleochroic halos around included zircons.

Crystals of apatite and grains of magnetite constitute the main accessory minerals. Stray zircons are also noticed.

The feldspathic schists described above, merge into permeation gneiss, with increased feldspar content. In handspecimen, the rock shows a uniform scattering of feldspar along the foliation and also forms thin feldspathic streaks. Biotite shows an increase. Magnetite becomes scarce and when present it occurs as well formed crystals.

Under microscope, the quartz and feldspar are seen to form a fine granoblastic aggregate forming continuous streaks. Parallel flakes of mica characterise the foliation. The rock contains quartz, plagioclase, biotite, muscovite and some microcline.

Quartz is the dominant mineral, and most of it appears to be the original constituent of the schists. Such quartz occurs as coarse grains with less sutured contacts. Occasionally, they are flattened parallel to the foliation. The original quartz has frequently preserved the healed fractures. Some quartz that is seen to occur as interlocked with plagioclase in groundmass, appears to have been added later on along with the sodic solutions and shows highly sutured contacts with plagioclase.

Plagioclase (An_{20-25}) occurs as tiny grains in groundmass as well as somewhat coarser porphyroblasts. It generally shows sutured borders with quartz. The coarser grains contain inclusions of quartz, muscovite biotite and apatite, the minerals which constitute the groundmass. It is generally twinned but some untwinned grains are also occasionally seen.

Microcline is present in small quantity only, and mostly forms small interstitial grains. A few larger grains are also recorded. In such cases, it contains plagioclase, quartz, muscovite and biotite as inclusions.

Muscovite occurs as tuft of slender flakes forming continuous streaks and marking the schistosity. It also occurs as tiny flakes in close association with feldspathic aggregates or as inclusions within plagioclase, quartz and microcline.

Biotite forms clusters elongated in the direction of foliation and occurs in close association with muscovite. Individually, it may show tendency towards decussate growth within the clusters. Biotite is found also as small, scattered flakes in the rock. It is pleochroic from light yellow to dark brown (with $X < Y < Z$).

Apatite, tourmaline, zircon form the important accessory minerals. Magnetite is very much scarce.

With a further advance in granitisation, the permeation gneiss is seen changing over to augen gneiss on account of the development of numerous feldspar augens along the foliation. These are obviously more feldspathic and coarser than the previous variety.

Texturally the augen gneiss is a medium to coarse grained rock containing 'eyes' or 'augens' of feldspars. The numbers of augens in the rock vary from place to place. They are abundant near the contact with porphyroblastic gneiss whereas their content decreases towards the permeation gneiss contact. The gneissic structure is characterised by the parallel arrangement of feldspar augens and lenses of quartz grains occurring in a foliated, granoblastic groundmass made up of quartz, feldspar, biotite, and muscovite. The micaceous foliae generally curve round the augens.

The augen gneiss contains quartz, plagioclase, biotite, muscovite, microcline as the chief constituents with very subordinate chlorite.

Quartz shows a variety of modes of occurrence. Its size similarly varies considerably from fine grain in groundmass to rather coarse porphyroblasts. It is seen to form elongate aggregates of polygonal grains with smooth outlines. Some such lenses are made up of quartz showing dimensional orientation. Another mode of occurrence is as inclusions in feldspars.

Plagioclase occurs both in the groundmass as well as if forms augen-shaped porphyroblasts. In the groundmass, it occurs in association with quartz and micas, and is recognised by its characteristic lamellar twinning and alteration to sericite. In composition it is mostly an oligoclase (An_{20-25}). The augens seem to have grown along foliation and mica flakes therefore wrap round them. Quartz grains very often crowd along their borders. The characteristic feature of these plagioclase crystals, is their inclusions of quartz and muscovite. Plagioclase is generally altered to sericite. Sometimes in its highly altered state, only the preservation of faint lamellae indicates its presence.

Muscovite and biotite occur in almost equal proportions. Muscovite occurs as small flakes in groundmass and also as inclusions within plagioclase. A few porphyroblastic laths of muscovite are also observed. Sometimes it shows faint pleochroism from colourless to light brown. Biotite is seen to occur as small, scattered flakes as well as bigger laths arranged in the form of elongated tufts. Individual flakes within such tufts show rough orientation in the elongation direction of such clusters which coicide with the general foliation in the rock. Biotite is pleochroic with X = yellow, Y = yellowish brown and Z = dark brown or greenish brown ($X < Y < Z$).

Microcline is seen in a subordinate quantity and is confined mostly to the groundmass forming irregular grains. It is recognised by its characteristic cross-hatching. When treated with sodium cobaltinitrite it gives yellow stain. In some thin sections, however, the proportion and size of microcline tends to increase considerably and in such cases the mineral tends to invade and replace the plagioclase porphyroblasts. Mostly, the microcline is much less sericitized than plagioclase, and often it is quite fresh.

Apatite, tourmaline and iron oxides are the common accessory minerals whereas zircon is occasionally recorded.

The augen-bearing gneisses change over to the porphyroblastic gneiss with increasing granitisation. The augens grow into discrete euhedral to subhedral feldspar porphyroblasts cutting across the foliation. These are quite coarse gneissic rocks, which further south gradually merge into granitoid rocks. The foliation though quite coarse is still preserved.

These gneisses represent an advanced stage of transformation of phyllites to feldspathic rocks. Their thin section study has revealed two main types, viz.

(I) with dominant porphyroblasts of plagioclase, (II) with dominant porphyroblasts of microcline. With the replacement of plagioclase by potash feldspars, Type I grades into Type II. In the higher stages where potash feldspar content has gone up, plagioclase has survived as relicts within the former. At the same time it shows much effects of sericitization.

The texture of the rock is porphyroblastic with large crystals of plagioclase and microcline embedded in a granoblastic, coarse gneissic groundmass. The porphyroblasts lie haphazardly in the plane of foliation and also across it. With the increase in quartzo-feldspathic content, the size of the feldspar porphyroblasts increase and they progressively show crowding and a random orientation. As a result, these gneisses gradually lose their foliation and start looking massive. In such cases, biotite flakes no more form continuous bands or lenses but occur as small clusters or as scattered individuals throughout the rock. Ultimately, the rock is so much enriched in quartzo-feldspathic material that the gneiss gradually passes into a rock looking like a granite.

The rock is composed essentially of quartz, plagioclase, microcline, biotite and muscovite.

Quartz is one of the most abundant constituents and is found in all sizes from very small granules forming mosaic in the groundmass to big grains. The larger grains mostly occur as elongated aggregate. Quartz also occurs as inclusions in feldspar porphyroblasts.

Plagioclase feldspar usually an oligoclase (An_{20-25}), show polysynthetic twinning on albite law. It occurs in the groundmass as well as big porphyroblasts. The mineral shows high degree of alteration to sericite. The porphyroblasts form well defined crystals and have grown in the rock without definite orientation (Plate II A). They contain tiny inclusions of muscovite and quartz.

These plagioclase porphyroblasts almost invariably show replacement by potash-feldspar. All stages of replacement are recorded. In final stage the plagioclase survives as small relicts within the microcline. Sometimes during such replacement, the altered plagioclase is seen to have been surrounded by a rim of fresh plagioclase which remains in contact with the enclosing potash-feldspar (Plate XXV A). This plagioclase has refractive index lower and extinction angle higher than the altered plagioclase. It is in all probability an albite (An_{6-8}).

The microcline content of the rock is quite variable. In the plagioclase dominant rock, it is generally confined to the groundmass only. But in later stages, it occurs both as porphyroblasts and in the groundmass. In the groundmass, microcline occurs in intimate association with quartz. It has quite often amoeboid outline and indicates interestitial growth. Cross-hatching is characteristically present in microcline. In its porphyroblastic growth, the mineral occurs as separate individuals or as a group of few grains. Quite a few porphyroblasts of microcline appear to have developed at the expenses of early formed plagioclases. In such instances, microcline contains the relicts of plagioclase as inclusions. The other inclusions are of quartz, biotite and muscovite. Some porphyroblasts appear to have grown independently and do not contain above inclusions. The potash-feldspar is generally free from sericitisation.

The relative proportions of muscovite and biotite are variable, but on the whole biotite predominates. The micas show a somewhat coarse parallelism and give rise to gneissic foliation. The biotite forms short as well as long flakes and occurs in the groundmass or as small tufts with stray intergrown muscovite flakes. Each of the clusters may show rough orientation parallel to the regional schistosity but individual flakes of biotite within the cluster may display a decussate arrangement (Plate XXV B). The parallelism of biotite clusters or tufts gradually gets obliterated when gneisses change to granite looking rock southward. Biotite is pleochroic with X = yellow, Y = yellowish brown and Z = dark brown ($X < Y < Z$). The pleochroic, halos around minute apatite and zircon crystals are common. Muscovite is usually present in the form of minute scales or flakes or as sericite. Such sericitic variety is obviously an alteration product of plagioclase. In many thin sections it appears that muscovite has been derived partly from the biotite. This is indicated by a progressive decolouration of some biotite flakes and the crowding of magnetite along the peripheries of some muscovites.

The accessory minerals are apatite, zircon, magnetite and tourmaline. Apatite is very common, and is in an appreciable quantity. Zircon is comparatively less. Magnetite is found as anhedral grains and in the form of well developed crystals with triangular and square sections. Tourmaline occurs as small grains. It is scattered in the rock and shows pleochroism from pink to dark slaty-blue.

Poyelli Quartzites

On freshly exposed surface these rocks are grey or greyish-white in appearance. They show varying degrees of recrystallisation, massiveness and homogeneity. Samples from the highly recrystallised rock near the granite contact are glassy-looking. Segregations of magnetite are frequently noticed at home places.

Texturally the rock shows a mosaic of polygonal quartz grains showing variation in shape and size (Plate XXVI A). The grains are generally of fine to medium size with occasional coarse ones. In some less metamorphosed varieties, a hematitic ferruginous cementing material is still preserved.

The rock contains, quartz, muscovite, biotite and magnetite.

Quartz is the dominant mineral and generally occurs as equant grains. Muscovite, though very subordinate, is always present and occurs as slender flakes interspersed between quartz grains. Sometimes, small clusters of tiny muscovite flakes are also present. Biotite is much less than muscovite and is seen in only a few samples. Magnetite, though always present is in a very small quantity. In most of the samples, it is seen to occur as sporadic tiny crystals.

<u>Tourmaline</u> is a common accessory mineral. The other accessory minerals are <u>zircon</u>, <u>apatite</u> and rarely <u>epidote</u>.

<u>Upper Slates and Phyllites</u>

This formation consists largely of slates and slaty-phyllites with frequent lenses of argillites. In its south-eastern part towards Vau, these tend to be chloritic-phyllites and chlorite schists, on account of the nearness of granite.

<u>Argillites</u>: These are firmly indurated argillaceous rocks devoid of slaty-cleavage. In handspecimen, these are dark grayish-black, compact, hard, and non-fissile massive rocks.

In thin section, argillites are very fine grained rocks and lack slaty-cleavage (Plate XXVI B). What appears as a homogeneous, massive rock in handspecimen, sometimes show presence of bedding in thin section. The bedding is characterised by layers rich in quartz grains in otherwise very fine clayey material. In polarised light, the rock shows uniformly spotted appearance on account of initial growth of brown specks in entire rock. Such specks, in the early stages of metamorphism, according to Turner (1968, p.31) are the oxidized chlorite-vermiculite.

Quartz, brown chlorite and stilpnomelane are the only minerals easily recognised in thin section. The accessory minerals include the needles of rutile, pyrite and grains of magnetite.

Quartz occurs as very small grains dispersed in the entire rock within dark argillaceous material. It is also seen to form sedimentary layerings, which are conspicuous in associated slates.

Chlorite is usually in the form of minute specks or grains which remain brown throughout the rotation of the stage. It imparts a spotted appearance to the rock and indicates early stages of recrystallisation of sedimentary mudstones.

Associated with brown chlorite, are a few, small scales of stilpnomelane. These scales in many cases are elongated at high angles to the bedding and indicate the direction of slaty-cleavage which has appeared in associated fissile varieties. Thus, these flakes mark the early phases in the course of a rock developing a slaty-cleavage, This mineral, unlike brown chlorite, is flaky and also pleochroic with X = yellow or golden yellow and Y and Z deep brown and ($X < Y$ and Z). The mineral has one set of cleavage. Wherever its interference figure is obtainable, the mineral gives almost an uniaxial figure with many coloured rings.

Slates and Phyllites: These are very fine grained metamorphic rocks showing a strong metamorphic cleavage. Bedding is generally present and is recognised by grain size variation and colour banding. Depending upon the varying intensity of the cleavage and grain size, the rocks can be called slates or phyllites. Phyllites tend to be of lighter colour than slates. While the slates are dark grey to steel grey in colour, the phyllites are generally grayish-green.

In thin section, the slates show a very fine grained mass consisting of aggregates of quartz, chlorite, stilpnomelane and sericite. The slaty cleavage is characterised by microscopic streaks of finely crystalline quartz and parallelism of flaky minerals.

Quartz is identified as very small grains showing 1st order gray interference colours and is seen distributed throughout the rock.

Chlorite and Stilpnomelane are recognised as in the argillites. Sericite occurs in close association with minerals.

Tiny grains of pyrite and magnetite are common and uniformly scattered throughout the mass.

Thin sections of phyllites appear to be coarser in grain size such that most of the minerals are easily identifiable.

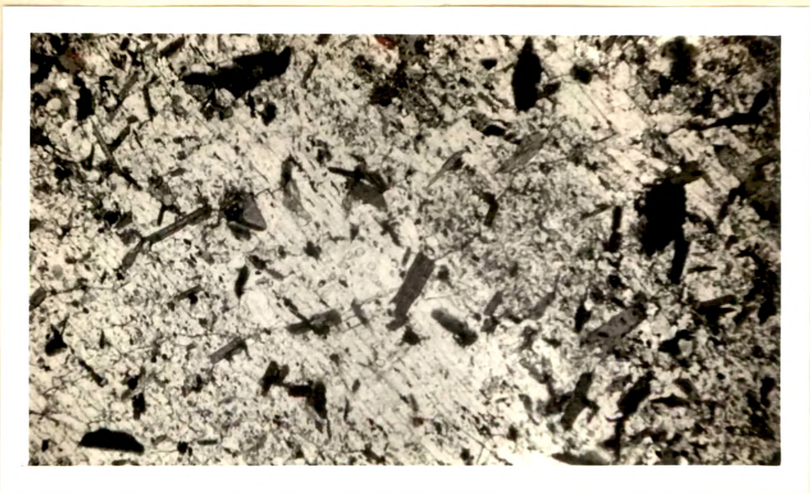
The minerals in phyllite are quartz, muscovite, stilpnomelane, chlorite, plagioclase and iron-oxides.

Quartz occurs as small grains, irregular or elongated parallel to the schistosity. It also forms lens like aggregates which alternate with micaceous bands.

Muscovite is quite abundant and is present in the form of tiny colourless flakes. It is found to form either almost continuous bands or occurs distributed in the entire rock.

The proportion of stilpnomelane in the rock is variable. It forms small flakes oriented parallel to the schistosity. It occurs either in the micaceous layers or as individual flakes in the rock. The pleochroism shown by stilpnomelane is X = yellow, and Y and Z = dark brown ($X < Y$ and Z).

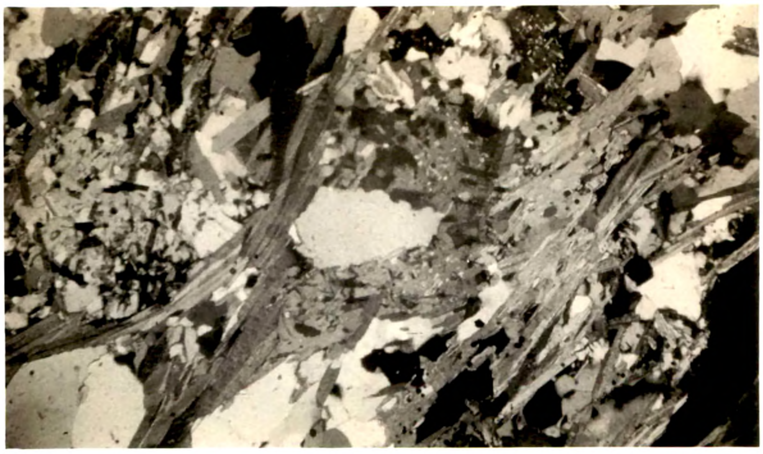
PLATE XXII



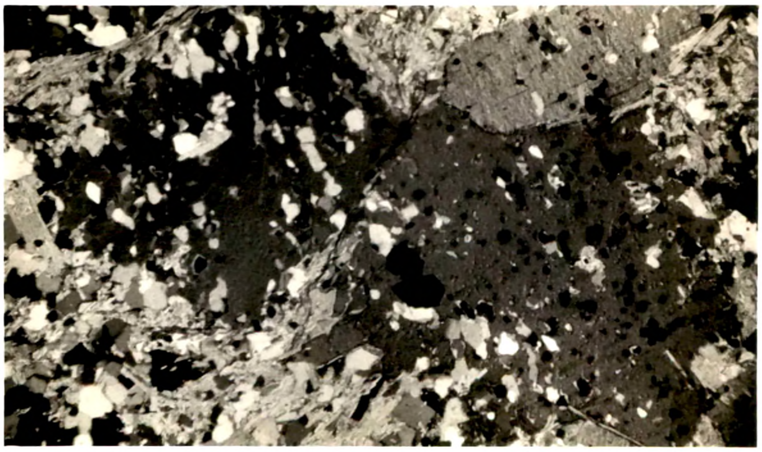
A. Photomicrograph showing inclusions in andalusite prophyroblasts (X30).

B. Photomicrograph showing textural characters of hornfels (X30).

PLATE XXIII

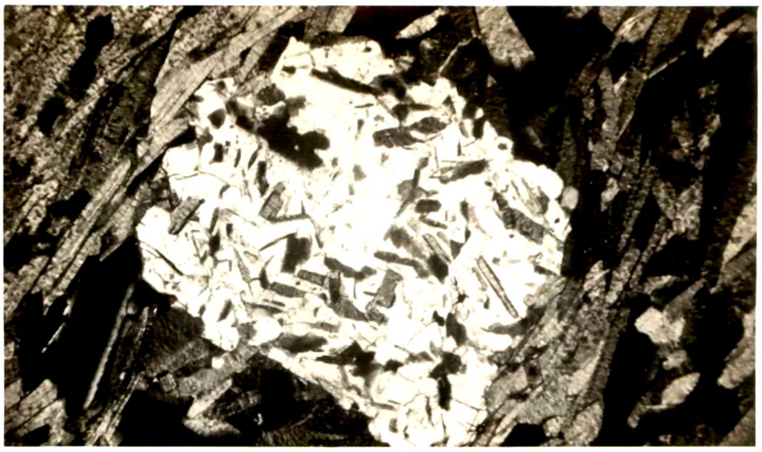


A. Photomicrograph showing textural characters of transitional varieties of hornfelses (X30).

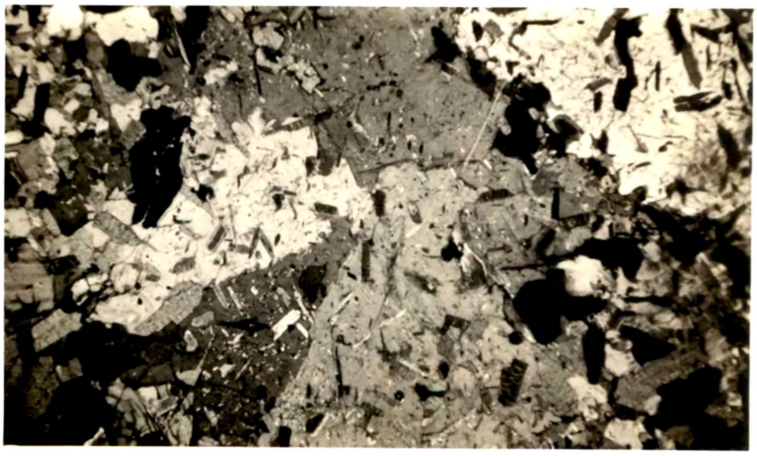


B. Photomicrograph showing biotite porphyroblasts in hornfelses (X30).

PLATE XXIV

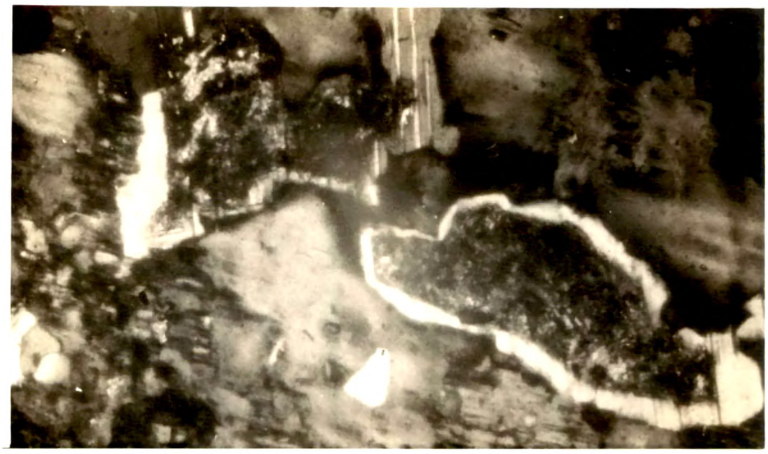


A. Photomicrograph showing well developed andalusite porphyroblasts in hornfelses.(X30)

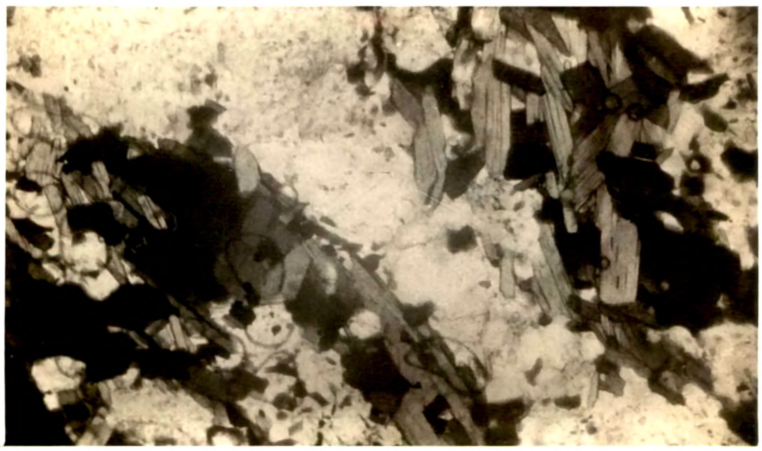


B. Photomicrograph of cordierite in hornfelses showing twinning (X30).

PLATE XXV



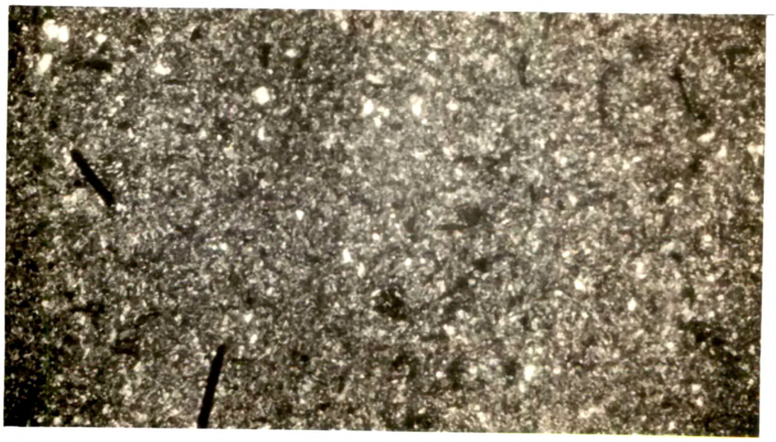
A. Photomicrograph showing a clear-rim of albite around plagioclase in migmatitic gneisses (X50).



B. Photomicrograph showing decussate arrangement of biotite in migmatitic gneisses (X30).

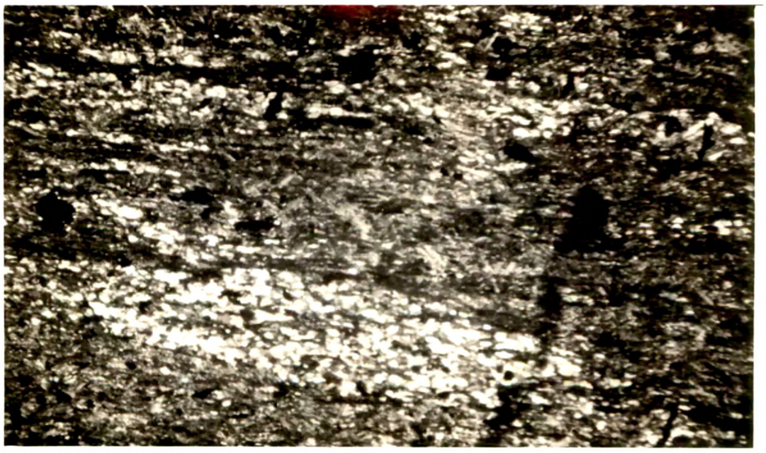
PLATE XXVI

A. Photomicrograph showing textural characters of Poyelli Quartzites (X30).



B. Photomicrograph showing textural characters of argillites from Gandhra Pelitic Group (X30).

PLATE XXVII



A. Photomicrograph showing textural characters of chlorite schist from Gandhra Pelitic Group (X30).

B. Photomicrograph showing textural characters of Gandhra Dolomites (X30).

Chlorite in these rocks is identified by its typical pleochroism in shades of green (X = Y = green; Z = pale green; X = Y > Z) and its first order gray interference colours. It occurs as small flakes associated with the micaceous layers.

Plagioclase (An_{10}) occurs in quartz rich bands only and its grains are identified by their typical twinning and refractive index less than canada balsam.

The iron oxide in the form of magnetite is frequently recorded.

Chlorite Schists: These are greenish rocks with well defined schistosity and appear to have originated on account of deficiency in potash and high Mg/Fe ratio in the original sediments. They may also indicate locally greater effects of stress.

In thin section, the rock is finely foliated and shows alternate bands rich in chlorite and quartz, the latter tending to form lenses (Plate XXVII A).

These schists consists of chlorite, quartz, a little biotite, muscovite and magnetite.

Chlorite forms distinct flakes and occurs in bands and layers in association with quartz. Some bands are very chloritic, while others dominate in quartz. Chlorite shows a distinct pleochroism (X = Y = green; Z = pale green; $X=Y>Z$).

Quartz occurs as grains distributed in chloritic layers or generally as aggregates forming small lenses or bands separating layers rich in chlorite.

Biotite usually occurs as small flakes in the chlorite rich layers. Small segregations of biotite are also noticed. The pleochroism of biotite is X = yellow, Y = brown, Z = dark brown ($X<Y<Z$).

Muscovite is much subordinate to all the above minerals and forms small, colourless, stray flakes.

Magnetite is present as irregular grains or euhedral crystals with square or triangular sections.

Gandhra Dolomites

Gandhra Dolomites occur as a big lensoid outcrop within the phyllites and slates. The constituent rocks are a crystalline dolomite with talc and tremolite. Near Gol Dungra (Jothwad), the rocks are dolomitic limestones which are caught up in granite and have given rise to skarns and calc-silicate rocks, showing varied assemblages. Thus the main dolomitic band comprises an assemblage which is derived by the regional metamorphism while at Jothwad are products of its reaction with the granite.

Dolomites: These rocks are white to grayish white in handspecimen, and contain dolomite, quartz, tremolite and sometimes talc. Thin bands of jasper are developed at some places. Also thin layers rich in iron ores and manganese ores are occasionally seen.

Under microscope, the rock shows a granoblastic texture (Plate XXVII B) with grain size varying from medium to coarse and is seen to consist of dolomite crystals, quartz grains and poikiloblasts of tremolite.

Dolomite is the dominant constituent and forms the main bulk of the rock. It is identified by staining with alizarin red-S, and while the white stains suggest pure dolomite, some bluish stained crystals are likely to be ferron-dolomite (Evamy, 1969). It shows a mosaic of medium to coarse grained crystals. It also occurs as inclusions within sieved plates of tremolite. In talc-bearing varieties, this mineral usually occurs as well developed crystals very often more than 1 cm across surrounded by talc on all sides.

Tremolite is common as large poikiloblastic plates containing numerous inclusions of dolomite and quartz (Plate XXVIII A). Generally it is scattered randomly in the rock, but sometimes it shows concentration as streaky aggregates. Generally, tremolite is non-pleochroic, though sometimes it may show a faint pleochroism from colourless to pale green.

Talc occurs as fine, scaly aggregates in association with dolomite (Plate XXVIII B). It is significant that talc never occurs in tremolite bearing varieties.

Quartz occurs as small equant grains uniformly scattered within the dolomitic mass. At times, it is seen forming streaky aggregates.

Skarn and associated Reaction Rocks

At Jothwad, the dolomitic limestone has reacted with granites and given rise to interesting reaction rocks. It appears that in this part, the carbonate band contained some manganiferous and argillaceous layers and depending on the lithology of the rock involved, varying assemblages have developed. Dolomitic limestone has given rise to skarn assemblages consisting of wollastonite, diopside, quartz, calcite, garnet epidote, phlogopite, scapolite, and plagioclase (oligoclase). Out of the above assemblage, two main types are recognised one predominantly rich in wollastonite, and the other lacking in wollastonite and rich in diopside.

Wherever manganese bearing limestone are involved, the assemblage is characterised by piemontite, epidote, garnet, scapolite, diopside, tremolite, quartz, calcite and oligoclase.

Manganiferous argillaceous portions of this dolomites, reacting with granite has given rise to an assemblage characterised by the presence of manganiferous silicates like winchite, blanfordite, manganophyllite and apatite, plagioclase, microcline and quartz.

The various minerals characteristically occur in banded segregations, and thus the rocks show varying proportions of different minerals from band to band.

<u>Skarn rocks</u>: These rocks contain the following mineral assemblages (i) Wollastonite - calcite - quartz (ii) Diopside - garnet - scapolite - epidote - phlogopite

(iii) Piemontite - garnet - quartz - epidote.

In thin section, the skarn rocks show a granoblastic texture, the wollastonite bearing variety contains big plates of the mineral, enclosing other minerals as inclusions.

Wollastonite when present, forms prisms, blades, plates and sheaf-like aggregates. It is quite often sieved and encloses numerous granules of quartz, calcite, diopside, garnet, scapolites and epidote (Plate XXIX A). Wollastonite is nearly a pure iron-free, triclinic variety (Sadashivaiah, 1963).

Diopside occurs as big as well as small grains of light green colour showing faint pleochroism (X = gree and Y = Z = yellowish green; X > Y = Z). Smaller grains either occur in close association with other minerals or as inclusions in wollastonite. The bigger crystals, which do not occur in wollastonite bearing variety, are always seen to contain numerous inclusions of quartz. Diopside has 2V of about 58° and is optically positive. Sadashivaiah (1963, p.309) has determined its composition as $Di_{63}\ He_{37}$.

Garnet is pale yellow, reddish yellow or reddish brown. It is seen as well formed grains, though idiomorphic shapes are lacking. Occasionally, garnet grains are highly fractured and poikiloblastic. When sieved, they contain inclusions of quartz and sometimes epidote and diopside. The grains are completely isotropic, and the mineral has refractive index 1.805 suggesting that it is a spessartite - almandine variety (Sadashivaiah, 1963).

Epidote forms granules disseminated in the rock. It often displays colour zoning and is generally pleochroic (X = colourless, Y = pale yellow and Z = lemon yellow or greenish yellow; $X < Y < Z$).

Tremolite is not a mineral of frequent occurrence and is sen developed in the zone away from the contact. It forms prismatic or fibrous crystals. Some crystals show a feeble pleochroism (X = colourless, Y = pale yellowish green and Z = bluish green; $X < Y < Z$).

Phlogopite occurs as small flakes. It is colourless or pale brownish, uniaxial negative.

Calcite is always present but in much variable proportions. It forms anhedral grains and shows all the usual characteristics.

Quartz also forms anhedral grains and its proportions in different samples are variable. It occurs in the main bulk of the rock and also as inclusions.

Scapolite is common in diopside bearing assemblages. It forms anhedral grains often showing two sets of cleavages. It is uniaxial, negative with N_e=1.545 and N_w=1.580 and $N_w - N_e$ = 0.035, indicating that the scapolite is of Mizzonite variety with Ma_{29} Me_{71} (Sadashivaiah, 1963).

Piemontite occurs as anhedral grains with strong reddish colour. The interference colours are masked by the body colours. Its common association is with quartz, epidote, garnet, calcite and manganese ores.

Microcline and plagioclase feldspars are the two minerals added by the granite near the contact with the intrusive body. Microcline generally occurs as small interstitial grains whereas plagioclase is present as fine as well as coarse grains, and shows complex twins. The large plagioclase crystals enclose several small granules of piemontite, diopside, garnet, etc.

Sphene, apatite and tourmaline are the common accessory minerals in skarn rocks. Sphene is granular or lozenge-shaped and brownish-red in colour. Apatite is recognised by its characteristic needle like shapes, high relief and low birefringence, while tourmaline forms strongly pleochroic (pink to blue) needles.

Winchite bearing rocks: In intimate association with the occurrences of calc-silicate assemblages, an interesting reaction rock consisting of winchite, blanfordite, manganophyllite with quartz, plagioclase, microcline and apatite, has developed. This assemblage is a product of the manganiferous argillaceous band in dolomitic limestones.

The rock shows a typical hornfelsic or granoblastic texture.

In this rock, winchite is generally prismatic and subhedral. Commonly it shows one set of prismatic cleavage but transverse sections display typical two sets of amphibolitic cleavage. Winchite is pleochroic with X = violet pink, Y = pale bluish violet and Z = blue. The mineral shows ultra-blue polarisation colours. According to Sadashivaiah (Sadashivaiah and Naganna, 1964, p.360) the winchite is a richterite variety with an affinity to arfvedsonite.

Blanfordite occurs as grains, pleochroic from rose-pink to sky-blue and has extinction angle varying from 40° to 45°.

Manganophyllite forms flakes, and is pleochroic from reddish brown to yellowish brown. The mineral usually has straight extinction. According to Sadashivaiah (1965,p.3) the manganophyllite shows chemically the characters of a phlogopite containing considerable amount of manganese.

Quartz occurs in anhedral grains and its proportion varies from sample to sample.

Microcline and plagioclase, obviously added from the granite, occur near the junction of winchite-rich rocks and the intrusive granite. Plagioclase is an oligoclase.

NARUKOT QUARTZITES

This quartizitic formation marks a very conspicuous and important horizon and its relationship with the underlying and overlying beds together with the lithology, and sedimentary structures, point to an environment characterising a beach type of deposition. Significantly, the grade of metamorphism shown by these rocks is quite low and the original sedimentary characters have been fully preserved. In view of the above, the samples of this quartzite collected from various spots, were subjected to a thin section grain size analysis, in addition to the routine petrographic study.

The Narukot Quartzites are seen to belong to two main varieties pebbly and non-pebbly.

Pebbly Variety

The pebbly variety, depending on the pebble content, can be named either as conglomerates or pebbly quartzites. In fact, while conglomerate occurs as distinct lenses at the base of the formation, the pebbly type may occur sporadically along and across the strike of the formation.

The conglomerates, essentially are rocks containing pebbles of quartzite vein-quartz and phyllites or slates. The pebbly variety is a quartz-pebble-sandstone in its original nature (Plate XXIX B). The matrix of all these rocks is generally sandy but sometimes in part argillaceous. The matrix when sandy, is seen to consist of an aggregate of quartz grains of variable size. Perhaps, in this variety the cementing material was siliceous, and on recrystallisation has given rise to finer aggregates of quartz.

Wherever, the matrix was psammo-pelitic or semi-pelitic, the recrystallisation has given rise to slender flakes of muscovite, chlorite and grains of magnetite, which occur in close association with the quartz grains.

Depending upon the proportions of the arenaceous and argillaceous percentage in the matrix, the proportions of quartz grains, flakes of micas, chlorite and iron ores vary in samples collected from different places.

Non-pebbly Variety

This variety is obviously a metamorphosed sandstone. The original rocks were either entirely a quartzose sandstone the original rocks were either entirely a quartzose sandstone or an argillaceous sandstone. Depending on the variation in the original lithology, two main metamorphic types are recognised.

(1) Entirely quartzose, consisting of grains of quartz coarse as well as fine and forming a mosaic of quartz grains in mutual contact. While the bigger grains of quartz might be the original clastic sand grains, the finer quartz perhaps represents the siliceous cementing material (Plate XXX A). This fact is supported by the manner in which the finer crystals of quartz are seen encroaching upon the boundaries of the coarser grains. Depending on the degree of recrystallisation, the different samples show varying degree of interlocking. Thus while most of the quartzite samples show interlocking

sutured grains, there are a few which exhibit a tesselate texture.

(2) Partially argillaceous, types show quartz grains embedded in a psamo-pelitic matrix. On recrystallisation, this argillaceous sandstone, has still preserved a number of sedimentary characters. Thin sections reveal that the clastic grains of quartz still retain their original shape and size, though the argillaceous matrix has recrystallised to muscovite, chlorite etc. (Plate XXX B). This type has furnished valuable sedimentological data. Thus the rock is seen to be made up of sub-rounded to rounded grains of quartz occurring in a groundmass consisting of small grains of quartz, muscovite (sericite), chlorite and iron-ores.

Grain Size Study of the non-pebbly argillaceous quartzites

The micaceous and chloritic quartzites described above represent an argillaceous sandstone, which during folding and metamorphism, have not been fully reconstituted. According to Moorehouse (1965, p.441) quartz grains in such argillaceous sandstones remain intact as the deformation is chiefly taken up by the fine-grained argillaceous portions and the quartz grains remain relatively underformed.

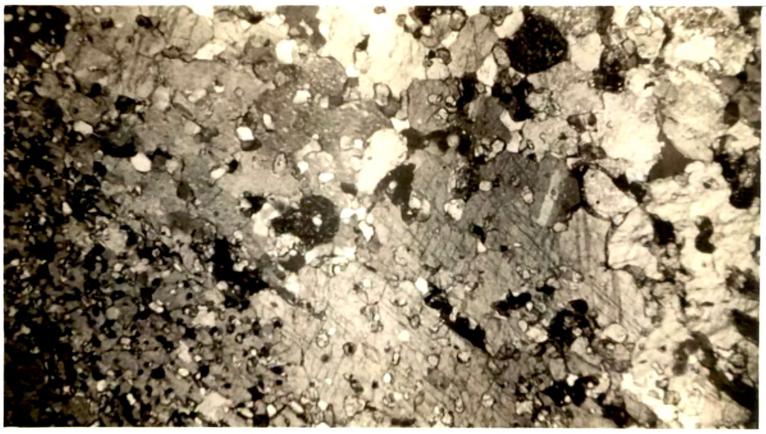
As the quartz-grains in this quartzite, thus were found to be undeformed, a few selected samples were subjected to a thin section mechanical analysis to obtain data on the possible environment and depositional conditions of this formation.

Grain-size data of the samples was obtained by studying thin sections following the methods suggested by Rosenfeld and et al. (1953) and Friedman (1958). The apparent long axes of 300 grains from each section were measured by means of a micrometer ocular. These measures were grouped into classes based on an interval of 1/4 Ø each. Grains finer than 4 Ø were grouped into one class.

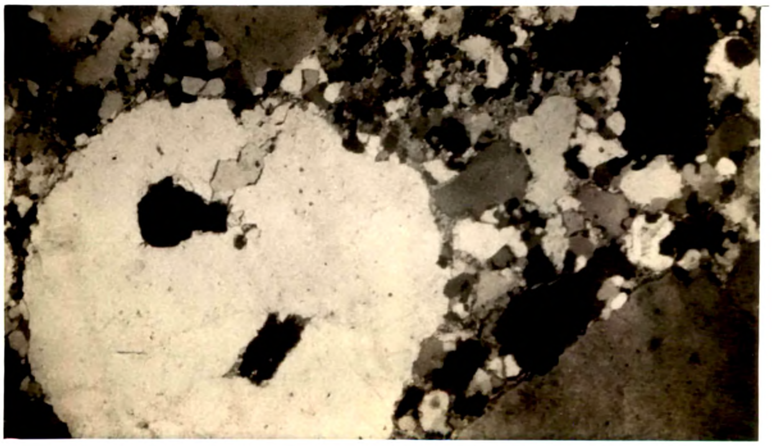
Grain-size thin section data (Table No.I) was subjected to interpretation based on the 'Graphic Measures' and 'Method of Moments'.

Graphic Measures: Cumulative curves on probability paper with abscissa as Ø scale of Krumbein and ordinate as "Number Percentage Frequency" were plotted (Rosenfeld and et al.,1953). From these curves 5th, 16th, 25th, 50th, 75th, 84th and 95th percentiles were read off and following the procedure suggested by Folk (1965), the four statistical parameters viz. Graphic Mean, Inclusive Graphic Standard Deviation, Inclusive Graphic Skewness and Graphic Kurtosis, were calculated (Table No. II).

PLATE XXIX

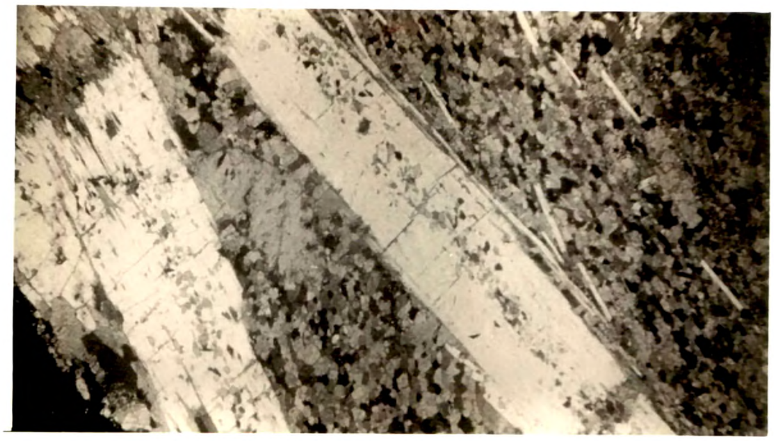


A. Photomicrograph showing sieved crystal of wollastonite from skarn rocks of Jothwad (X30).

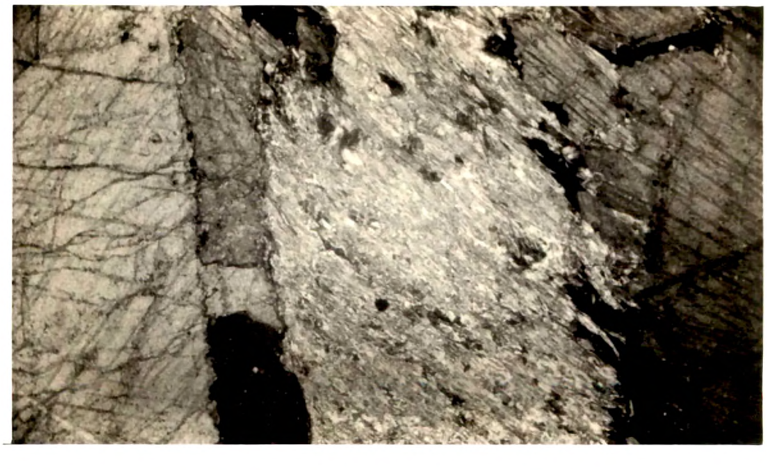


B. Photomicrograph showing quartz-pebble in Narukot Quartzites. (X30)

PLATE XXVIII

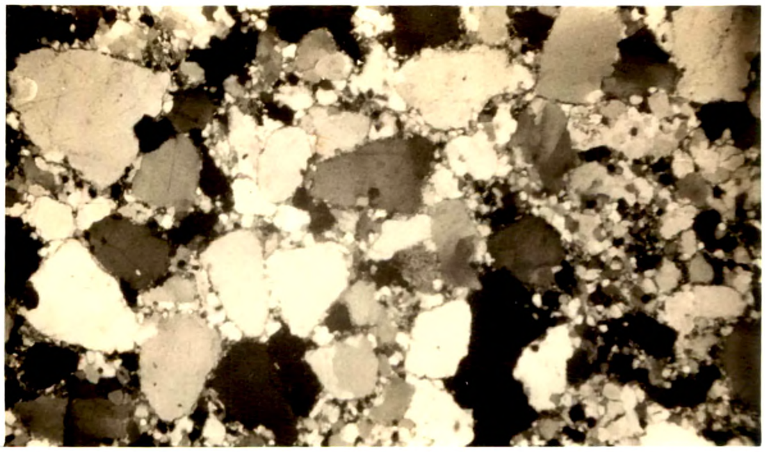


A. Photomicrograph showing blades of tremolite in Gandhra Dolomites (X30).

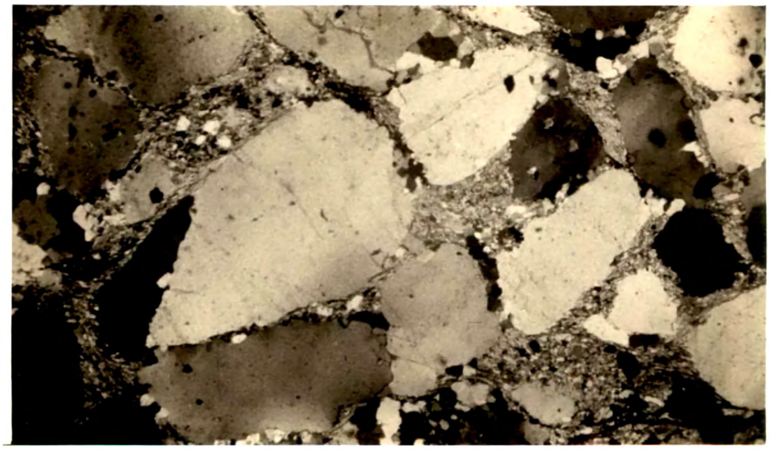


B. Photomicrograph showing scaly aggregates of talc with dolomites in Gandhra dolomites (X60).

PLATE XXX



A. Photomicrograph showing textural characters of Narukot Quartzites with siliceous matrix (X30).



B. Photomicrograph showing textural characters of Narukot Quartzites with argillaceous matrix (X30).

TABLE I

GRAIN-SIZE DISTRIBUTION DATA FOR THIN SECTION ANALYSIS

Cumulative and Individual Percentages in 0.50 Intervals

Sample No.	ø	<0.00	0.00-0.50	0.50-1.00	1.00-1.50	1.50-2.00	2.00-2.50	2.50-3.00	3.00-3.50	3.50-4.00
	Mm.	>1.00	1.000-0.710	0.710-0.500	0.500-0.350	0.350-0.250	0.250-0.177	0.177-0.125	0.125-0.880	0.880-0.062
1	Cum.	-	-	0.80	6.40	16.00	28.80	52.40	70.80	86.00
	Ind.			0.80	5.60	9.60	12.80	23.60	18.40	15.20
2	Cum.	0.80	3.60	6.00	9.60	12.80	30.80	58.00	74.40	88.00
	Ind.	0.80	2.80	2.40	3.60	3.20	18.00	27.20	16.40	13.60
3	Cum.	2.00	6.00	12.00	30.00	48.66	68.33	82.00	85.66	92.66
	Ind.	2.00	4.00	6.00	18.00	18.66	19.67	13.77	3.66	7.00
4	Cum.	4.00	14.66	20.33	26.00	27.66	36.00	55.33	69.66	84.33
	Ind.	4.00	10.66	5.67	5.67	1.66	8.34	19.33	14.33	14.67

TABLE II

STATISTICAL PARAMETERS (GRAPHIC METHOD)

Sample No.	Graphic Mean M_z (ϕ)	Inclusive Graphic Standard Deviation σ_I (ϕ)	Inclusive Graphic Skewness Sk_I	Graphic Kurtosis K_G
1.	2.95 (Fine sand)	0.952 (Moderately sorted)	+0.008 (Positively skewed)	1.03 (Mesokurtic)
2.	2.85 (Fine sand)	1.025 (Moderately sorted)	-0.048 (Negatively skewed)	1.19 (Leptokurtic)
3.	2.08 (Fine sand)	1.131 (Moderately sorted)	+0.10 (Positively skewed)	1.16 (Leptokurtic)
4.	2.50 (Fine sand)	1.526 (Poorly sorted)	-0.282 (Negatively skewed)	0.81 (Platykurtic)
5.	2.38 (Fine sand)	1.54 (Poorly sorted)	-0.23 (Negatively skewed)	0.75 (Platykurtic)

Method of Moments: The Method of Moments is a computational (not graphical) method used by Inman (1952) for obtaining values of grain size parameters. The details of the computation of first four moments of all the samples are shown in Tables IIIA to IIIE. The class interval, C, used in this computation is 1/2 phi, and the total number of classes H, is 10. The first column gives the class limits in phi units, the second column lists the mid-point or class mark, x_i, for each class, and the frequency for each class, F, in per cent is listed in column 3. The variable, U,($U=(x_i-x_o)/c$), is shown in column 4 with the zero value being different in different samples.

The product of columns 3 and 4 gives the first moment for each class. The algebric sum of these products (column 5), divided by the total percentage (100) gives, v_1, the first moment about x_o as origin. The arithmetic mean, M, which is the first moment about the phi-origin is obtained from equation

$$n_1 = M = cv_1 + x_o$$

The second, third and fourth moments about x_o are given ate the ends of columns 7, 9 and 11 respectively.

TABLE IIIA
DATA
COMPUTATION OF THE FIRST FOUR/MOMENTS OF SAMPLE NO.1

Class Limits ø units	Class Mark x_i	f	u	uf	u^2	u^2f	u^3	u^3f	u^4	u^4f
1	2	3	4	5	6	7	8	9	10	11
$<$ 1	-	0.8	-4	- 3.2	16	12.8	-64	- 51.2	256	204.8
1 to $1\frac{1}{2}$	1.25	5.6	-3	-16.8	9	50.4	-27	-151.2	81	453.6
$1\frac{1}{2}$ to 2	1.75	9.6	-2	-19.2	4	38.4	-8	- 76.8	16	153.6
2 to $2\frac{1}{2}$	2.25	12.8	-1	-12.8	1	12.8	-1	- 12.8	1	12.8
$2\frac{1}{2}$ to 3	x_o=2.75	23.6	0	-	-	-	-	-	-	-
3 to $3\frac{1}{2}$	3.25	18.4	1	18.4	1	18.4	1	18.4	1	18.4
$3\frac{1}{2}$ to 4	3.75	15.2	2	30.4	4	60.8	8	121.6	16	243.2
4 to $4\frac{1}{2}$	4.25	7.6	3	22.8	9	68.4	27	205.2	81	615.6
$4\frac{1}{2}$ to 5	4.75	5.6	4	22.4	16	89.6	64	358.4	256	1433.6
$>$ 5	-	0.8	5	4.0	25	20.0	125	100.0	625	500.0
Total		100.0		+46.0		+371.6		+511.6		+3635.6
Moments about x_o			v_1 = +0.46		v_2 = +3.716		v_3 = +5.116		v_4 = +36.356	

TABLE IIIB

COMPUTATION OF THE FIRST FOUR DATA MOMENTS OF SAMPLE NO.2

Class Limits ø units	Class Mark x_i	f	u	uf	u^2	u^2f	u^3	u^3f	u^4	u^4f
1	2	3	4	5	6	7	8	9	10	11
< 0	-	0.8	-6	- 4.8	36	28.8	-216	-172.8	1296	1036.8
0 to ½	0.25	2.8	-5	-14.0	25	70.0	-125	-350.0	625	1750.0
½ to 1	0.75	2.4	-4	- 9.6	16	38.4	- 64	-153.6	256	614.4
1 to 1½	1.25	3.6	-3	-10.8	9	32.4	- 27	- 97.2	81	291.6
1½ to 2	1.75	3.2	-2	- 6.4	4	12.8	- 8	- 25.6	16	51.2
2 to 2½	2.25	18.0	-1	-18.0	1	18.0	- 1	- 18.0	1	18.0
2½ to 3	x_o=2.75	27.2	0	-	-	-	-	-	-	-
3 to 3½	3.25	16.4	1	16.4	1	16.4	1	16.4	1	16.4
3½ to 4	3.75	13.6	2	27.2	4	54.4	8	108.8	16	217.6
> 4	-	12.0	3	36.0	9	108.0	27	324.0	81	972.0
Total		100.0		+16.0		+379.2		-368.0		+4968.0
Moments about x_o			v_1 = +0.16		v_2 = +3.792		v_3 = -3.68		v_4 = +49.68	

TABLE IIIC

COMPUTATION OF THE FIRST FOUR DATA MOMENTS OF SAMPLE NO.3

Class Limites ∅ units	Class Mark x_i	f	u	uf	u^2	u^2f	u^3	u^3f	u^4	u^4f
1	2	3	4	5	6	7	8	9	10	11
< 0.0	-	2.00	-4	- 8.00	16	32.00	-64	-128.00	256	512.00
0 to ½	0.25	4.00	-3	-12.00	9	36.00	-27	-108.00	81	324.00
½ to 1	0.75	6.00	-2	-12.00	4	24.00	- 8	- 48.00	16	96.00
1 to 1½	1.25	18.00	-1	-18.00	1	18.00	- 1	- 18.00	1	18.00
1½ to 2	x_o=1.75	18.66	0	-	-	-	-	-	-	-
2 to 2½	2.25	19.67	1	19.67	1	19.67	1	19.67	1	19.67
2½ to 3	2.75	13.67	2	27.34	4	54.68	8	109.36	16	218.72
3 to 3½	3.25	3.66	3	10.98	9	32.94	27	98.82	81	296.46
3½ to 4	3.75	7.00	4	28.0	16	112.00	64	448.00	256	1792.00
> 4	-	7.34	5	36.70	25	183.50	125	917.50	625	4587.50
Total		100.00		+72.69		+512.79		+1291.35		+7864.35
Moments about x_o			v_1 = +0.727		v_2 = +5.128		v_3 = +12.913		v_4 = +78.644	

TABLE IIID

COMPUTATION OF THE FIRST FOUR DATA MOMENTS OF SAMPLE NO.4

Class Limits ø units	Class Mark x_i	f	u	uf	u^2	u^2f	u^3	u^3f	u^4	u^4f
1	2	3	4	5	6	7	8	9	10	11
< 0.0	-	4.00	-5	-20.00	25	100.00	-125	-500.00	625	2500.00
0 to ½	0.25	10.66	-4	-42.64	16	170.56	- 64	-682.24	256	2728.96
½ to 1	0.75	5.67	-3	-17.01	9	51.03	- 27	-153.09	81	459.27
1 to 1½	1.25	5.67	-2	-11.34	4	22.68	-8	- 45.36	16	90.72
1½ to 2	1.75	1.66	-1	- 1.66	1	1.66	-1	-1.66	1	1.66
2 to 2½	x_o=2.25	8.34	0	-	-	-	-	-	-	-
2½ to 3	2.75	19.33	1	19.33	1	19.33	1	19.33	1	19.33
3 to 3½	3.25	14.33	2	28.66	4	57.32	8	114.64	16	229.28
3½ to 4	3.75	14.67	3	44.01	9	132.03	27	396.09	81	1188.27
> 4	-	15.67	4	62.68	16	250.72	64	1002.88	256	4011.52
Total		100.00		+62.03		+805.33		+150.59		+11229.01
Moments about x_o			v_1 = +0.620		v_2 = +8.053		v_3 = +1.506		v_4 = +112.29	

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TABLE IIIE

COMPUTATION OF THE FIRST FOUR DATA MOMENTS OF SAMPLE NO.5

Class Limits ø units	Class Mark x_i	f	u	uf	u^2	u^2f	u^3	u^3f	u^4	u^4f
1	2	3	4	5	6	7	8	9	10	11
< 0.0	-	5.33	-5	-26.65	25	133.25	-125	-666.25	625	3331.25
0 to ½	0.25	8.00	-4	-32.00	16	128.00	- 64	-512.00	256	2048.00
½ to 1	0.75	8.67	-3	-26.01	9	78.03	- 27	-234.09	81	702.27
1 to 1½	1.25	10.00	-2	-20.00	4	40.00	-8	- 80.00	16	160.00
1½ to 2	1.75	5.66	-1	- 5.66	1	5.66	-1	-5.66	1	5.66
2 to 2½	x_o=2.25	11.00	0	-	-	-	-	-	-	-
2½ to 3	2.75	15.34	1	15.34	1	15.34	1	15.34	1	15.34
3 to 3½	3.25	4.66	2	9.32	4	18.64	8	37.28	16	159.12
3½ to 4	3.75	16.00	3	48.00	9	144.00	27	432.00	81	1296.00
> 4	-	15.34	4	61.36	16	245.44	64	981.76	256	3927.04
Total		100.00		+23.70		+808.36		-31.62		+11644.68
Moments about x_o			v_1 = +0.237		v_2 = +8.084		v_3 = -0.316		v_4 = +116.45	

These measures were converted to moments about the mean by equations viz.

$$\text{(i)}\ m_2 = c^2\ (v_2 - v_1^2)$$

$$\text{(ii)}\ m_3 = c^3\ (v_3 - 3v_1v_2 + 2v_1^3)$$

$$\text{(iii)}\ m_4 = c^4\ (v_4 - 4v_1v_3 + 6v_1^2v_2 - 3v_1^4)$$

The Standard Deviation, Skewness and Kurtosis were then calculated by using simple formulae (Inman, 1952) like $\sigma = \sqrt{m_2}$; $\alpha_3 = m_3/\sigma^3$ and $\beta_2 = m_4/\sigma^4$ respectively. The results are given in Table No.IV.

JABAN SLATES

The dominant constituent rock of this formation is slate but a number of its modifications, is also present. In the upper parts of this formation, the rock can best be described as an argillite with very little cleavage developed. Highly cleaved variety occurring in close association with slates, is a phyllite. In the vicinity of the granite contact, this pelitic rock has been transformed into hornfelses.

Slates and Slaty Phyllites

Slates are greyish-green or dark gray in colour, and possess a good slaty cleavage. Somewhat more micaceous

TABLE IV

STATISTICAL PARAMETERS (MOMENT METHOD)

Sample No.	PHI MEAN DIAMETER M ϕ	STANDARD DEVIATION $\sigma = \sqrt{m_2}$	SKEWNESS $\alpha_3 = m_3/\sigma^3$	KURTOSIS $\beta_2 = m_4/\sigma^4$
1.	2.98 (Fine sand)	0.938 (Moderately sorted)	+0.017 (Positively skewed)	3.125 (Less peaked)
2.	2.83 (Fine sand)	0.97 (Moderately sorted)	-0.75 (Negatively skewed)	3.7 (Less peaked)
3.	2.11 (Fine sand)	1.072 (Moderately sorted)	+0.252 (Positively skewed)	2.6 (More peaked)
4.	2.56 (Fine sand)	1.385 (Moderately sorted)	-0.61 (Negatively skewed)	2.16 (More peaked)
5.	2.37 (Fine sand)	1.416 (Poorly sorted)	-0.26 (Negatively skewed)	1.85 (More peaked)

varieties with pronounced cleavage tend to be phyllitic.

In thin sections, the rocks are generally seen to be very fine grained and consisting of alternating layers rich in quartz and flaky minerals. This banding marks the original bedding of the rock, which is clearly visible even in handspecimen. The cleavage is developed by parallel orientation of flaky minerals and elongated quartz-grains. The bedding and cleavage are seen to intersect at variable angles depending on the samples collected from different parts of the folds (Plate XXXI A).

The rock is seen to consist of quartz, stilpnomelane, sericite, chlorite, iron oxides and graphite.

Quartz mostly occurs as very tiny grains in the rocks. Some bands are rich in quartz while others contain it in lesser proportion. Small lenticular aggregates of quartz are also noted.

Stilpnomelane forms tiny flakes and it has typical pleochroism (X = yellow or golden yellow and Y and Z deep brown; $X < Y$ and Z).

Sericite is quite abundant in the rock and it surrounds quartz grains in the rock, and indicates recrystallisation of argillaceous matrix. Its development into small flakes of muscovite is, also, sometimes seen. Chlorite is present in a variable amount. It is pleochroic from pale yellow to green (X = Y = green, Z = pale yellow; $X = Y > Z$). It has same occurrence as that as sericite.

Iron ores generally, magnetite occur as disseminated grains scattered in the rock. Graphite is also recognised in some of the samples and it form fine isotropic dust. Pyrite and tourmaline are other accessory minerals occasionally present in the rock.

Argillites

These are finegrained dark coloured rocks differing from slates in not possessing the slaty-cleavage. Obviously, argillites are metamorphically reconstituted shales and siltstones which have failed to develop a cleavage.

Under microscope, these rocks show a banding characterised by the dominance in layers of quartz grains indicating the original bedding. These are finer grained than the slates, and their flaky minerals do not show preferred orientation. The minerals present are quartz, stilpnomelane sericite and chlorite. Sometimes a little calcite is also present.

Quartz occurs as extremely fine grains widespread in a micaceous mass.

Sericite, chlorite and stilpnomelane, all occurring together comprise the main bulk of the rock, and occur as tiny specks.

Calcite, when present, occurs as distinct patches and clusters of fine grains.

Magnetite and pyrite are the common accessory minerals and form identifiable grains.

Hornfels

In handspecimen, the rock is greyish in colour abundantly speckled with small brown spots. It is much coarser in grain size than the slates or phyllites.

Under the microscope, the rock shows a granoblastic aggregate of quartz, biotite and muscovite and chlorite.

Quartz forms a mosaic of almost equidimensional grains.

Biotite dominates over muscovite and occurs as large flakes which are pleochroic from yellow to brown.

Muscovite also forms good flakes. The two micas do not show orientation.

Yellow, isotropic, chlorite as well as the green pleochroic variety (X = Y = pale green, Z = pale yellow is green and X = Y > Z) both are present.

The most conspicuous accessory mineral is dravite which is frequently recorded as well developed crystals pleochroic from O = dark yellow to E = yellow and O > E.

Iron ores, both hematite and magnetite occur in the rock.

JABAN CONGLOMERATIC GRAYWACKES

This suite of rocks comprises two main types, viz. graywackes and protoquartzites. The lower portion of this formation is made up of graywackes, while the upper portions are protoquartzitic. The transition between the two types is rather gradual and a number of intermediate varieties containing the two components in varying proportions are met with.

The two main end members of the suite graywacke and protoquartzites have been described below:

Graywacke

In handspecimen, the rock is dark gray to black in colour and is seen to consist of fragments of varied lithology bounded together by an argillaceous gritty matrix. Quite often the rock has developed a regional schistosity.

In thin section, the larger particles comprise angular to sub-rounded grains of quartz, feldspars, biotite and rock fragments of slate, phyllite, quartzite, recrystallised limestone, granite etc. The fragments of softer rocks like slates and limestones are angular whereas those of granite, quartzite are mostly well rounded. The rock fragments are quite often readily recognised by their clastic outlines as seen in ordinary light (Plate XXXI B).

Larger grains and rock fragments are embedded in a matrix which contains larger proportion of argillaceous material, recrystallised to sericite, chlorite, quartz etc. Depending upon the intensity of deformation the matrix is either non-cleaved or cleaved. In undeformed samples, it is seen that the embedding matrix forms a uniform mass of very fine quartz grains, sericite flakes and chlorite, while in the deformed varieties the flaky minerals by their parallel orientation impart a cleavage to the rock. The rock mass at times, shows abundant effects of shearing. The bigger fragements of quartzite and gneiss have broken and fractured. The fragements of limestones and phyllites (or slates) almost invariably show intense stretching and form elongated streaks. Sometimes quartz is also seen forming streaky aggregates. Smaller fragments of limestone, on being sheared, have intimately mixed with the matrix and occur in close association with the foliated sericitic and micaceous mass. Feldspar fragments have deformed and altered to sericite and kaolin.

Quartz is one of the dominant constituents. It is found as larger grains of clastic origin. Such big grains are often surrounded by a rim of smaller quartz grains which perhaps represent a secondary growth of the mineral, SiO_2 being derived from the matrix. The other mode of occurrence of this mineral is a fine aggregate in the matrix.

Feldspars include microcline and oligoclase and generally occur as bigger grains of detrital origin. Obviously the source rock that furnished these feldspars, must be granitic. Microcline is identified by its typical cross-hatching while plagiolcase shows lamellar twinning. Significantly, the feldspars show a varying degree of alteration ranging from almost pure and unaltered to entirely clouded grains.

Muscovite is an important constituent of the matrix. Flakes of muscovite occur either as continuous streaks or they are scattered in the rock as separate individuals. Its finer grained sericitic type is abundant in the groundmass and indicates recrystallisation of argillaceous material.

Like muscovite, biotite is also abundant. It is more common in darker coloured varieties. This biotite is pleochroic from X = yellow to Y = Z = brown ($X < Y = Z$). Some of the biotite flakes are unusually large and indicate detrital origin.

Chlorite occurs generally in the finer grained matrix and is obviously produced by the recrystallisation of the clayey material. It is pleochroic from pale green to green ($X = Y > Z$). Some of the flakes are isotropic between cross-sections while others show blue polarisation colours.

Calcite is sporadically distributed in the matrix, and is seen to form small irregular interstitial grains.

The heavy minerals include magnetite, pyrite, zircon, apatite, tourmaline and epidote.

Protoquartzites

In handspecimen, the protoquartzites are light coloured, generally gray, compact, hard rock. With a progressive decrease of the rock fragments and the argillaceous material from the matrix, containing quartz, feldspars and muscovite, graywackes grade upward into these subarkosic rocks. These rocks contain frequent pebbles and boulders of slates, limestones, quartzites and also of graywackes which lie below these rocks.

The main bulk of the rock is characterised by an assemblage of sub-angular to sub-rounded grains of quartz and feldspars, microscopic sized pellets of slates or phyllites and fragments of quartzite and limestone embedded in a fine-grained matrix comprising quartz, feldspar and sericite. It is evident that the present rock represents a recrystallised variety intermediate between protoquartzite and sub-arkose belonging to a graywacke suite (Plate XXXII A).

Apart from the rock-fragments, the mineral present are quartz, feldspars (microcline, oligoclase), muscovite (sericite), biotite and calcite.

Quartz occurs as larger grains as well as smaller grains in the groundmass. The larger grains are of clastic origin. But smaller ones in the matrix could be clastic or recrystallised siliceous cement. The detrital quartz grains show a sutured and interlocking boundaries with finer quartz that surround them. Thus the originally clastic quartz grains show tendency to grow at the expense of the silica recrystallised from the binding material. Such grains quite often contain inclusions of sericite along the peripheries giving rise to intergrowths.

Grains of microcline and plagioclase (oligoclase, An_{24}) are present and those of microcline predominate. Most feldspar grains are clouded to varying degrees and they are quite often seen altered to kaolin and sericite. Microcline is comparatively fresh. Smaller grains of feldspars also occur in the matrix along with quartz and muscovite, These feldspar grains are of clastic origin.

Muscovite (sericite): Muscovite is present as small flakes in the ground mass. Sometimes, minute individuals are also found as inclusions within feldspars. Sericitic mica is the most abundant constituent. It occurs in the matrix and also as inclusions in the quartz. It is also an alteration product of feldspars.

Biotite is only occasionally present as small flakes. It is pleochroic from pale yellow to dark brown. The somewhat larger flakes of biotite indicate detrital origin.

Calcite is recorded sporadically and is of two different origin. A few larger grains which possess good twin lamellae are of detrital origin, while small illdefined, interstitial patches in the groundmass perhaps indicate the recrystallised calcareous cement.

Heavy minerals include zircon, iron ores and epidote.

BHAT SLATES

This formation entirely consists of slates and slaty phyllites, the former are more prevalent. Slates are dark gray rocks and show development of an incipient cleavage. Wherever the cleavage is better developed the slates tend to be phyllitic. Sedimentary lamination is widely developed and clearly preserved. Lithological banding is more pronounced near the base of the formation. In the upper part, these slates contain frequent nodules of manganese ores. In thin sections, the rock is seen to consist of a very fine mass made up mainly of quartz, sericite and chlorite.

SHIVARAJPUR QUARTZITES AND PHYLLITES

In this formation two main rock types occur viz. quartzites and phyllites with subordinate limestones.

Quartzites

These are usually fine grained compact rocks of cream colour and under the microscope show a fine interlocking mosaic of equigranular quartz. In some of the samples, the rock contains numerous black opaque grains of manganese ores.

Phyllites

Phyllites are typically cleaved, light gray or pink coloured rocks. The minerals that make this rock are mostly quartz and sericite and the gray colour is often due to small specks of manganese ores.

Limestones

These comprise flattened and interlocking grains of calcite a little quartz, muscovite and chlorite ~~(Photomicrograph)~~. Staining with alizarin red-s has shown complete absence of dolomite. Most of the twin lamellae of calcite in some samples show bending and deformation. This is due to the effect of faulting.

BAMANKUA LIMESTONES

These limestones are usually fine grained and contains numerous grains of quartz associated with the main constituent calcite (Plate XXXII B). Occasionally, the contain grains of pyrite.

RAJGAD SLATES

This formation comprises essentially of slates and slaty-phyllites with subordinate argillites, siliceous limestones and quartzites.

Slates and Slaty-Phyllites

These are of light gray, greenish gray or dark in colour, and show well developed metamorphic cleavage and also the original sedimentary layering. Depending on the intensity of the cleavage, the slates can be distinguished from the slaty phyllites. Otherwise, in all respect both are identical (Plate XXXIII A).

In thin sections, the slates and phyllites show a finely foliated mass of quartz, stilpnomelane, sericite, chlorite, calcite,iron ores.

Quartz, occurs as tiny granules in the rock and quite often shows tendency to form small elongated clusters which lie parallel to the schistosity.

Stilpnomelane (?) is the mineral next in abundance in many samples. This mineral is partly responsible for the dark colour of the rocks. It occurs in subparallel specks in close association with other flaky minerals, imparting cleavage to the rock.

Sericite is also universal in all the samples and occurs as very minute flakes scattered throughout the rock.

Chlorite is also one of the important minerals in these rocks. It occurs in close association with micas and is recognised by its yellowish green to green pleochroism and low polarisation colours. Sometimes, chlorite segregates into small streaks.

Calcite is present in a few samples and quite often it occurs in such proportions that the rock can be better called a calcareous slate or phyllite.

Crystals of magnetite sporadically occur in the foliated mass and shows typical triangular and square outlines. The other accessories include tourmaline and zircon.

GRANITIC ROCKS

Granitic rocks show a considerable variation in texture and mineral content, but essentially consist of quartz, feldspars (both potash feldspar and plagioclase), biotite, in varying proportions. Based on the relative proportions of potash feldspar and plagioclase, two main types have been recognised:

(i) Potash granite - Potash feldspar dominates over the plagioclase.

(ii) Trondhjemite - Plagioclase dominates over the potash feldspars.

Both the above types occur in close association and show a wide range of grain size - coarse to fine. Porphyritic varieties are also recorded. The biotite content is almost uniform in the trondhjemitic type, but in the potash granite, its proportion varies, and even biotite free varieties are not uncommon. On the whole, the main mass of the granite is coarse and porphyritic, and the most of the textural and mineralogical variations are confined to the peripheral parts of the pluton.

Potash granites:

Ranging from fine to coarse grained, these rocks have been found to show mineral assemblages consisting of quartz, microcline (perthite), oligoclase and biotite.

Texturally, these rocks are hypidiomorphic (Plate XXXIII B), granular and sometimes porphyritic; the plagioclase tends to be subhedral to euhedral, while most of the potash feldspar is anhedral to subhedral, or with quartz occupy irregular interspaces. In porphyritic variety, the phenocrysts are of microcline. Myrmekitic texture is quite common.

Quartz in this rock is invariably anhedral and is usually comparable in size to feldspars. It also forms small rounded, inclusions in the latter.

Potash-feldspar is microcline and is identified by its typical crosshatching. In porphyritic types, microcline occurs as big phenocrysts enclosing quartz and plagioclase as distinct inclusions. Such phenocrysts quite often show carlsbad twin which divide the whole grain into two broad lamellae lengthwise suggesting the possible inversion of original orthoclase to microcline. Microcline is either fresh or slightly altered to sericite and kaolin.

Plagioclase grains which are an oligoclase (An_{16-20}) show subhedral to euhedral tendency, and are found to occur as separate individuals, or as inclusions within microcline. The mineral shows high degree of alteration to a fine aggregate of muscovite, sericite and epidote. These products of alterations show a zonal arrangement which indicates original zoning in plagioclase.

Biotite occurs as small sized flakes and it is usually pleochroic with X = yellow, Y = brown and Z = dark brown ($X < Y < Z$). Inclusions of zircon and apatite are common, which produce pleochroic halos.

Accessory minerals are apatite, zircon, epidote and iron ores.

Trondhjemites

Texturally, these rocks are medium to coarse grained, hypidiomorphic, containing porphyritic plagioclase, quartz, some microcline and biotite as the important constituents of the rock.

Plagioclase is an oligoclase (An_{18-24}) and is the dominant constituent. It occurs, generally as subhedral to euhedral grains with rectangular sections. It shows alteration to sericite (muscovite), clinozoisite, calcite and albite showing effects both of sericitization and saussuritization. Zoning in the plagioclase is quite common.

Quartz forms anhedral grains and occupy interstitial spaces.

Microcline is very subordinate and occurs as few anhedral to subhedral grains. Its myrmekitic replacement by plagioclase is often recorded.

Biotite (X = pale yellow, Y = green, Z = dark greenish brown; $X < Y < Z$) forms stray flakes, and shows pleochroic halos around included zircon.

Among the accessories, zircon is well observed with euhedral crystals and high briefringence. Others are apatite, sericite and clinozoisite.